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A hybrid PSS–SSSC GA-stabilization scheme for damping power system small signal oscillations

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ABSTRACT

Nonlinear and fast quasi dynamic type loads of different time-varying ranges are introduced to the electric grid systems due to renewable Energy, distributed Generation and Power electronic AC–DC–AC interface converters used in several parts of the power network, the dynamic small signal electromechanical modes are destabilized and dynamic stability limits of AC system is reduced. FACTS – Flexible AC Transmission Devices with conventional coordinated power system Stabilizers are utilized to improve dynamic stability margins and damp unstable and oscillatory electromechanical modes of oscillations. Coordinated Flexible Soft Computing Control Strategies are proposed for damping modes of through supplementary damping torques provided by Static Synchronous Series Compensator – SSSC in addition to classical Power System stabilizers – PSS.

To coordinate the dual action of both SSSC and PSS devices a Genetic algorithm Tuning Controller is applied. The dynamic simulation results for optimized controllers are validated using Matlab/Simulink Software Environment.

Introduction

The growing demand for energy and rising cost of fossil fuel combined with environmental Green House Gas (GHG) Emissions and Global warming have renewed the interest for interconnected large energy pools connecting neighboring electric grids together and transmit bulk energy during peak times of load demand; while, the linking of the power systems together introduces some modes of electromechanical oscillations and frequency deviations within the range of 0.2–2 Hz in the power system. When such electromechanical oscillations persist in the electric system, the full use of the power system is limited and there is the possibility of the generation-load mismatching and dynamic instability. On the other hand, these oscillations will have a negative effect on the turbine shaft fatigue of turbine-generator and gradually bring about great damage and possible torsional oscillations and sub-synchronous resonance conditions in case of in the long-compensated transmission lines with series capacitor banks. Electromechanical damping systems as well as power system stabilizers are employed in traditional methods; although they reduce oscillations in the power system, they ultimately bring about other negative effects such as increasing the short circuit currents or making the system more complicated [1,2].

One of long proven and effective methods for damping electromechanical oscillations is the use of the power system stabilizer (PSS) which has highly been taken into consideration due to its suitable effect on the damping local modes of oscillations [3]. Classical control methods like PID, lead-lag compensation stages, placement of the poles. New control methods such as fuzzy logic control, adaptive/comparative control, neural network based and predictive control are employed in the control section of this stabilizer which are significant for their performance [4–6].

New development in power electronic devices and emerging VSC–FACTS based converter topologies offer fast controllability and enhanced dynamic performance and better FACTS performance [7]. Applications of the FACTS cover voltage control, loss reduction, voltage stabilization, peak load release, energy efficient operation and improvement of transient and dynamic stability, and Fault-Ride through as well as Flicker control.

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One of the FACTS devices implemented is static series compensators (SSSC) and because of its dynamic fast performance in voltage and current controlling, it is useful in decreasing and also damping the oscillations in power system [8–13]. Thyristor-Controlled Series Capacitor (TCSC) is a simple FACTS device with series link which improve the stability of the power system and limit the low frequency oscillations (less than 2 Hz) by controlling the effective reactance of the transfer line [9–14,33]. The static VAR compensator of the reactive power (SVC) as a parallel compensator can play the role of a controllable variable reactor to absorb or generate the reactive power to stabilize the circuit voltage within the range of inductive to capacitive [10].

SSSC as series FACTS device has a DC capacitor in structure of voltage inverter and delivers a balanced synthesized three-phase voltage to the network (VSC) [10,11]. Although about this voltage in order to have only reactive power exchange with the network, it should be perpendicular to the current line. In fact, if this voltage has a phase priority relative to the current by $\pi/2$ Radian, the VSC acts like an inductive and if it has a phase lag, it acts such a capacitor.

Considering the above advantages, SSSC can be an elegant low cost solution for active and reactive power control in long transmission lines and enhance the transfer power capability of the line; ultimately, effectuating the stability of the power system. By placing SSSC in the power system, there is the possibility of increasing the reliability of the power network and preventing inappropriate exploitation of the generators and cases leading to the loss of a part of the network loads [16,17]. In the direction of improving the SSSC performance and damping the power oscillations, different studies have been performed on the regulation of its control parameters and the effect of the control mode and its degree of compensation on the dynamic and transient stability in different tasks [15–19]. In regulating the SSSC control parameters under different load conditions, it should be acted in a manner that the damping and undamming modes are directly transferred to the stable intended region without damaging the system mode conditions [20–28]. A hybrid compensator was used in a study [29], in a manner that two phases were series connected by the capacitor and the third phase was series connected by SSSC and compensated by the fixed capacitor to damp the interregional oscillations in multi-machine model. In regulating the controlling parameters of the SSSC set, intelligent searching methods are used to damp the oscillations of the power [16].

Common control tuning methods such as the relocation of poles [17], compensation of phases [18], compensation of the residuals [22], and modern control methods have been used for the design and control of the power system stabilizers in the researches performed so far [21]. The disadvantages of most tuning methods for controllers are their complexity and computational burden with high volume of computations, low convergence velocity, and also the possibility of obtaining local and optimal answers. Today, intelligent methods such as the method of the group of particles [23,24], genetic algorithm [25], differential algorithm [26], and fuzzy logic [3,27] are extensively used in the design of the power system stabilizations to reduce the problems existing in the common design methods.

In this paper, the SSSC compensator system and the power system stabilizer are regulated and coordinated by the genetic algorithm to increase the stability of the power network confronting load changes and to reduce oscillations resulting in results. The result of its performance is simulated in Matlab–Simulink. In the next section of this paper, the structure and performance of SSSC along with proposed controller are studied. The third part of this paper is devoted to the modeling of a power system along with power stabilization and SSSC. Then, in the simulation section, the effectiveness of the optimal control of the power stabilizer and SSSC in different conditions are illustrated.

The SSSC-structure and controller

The Static Synchronous Series Compensator (SSSC) is a voltage source convertor of the solid state with the capability of generating a controllable AC voltage connected to the transmission line in series as depicted in Fig. 1. By injecting the Vq voltage in series with the transmission line, SSSC enjoys the capability of compensating the transmission line impedance. Vq is perpendicular to the line current and is able to change the line impedance from inductive property to capacitive property. Also, the value of the injection Vq is independent of the line current size influencing the distribution of the transmission line power [14]. The Vq changes are done by the voltage source convertor connected to the secondary of the coupling transformer. The rate of compensation can be continuously changed by a change in the size and the injection voltage phase; this element can be exploited both in the inductive and capacitive states. VSC as one of the devices of the power electronic generates an AC voltage from a DC voltage source performed by a capacitor connected to the DC section of the convertor. To compensate the transformer and convertor losses and the capacitor charge holding, a small value of the real power is drawn from the transmission line in consumption form.

The single-machine system connected to infinite bus in the presence of SSSC is shown in Fig. 1. The transformer reactance, the transformer reactance connected to SSSC, and the transmission line reactance are represented by X_{ts}, X_{sct}, and X_{line}, respectively. Also, V_t and V_b are the generator terminal voltage and the infinite bus voltage, respectively. In a general state, SSSC includes a three-phase voltage source convertor connected in series to the transmission line through a transformer. The performance of SSSC is based on the PWM technique and V_{INV}, C_{DC}, m, and ψ are the series injected voltage, DC link capacitor capacitance, modulation index size, and the voltage phase angle, respectively.

Sample power system model with SSSC

In order to analysis the power system oscillations it is better to model the system in small signal states. In this modeling the single machine infinite bus network in Fig. 1 is modeled by Heffron–Phillips model which is shown in Fig. 2 [1–32].

By the linearization of the nonlinear dynamic model of state space of system in nominal operating point, the following small signal linear dynamic model of the following small signal is obtained as (1), and the details of equations are mentioned in [28].

$$
\begin{aligned}
\Delta\dot{\delta} &= \omega_0\ \Delta\omega \\
\Delta\dot{\omega} &= \frac{\Delta P_m - \Delta P_e - \Delta P_D}{M} \\
\Delta\dot{E}'_q &= \frac{-\Delta E_q + \Delta E_{fd}}{T'_{d0}} \\
\Delta\dot{E}_{fd} &= \frac{-\Delta E_{fd} + K_A(\Delta V_{ref} - \Delta V_t)}{T_A} \\
\Delta\dot{V}_{DC} &= (K_7\Delta\delta + K_8\Delta E'_q + K_9\Delta V_{DCm}K_{pm}\Delta m)
\end{aligned}
\quad (1)
$$

$$\Delta P_e = (K_1\Delta\delta + K_2\Delta E'_q + K_{pdc}\Delta V_{DC} + K_{pm}\Delta m)$$

$$\Delta P_q = (K_4\Delta\delta + K_3\Delta E'_q + K_{qdc}\Delta V_{DC} + K_{pm}\Delta m)$$

$$\Delta V_t = (K_5\Delta\delta + K_6\Delta E'_q + K_{vdc}\Delta V_{DC} + K_{pm}\Delta m)$$