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POWER OSCILLATION DAMPING CONTROLLER BY STATCOM

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Abstract: This paper describes an approach to design a damping controller of a energy storage type STATCOM (E-STATCOM). The energy storage type STATCOM is an advanced flexible AC transmission system (FACTS) device, which controls both active and reactive power injection/absorption to the power system. It also provides a better power swing damping. Using a linearized block diagram proposed by the author, the present study examines the design of the E-STATCOM damping controller. Several case studies have been performed to evaluate the power swing damping effect of the ESTATCOM a machine infinite bus system. The results of the study show that an E-STATCOM, which control both reactive and active power injection/absorption to power system, has a more significant effect on power swing damping than that controlling the reactive power alone.

Keywords: Power system stability, Flexible ac transmission system (FACTS), Static synchronous compensator (STATCOM), Energy storage, Linearized model.

I. INTRODUCTION

Along with the increasing scale of the power system and stressed operation in the transmission network, more electromechanical oscillations are observed in today's power systems. Once started, the oscillations may continue for a while and then disappear by the damping toque from the system, or continue to grow and cause system instability through losing synchronism. In steady state operation, the primary objective of facts devices is to control power flow and improve transmission capability. However, in recent years, the application of facts devices in suppressing system oscillations has attracted increasing interests for research and development. The electromechanical oscillation appears in a power system due to the interactions among the system components. Most of the oscillation modes are generator rotors swing against each other. The oscillation normally occurs in the frequency range of 0.2 Hz to 2.5 Hz. The inter-area oscillations, which are typically in the lower frequency range of 0.2 Hz to 1 Hz, are exhibited as one group of machines swing relative to other groups. Compared with lower frequency, the higher frequency oscillation modes typically involve one or two generators swinging against the rest of the power system, which is called local mode oscillation. The oscillations stability analysis and control is an important and active topic in power system research and applications. In the past, power system stabilizer (pss) is recognized as an efficient and economical method to damp oscillations. In recent years, as a new solution, various facts controllers have been developed for damping of power system oscillations. Based on the control theory applied, the presented controllers can be divided to two groups: linear controllers and nonlinear controllers. In linear control, the system dynamics are linearized around the pre-selected system operating point according to lyapunov's linearization method. The linearized system is an approximation of the original system at the operating point. Therefore, these controllers suffer from the performance degeneracy problem when system operating point deviates from the pre-designed point. Nonlinear control techniques can provide more effective control of power systems due to their capability to handle nonlinear operating characteristics. There are already some researches on nonlinear facts controller design for damping power system oscillations in recent years. The feedback linearization (fl) method has been used in facts controller design in. Energy based control lyapunov function method (clf) had been successfully applied in series facts devices controller in. The adaptive control is used in facts controller design in. The h∞ control is also successfully applied in tcsc controller to damp inter-area oscillations in. These nonlinear controllers have good performance if the system model is accurate and the parameters are precisely obtained. The shortcoming is that the robustness is not guaranteed in the presence of modelling inaccuracies. i.e. Parameter uncertainty and un-modelled dynamics, especially in fl method.

II. INTEGRATION OF BATTERY ENERGY STORAGE WITH A STATCOM

The static synchronous compensator or statcom is a shunt-connected device. The statcom does not employ capacitor or reactor banks to produce reactive power as does the Static Variable Compensator (SVC). In the StatCom, the capacitor bank is used to maintain a constant DC voltage for the voltage-source converter operation. Common StatComs may vary from six-pulse topologies up to forty-eight-pulse topologies that consist of eight six-pulse converters operated from a common dc link capacitor. The displacement angle between two consecutive six-pulse converters in a multi pulse converter configuration is where the total number of six-pulse converters is. The configuration of an integrated StatCom/ESS is shown in Fig: 1 Phase adjustments between the 6-pulse converter groups are accomplished by the use of appropriate magnetic circuits. Using this topology, the angle of the statcom voltage can be varied with respect to the AC system voltage. By controlling the angle, the StatCom can inject capacitive or inductive current at the AC system bus. Although the ability of a StatCom to improve power system performance has been well accepted, very little information regarding its dynamic control has been published. The StatCom is best suited for voltage control since it may rapidly inject or absorb reactive power to stabilize voltage

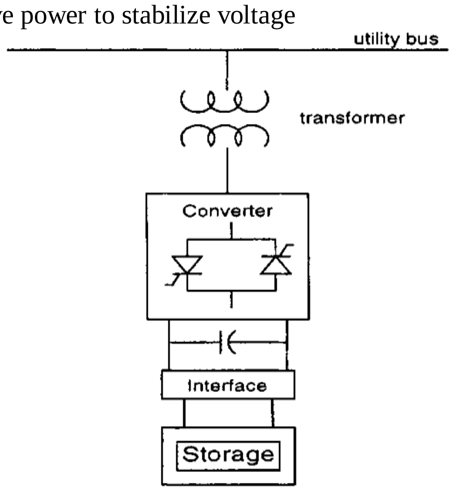

Fig: 1.Integrated StatCom with energy storage

Excursions and has been shown to perform very well in actual operation. Several prototype StatCom installations are currently in operation. The ability of the StatCom to maintain a pre-set voltage magnitude with reactive power compensation has also been shown to improve transient stability and sub synchronous oscillation damping. However, a combined StatCom/ESS system can provide better dynamic performance than a stand-alone StatCom. The fast, independent active and reactive power support provided by an ESS coupled to a StatCom can significantly enhance the flexibility and control of transmission and distribution systems. The traditional StatCom (with no energy storage) has only two possible steady-state operating modes: inductive (lagging) and capacitive (leading). Although both the traditional StatCom output voltage magnitude and phase angle can be controlled, they cannot be independently adjusted in steady state since the StatCom has no significant active power capability. Thus it is not possible to significantly impact both active and reactive power simultaneously. For the StatCom/ESS, the number of steady state operation modes is extended to all four quadrants. These modes are inductive with DC charge, inductive with DC discharge, capacitive with DC charge, and capacitive with DC discharge. Due to the nature of ESS, the StatCom/ESS cannot be operated infinitely in one of the four modes (i.e., the battery cannot continuously discharge); therefore these modes represent quasi steady-state operation. However, depending on the energy output of the battery or other ESS, the discharge/charge profile is typically sufficient to provide enough energy to stabilize the power system and maintain operation.

III. POD CONTROLLER DESIGN

Considering the simplified two-machine system in Fig: 2, the active power output from each generator should change in proportion to the change in its speed to provide damping. It can be observed that the effect of the power injected by the compensator on the generator active power output highly depends on the parameter α, i.e., on the location of the E-STATCOM. Using the equivalent system, a control input signal that contains information on the speed variation of the generators can be derived. When the E-STATCOM is not injecting any current, the variation of the locally measured signals, Θ_g and P_{tran} and at different E-STATCOM connection points using the dynamic generator rotor angles $\delta_{g1}$and δ_{g2} is given by

$$\theta g = \delta g2 + tan - 1\left[\frac{(1-a)Vg1\sin(\delta g1-\delta g2)}{(1-a)Vg1Cos(\delta g1-\delta g2)+aVg2}\right]$$

$$Ptran = \frac{Vg1Vg2\sin(\delta g1-\delta g2)}{X1+X2}$$

From a small-signal point of view and under the assumption that the PCC-voltage magnitude along the line $E_g$does not change significantly, the required control input signals can be derived from the PCC-voltage phase and transmitted active power as

$$\frac{d\theta g}{dt} \approx \Gamma P\omega g0\Delta\omega g1 + (1-\Gamma P)\omega g0\Delta\omega g2$$

$$\text{dPtran/dt} \approx \left\{\frac{Vg1Vg2\cos(\delta g10-\delta g20)}{X1+X2}\right\}\omega[\Delta\omega g1 - \Delta\omega g2]$$

Where $\acute{\Gamma}_p$is aconstant (transmitted active power). The nominal system frequency is represented by w_{g0} whereas $\Delta w_{g1}$and Δw_{g2} represent the speed variation of the generators in p.u. The electromechanical dynamics for each generator is given by

$$2\text{Hgi}\,\frac{d\Delta\omega gi}{dt} = \Delta Tmi - \Delta Tgi - KDmi\Delta\omega gi$$

Where Hgi , Δw_{gi} , ΔT_{mi} , ΔT_{gi} , and K_{Dmi} represent inertia constant, speed variation, change in input torque, change in output torque and mechanical damping constant for the ith generator, respectively. The derivative of the PCC-voltage phase and transmitted active power are both dependent on the speed variation of the generators. Moreover, the derivative of the PCC-voltage phase depends on the location of E-STATCOM, through the parameter, as well as the mechanical dynamics of the generators as shown in above equation. This information will be exploited in the POD controller design. For the two machine system in Fig: 2, damping is related to the variation of the speed difference between the two generators, $\Delta w_{g12} = \Delta w_{g1} - \Delta w_{g2}$. It can be understood that the change in the output power from the generators due to injected active power is maximum when the compensator is installed at the generator terminals. Assuming equal inertia constant for the two generators, no damping is provided by injection of active.

IV. Estimation of Control Input Signals

To describe the estimation algorithm, an input signal which could be either w_g or P_{tran}, as shown in Fig: 2, is considered. Following a power system disturbance, will consist of an average value that varies slowly and a number of low-frequency oscillatory components, depending on the number of modes that are excited by the disturbance. For simplicity, let us assume that there exists a single oscillatory component in the input signal.

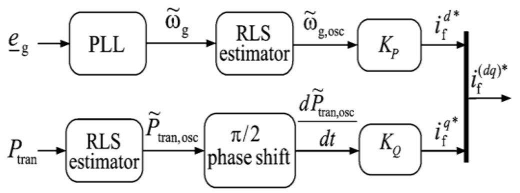

Fig: 2Block diagram of the POD controller.

Therefore, the input signal consists of an average component Y_{avg} and an oscillatory component Y_{osc} which can be modelled as

$$y(t) = Yavg(t) + Yph(t)\cos\,[\omega osct + \varphi(t)]$$

Where Y_{osc} is expressed in terms of its amplitude (Y_{ph}), frequency (w_{osc})and phase (φ) and it can be rewritten as

$$y(t) = Yavg(t) + Yph,d(t)\cos(\theta osc(t)) - Yph,q(t)\sin(\theta osc(t))$$

Where $Y_{ph,d}$and $Y_{ph,q}$ are given by

$$Yph,d(t) = Yph(t)\cos(\varphi(t)) \qquad Yph,q(t) = Yph(t)\sin(\varphi(t))$$

From the observation matrix and measured input signal y(t), the estimated state vector ĥ is derived using RLS algorithm in discrete time as

$$\tilde{h}(k) = \tilde{h}(k-1) + G(k)[y(k) - \Phi(k)\tilde{h}(k-1)]$$

$$\tilde{h}(k) = [\tilde{Y}avg(k) \;\; \tilde{Y}ph,d(k) \;\; \tilde{Y}ph,q(k)]T$$

$$\Phi(k) = [1 \;\; \cos(\theta osc(k)) - sin(\theta osc(k))]$$

Calling the **I** identity matrix, the gain matrix **G** and covariance Matrix **R** are calculated recursively starting with an initial invertible matrix **R(0)** as:

$$G(k) = R(k-1)\Phi T(k)[\lambda + \Phi(k)R(k-1)\Phi T(k)] - 1$$

$$R(k) = [I - G(k)\Phi(k)]R(k-1)/\lambda$$

Where λ represents the forgetting factor for the RLS algorithm such that 0< λ <1 . With $T_s$representing the sampling time, the steady-state bandwidth of the RLS α_{RLS} and the estimation error is given by:

$$\alpha RLS = \frac{(1-\lambda)}{Ts}, \qquad \epsilon(k) = y(k) - \Phi(k)\tilde{h}(k-1)$$

V. STABILITY ANALYSIS OF SYSTEM MODEL

The POD controller described in this section is verified by using the well-known two area four machine system as shown in Fig: 3.

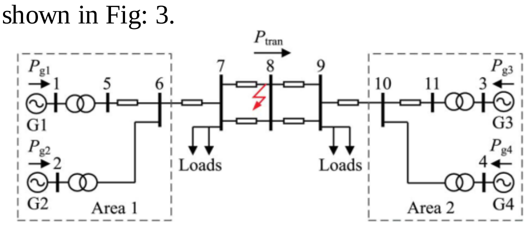

Fig 3: simplified two-area four machine power systems.

As it is seen in these figures, voltage angles are controlled in order to damp oscillations and variations of voltage magnitudes are rather small. This clearly shows that inter-area oscillations have close relationship with active power flow changes throughout the network. Fig: 4depictdc capacitor voltages and Fig: 5 Shows injected active powers by STATCOMs. As it is seen, STATCOMs need to inject multiple orders of their nominal active powers in a short period of time and this in turn causes dc capacitors to be discharged temporarily.

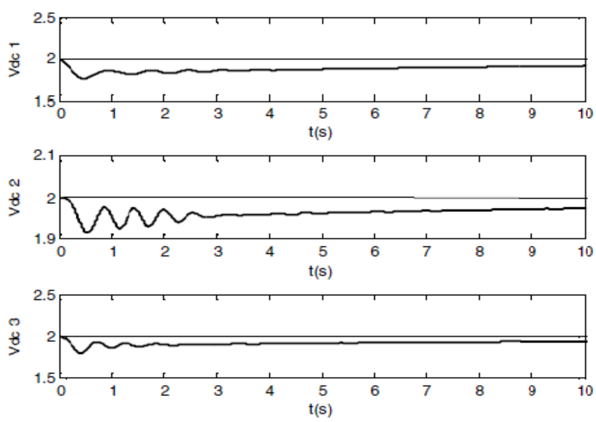

Fig: 4 STATCOM DC voltages (uncontrolled: thin, decentralized controlled: bold)

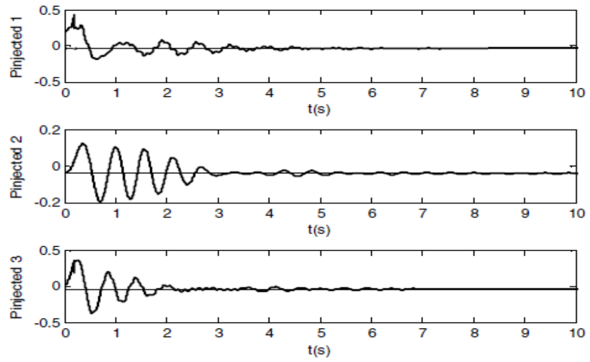

Fig: 5STATCOM injected active powers (uncontrolled: thin,decentralized controlled: bold)

Conclusion

The ESTATCOM, Which controls both receptive and dynamic force infusion assimilation, has a more noteworthy impact on the swaying damping contrasted with that controlling just the responsive force infusion retention a versatile POD controller by E-STATCOM has been produced in this paper. For this, a changed RLS calculation has been utilized for estimation of the low-recurrence electromechanical motions segments from privately measured signs amid force framework unsettling influences. The dynamic execution of the POD controller to give compelling damping at different association purposes of the E-STATCOM has been approved through reproduction and additionally test check.

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