Design of Damping of Power System Oscillation using STATCOM With Energy Storage

R.Mounika  
M.Tech, Electrical Power Systems  
Talla Padmavathi College Of Engineering, Kazipet, Warangal

V.Prakash  
Associate Professor, EEE  
Talla Padmavathi College Of Engineering, Kazipet, Warangal

Abstract: The motto of present paper is to find out the enhancement of damping the power system oscillation through co-ordinated model of ‘Static Synchronous Compensator’ (STATCOM) situated in shunt with transmission line side. This is achieved using a signal estimation technique based on a modified recursive least square (RLS) algorithm, which allows a fast, selective, and adaptive estimation of the low-frequency electromechanical oscillations from locally measured signals during power system disturbances. The proposed method is effective in increasing the damping of the system at the frequencies of interest, also in the case of system parameter uncertainties and at various connection points of the compensator.

Keywords: Energy storage, low-frequency oscillation, power oscillation damping (POD), recursive least square (RLS), staticsynchronous compensator (STATCOM).

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 torque 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 swinging 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 generatorsswinging 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 into 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, those 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 powersystem 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 also successfully applied in TSC.
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. BLOCK DIAGRAM OF THE STATCOM

The STATCOM is one of the most important shunt connected FACTS controllers to control the power flow and make better transient stability. A STATCOM is a controlled reactive power source. It provides voltage supports by generating or absorbing capacitor banks.

STATCOM has three operating parts:

(i) STATIC: based on solid state switching devices with no rotating components,

(ii) SYNCHRONOUS: analogous to an ideal synchronous machine with 3 sinusoidal phase voltage at fundamental frequency,

(iii) COMPENSATOR: rendered with reactive compensation.

Modern electric power system is facing many challenges due to day by day increasing complexity in their operation and structure. In the recent past, one of the problems that got wide attention is the power system instability. With the lack of new generation and transmission facilities and over exploitation of the existing facilities geared by increase in load demand make these types of problems more imminent in modern power systems. Demand of electrical power is continuously rising at a very high rate due to rapid industrial development. To meet this demand, it is essential to raise the transmitted power along with the existing transmission facilities. The need for the power flow control in electrical power systems is thus evident. With the increased loading of transmission lines, the problem of transient stability after a major fault can become a transmission power limiting factor. To solve the problem of transient stability in the late 1980s, the Electric Power Research Institute (EPRI) introduced a new approach to solve the problem of designing and operating power systems; the proposed concept is known as Flexible AC Transmission Systems (FACTS). The two main objectives of FACTS are to increase the transmission capacity and control power flow over designated transmission routes. FACTS are defined by the IEEE as “a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability”.

Fig2: Basic Structure of STATCOM

“A Static synchronous compensator is a shunt connected static VAR compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage”. The concept of STATCOM was proposed by Gyugyi in 1976. Power converter employed in the STATCOM is mainly of two types i.e., Voltage Source Converter and Current Source Converter. In Current source converter direct current always has one polarity and the power reversal takes place through reversal of dc voltage polarity while in Voltage Source Converter, dc voltage always has one polarity, and the power reversal takes place through reversal of dc current polarity. The
III. SYSTEM MODELING FOR CONTROLLER DESIGN

A simplified power system model, such as the one depicted in Fig. 3, is used to study the impact of the E-STATCOM on the power system dynamics. The investigated system approximates an aggregate model of a two-area power system, where each area is represented by a synchronous generator.

The synchronous generators are modeled as voltage sources of constant magnitude \( (V_{g1}, V_{g2}) \) and dynamic rotor angles \( (\delta_{g1}, \delta_{g2}) \) behind a transient reactance \( (X'_{d1}, X'_{d2}) \). The transmission system consists of two transformers represented by their equivalent leakage reactance \( (X_{f1}, X_{f2}) \) and a transmission line with equivalent reactance \( (X = X_{f1} + X_{f2}) \). The losses in the transmission system are neglected for simpler analytical expressions. If the mechanical damping in the generators is neglected, the overall damping for the investigated system is equal to zero. Therefore, the model is appropriate to allow a conservative approach of the impact of the E-STATCOM when used for stability studies [14].

The control of the E-STATCOM consists of an outer control loop and an inner current control loop, as shown in Fig. 4. The outer control loop, which can be an ac voltage, dc-link voltage or POD controller, sets the reference current for the inner current controller. The generic measured signal \( y_m \) depends on the type of outer loop control. The control algorithm implemented in dq-reference frame where a phase-locked loop (PLL) [15] is used to track the grid-voltage angle \( \theta_g \) from the grid-voltage vector \( e_g \). By synchronizing the PLL with the grid-voltage vector, the \( d \)- and \( q \)-components of the injected current \( (i^d_t, i^q_t) \) control the injected active and reactive power, respectively. In the notation in Fig. 2, the superscript “*” denotes the corresponding reference signals.

IV. POD CONTROLLER DESIGN

The derivation of the POD controller from locally measured signals will be made in this section.

A. Derivation of Control Input Signals

Considering the simplified two-machine system in Fig. 3, the active power output from each generator should change in proportion to the change in its speed to provide damping [9]. 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 , i.e., on the location of the E-STATCOM. Using the equivalent system in Fig. 5, a control input signal that contains information on the speed variation of the generators can be derived.

B. Estimation of Control Input Signals

As described in the Introduction, effective power oscillation damping for various power system operating points and E-STATCOM locations require fast, accurate, and adaptive estimation of the critical power oscillation frequency component. This is achieved by the use of an estimation method based on a modified RLS algorithm. For reasons described in the previous subsection, the derivative of the PCC-voltage phase and the transmitted power should be estimated for controlling the active and reactive power injection, respectively. The aim of the algorithm is therefore to estimate the signal components that consist of only the low-frequency electromechanical oscillation in the measured signals \( \theta_c \) and \( P_{trans} \).

To describe the estimation algorithm, an input signal which could be either or , as shown in Fig. 6, 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.

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Modification in the Conventional RLS Algorithm:

A high forgetting factor results in low estimation speed with good frequency selectivity. With increasing estimation speed (decreasing \( \lambda \)), the frequency selectivity of the algorithm reduces. For this reason, the conventional RLS algorithm must be modified in order to achieve fast transient estimation without compromising its steady-state selectivity.

Modification for Multiple Oscillation Modes: The investigated control method has been derived under the assumption of a single oscillatory frequency component in the input signal. A brief description of how the proposed algorithm can be extended for multi-area system with multiple oscillation modes will be briefly presented here for future reference. The RLS described in the sections (including variable forgetting factor and frequency adaptation for each considered oscillation mode) can be modified as described in Fig. 7. Thus, the POD controller in Fig. 6 can be modified accordingly to control each mode independently.

V. SIMULATION RESULTS

The POD controller described in Section III is here verified via PSCAD/EMTDC simulation using the well known two-area four-machine system in Fig. 7. The implemented system is rated 20/230 kV, 900 MVA and the parameters for the generators and transmission system together with the loading of the system are given.

VI. CONCLUSION

An adaptive POD controller by E-STATCOM has been developed in this paper. For this, a modified RLS algorithm has been used for estimation of the low-frequency electromechanical oscillation components from locally measured signals during power system disturbances. The estimator enables fast, selective and adaptive estimation of signal components at the power oscillation frequency.
REFERENCES


Authors:


V. Prakash working as Associate Professor, Department of EEE in Talla Padmavathi College Of Engineering, Kazipet, Warangal.