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

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**Abstract:**The motto of present paper is to find out theenhancement of damping the power system oscillationthrough co-ordinated model of 'Static SynchronousCompensator' (STATCOM) situated in shunt withtransmission line.side.This isachieved using a signal estimation technique based on a modifiedrecursive least square (RLS) algorithm, which allows a fast,selective, and adaptive estimation of the low-frequency electromechanical oscillations from locally measured signals duringpower system disturbances. The proposed method is effective inincreasing the damping of the system at the frequencies of interest,also in the case of system parameter uncertainties and at variousconnection points of the compensator.

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

## I. INTRODUCTION

Along with the increasing scale of the power systemand stressed operation in the transmission network,more electromechanical oscillations are observed intoday's power systems. Once started, the oscillationsmay continue for a while and then disappear by thedamping toque from the system, or continue to growand cause system instability through losingsynchronism. In steady state operation, the primaryobjective of facts devices is to control power flow andimprove transmission capability. However, in recentyears, the application of facts devices in suppressingsystem oscillations has attracted increasing interestsfor research and development. The electromechanicaloscillation appears in a power system due to theinteractions among the system components. Most ofthe oscillation modes are generator rotors swingagainst each other. The oscillation normally occurs inthe frequency range of 0.2 Hz to 2.5 Hz. The inter-areaoscillations, which are typically in the lower frequencyrange of 0.2 Hz to 1 Hz, are exhibited as one group ofmachines swing relative to other groups. Comparedwith lower frequency, the higher frequency oscillationmodes typically involve one or two generatorsswinging against the rest of the power system, which iscalled local mode oscillation. The oscillations stabilityanalysis and control is an important and active topic inpower system research and applications. In the past,power system stabilizer (pss) is recognized as anefficient and economical method to damp oscillations.In recent years, as a new solution, various factscontrollers have been developed for damping of powersystem oscillations. Based on the control theoryapplied, the presented controllers can be divided to twogroups: linear controllers and nonlinear controllers. Inlinear control, the system dynamics are linearizedaround the pre-selected system operating pointaccording to lyapunov's linearization method. Thelinearized system is an approximation of the originalsystem at the operating point. Therefore, thesecontrollers suffer from the performance degeneracyproblem when system operating point deviates fromthe pre-designed point. Nonlinear control techniquescan provide more effective control of power systemsdue to their capability to handle nonlinear operatingcharacteristics. There are already some researches onnonlinear facts controller design for damping powersystem oscillations in recent years. The feedbacklinearization (fl) method has been used in factscontroller design in. Energy based control lyapunovfunction method (clf) had been successfully applied inseries facts devices controller in. The adaptive controlis used in facts controller design in. The h∞ control isalso successfully applied in tcsc controller to dampinter-area oscillations in. These nonlinear controllershave good performance if the system model is accurateand the parameters are precisely obtained. Theshortcoming is that the robustness is not guaranteed inthe presence of modelling inaccuracies. i.e. Parameteruncertainty and un-modelled dynamics, especially in fl method.

## II. BLOCK DIAGRAM OF THE STATCOM

The STATCOM is one of the most important shuntconnected FACTS controllers to control the power flowandmake better transients stability. A STATCOM is acontrolled reactive power source. It provides voltagesupports by generating or absorbing capacitor banks.

STATCOM has three operating parts:

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

(ii) SYNCHRONOUS: analogous to an ideal synchronousmachine with 3 sinusoidal phase voltage at fundamentalfrequency,

(iii) COMPENSATOR: rendered with reactivecompensation.

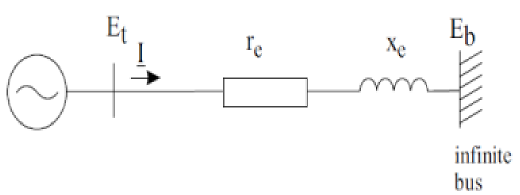


Fig1: One machine to infinite bus system

Modern electric power system is facing manychallenges due to day by day increasing complexity in theiroperation and structure. In the recent past, one of theproblems that got wide attention is the power systeminstability. With the lack of new generation andtransmission facilities and over exploitation of the existingfacilities geared by increase in load demand make thesetypes of problems more imminent in modern powersystems. Demand of electrical power is continuously risingat a very high rate due to rapid industrial development . Tomeet this demand, it is essential to raise the transmittedpower along with the existing transmission facilities. Theneed for the power flow control in electrical power systemsis thus evident. With the increased loading of transmissionlines, the problem of transient stability after a major faultcan become a transmission power limiting factor. To solvethe problem of transient stability in the late 1980s, theElectric Power Research Institute (EPRI) introduced a newapproach to solve the problem of designing and operatingpower systems; the proposed concept is known as FlexibleAC Transmission Systems (FACTS). The two mainobjectives of FACTS are to increase the transmissioncapacity and control power flow over designatedtransmission routes. FACTS are defined by the IEEE as “apower electronic based system and other static equipmentthat provide control of one or more AC transmissionsystem parameters to enhance controllability and increase power transfer capability”.

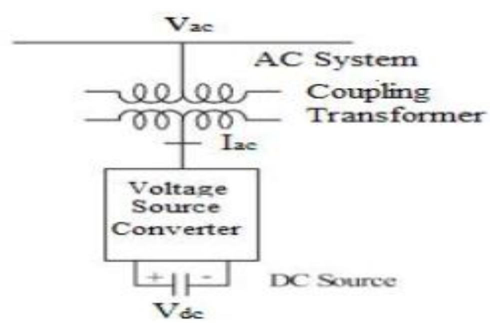


Fig2: Basic Structure of STATCOM

“A Static synchronous compensator is a shuntconnected static VAR compensator whose capacitive orinductive output current can be controlled independent ofthe ac system voltage”.The concept of STATCOM wasproposed by Gyugyi in 1976. Power Converter employedin the STATCOM mainly of two types i.e. is VoltageSource Converter and Current Source Converter. InCurrent source Converter direct current always has onepolarity and the power reversal takes place through reversalof dc voltage polarity while In Voltage Source Converterdc voltage always has one polarity, and the power reversaltakes place through reversal of dc current polarity. The

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## III. SYSTEM MODELING FOR CONTROLLER DESIGN

A simplified power system model, such as the one depictedin Fig. 3, is used to study the impact of the E-STATCOM on thepower system dynamics. The investigated system approximatesan aggregate model of a two-area power system, where eacharea is represented by a synchronous generator.

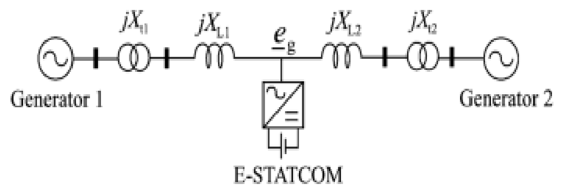


Fig. 3. Simplified two-machine system with E-STATCOM

The synchronous generators are modeled as voltage sourcesof 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 bytheir equivalent leakage reactance $(X_{t1}, X_{t2})$and a transmission line with equivalent reactance$(X_L = X_{l1} + X_{l2})$ . Thelosses in the transmission system are neglected for simpler analytical expressions. If the mechanical damping in the generatorsis neglected, the overall damping for the investigated systemis equal to zero. Therefore, the model is appropriate to allow aconservative approach of the impact of the E-STATCOM whenused for stability studies [14].

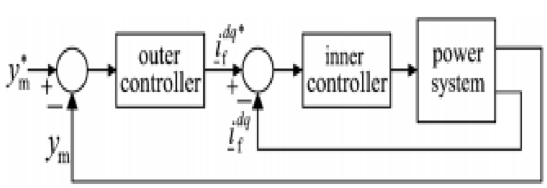


Fig. 4. Block diagram of the control of E-STATCOM

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-linkvoltage or POD controller, sets the reference current for theinner current controller. The generic measured signal $y_m$depends on the type of outer loop control. The control algorithmis implemented in dq-reference frame where a phase-lockedloop (PLL) [15] is used to track the grid-voltage angle$\theta_g$ fromthe grid-voltage vector $e_g$. By synchronizing the PLL with thegrid-voltage vector, the d- and q-components of the injected current ($i_f^d$and$i_f^q$) control the injected active and reactive power,respectively. In the notation in Fig. 2, the superscript "* " denotes the corresponding reference signals.

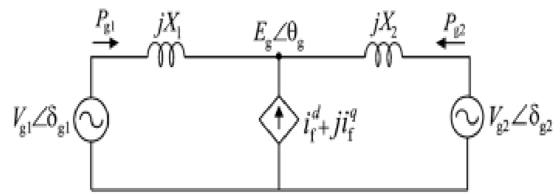

Fig. 5.Equivalent circuit for two-machine system with E-STATCOM.

In this paper, the outer control loop is assumed to be aPOD controller, and the detail of the block will be describedin Section IV. For this reason, we assume that the injectedactive and reactive powers in the steady state are zero. Whendesigning a cascaded controller, the speed of outer control loopis typically selected to be much slower than the inner one toguarantee stability. This means that the current controller canbe considered infinitely fast when designing the parameters ofthe outer controller loop. Therefore, the E-STATCOM can bemodeled as a controlled ideal current source, as depicted in theequivalent circuit in Fig.5, for analysis purpose.The level of power oscillation damping provided by the

converter depends on how much the active power output fromthe generators is modulated by the injected current, . For thesystem in Fig. 5, the change in active power output from thegenerators due to injected active and reactive power from theE-STATCOM.

## IV. POD CONTROLLER DESIGN

The derivation of the POD controller from locally measuredsignals 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 inproportion 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 outputhighly depends on the parameter , i.e., on the location of theE-STATCOM. Using the equivalent system in Fig. 5, a controlinput signal that contains information on the speed variation ofthe 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 andE-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 amodified RLS algorithm. For reasons described in the previoussubsection, the derivative of the PCC-voltage phase and thetransmitted power should be estimated for controlling the active and reactive power injection, respectively. The aim of thealgorithm is therefore to estimate the signal components thatconsist of only the low-frequency electromechanical oscillation in the measured signals $\theta_g$ and $P_{tran}$.

To describe the estimation algorithm, an input signal whichcould 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-frequencyoscillatory components, depending on the number of modes thatare excited by the disturbance.

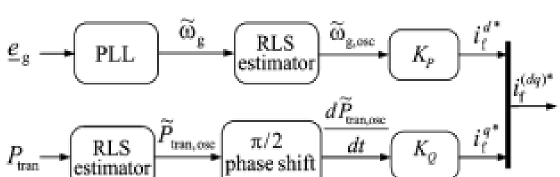


Fig. 6. Block diagram of the POD controller.

**Modification in the Conventional RLS Algorithm:**
A high forgettingfactor results in low estimation speed with good frequency selectivity. With increasing estimation speed (decreasing $\lambda$), thefrequency selectivity of the algorithm reduces. For this reason,the conventional RLS algorithm must be modified in orderto achieve fast transient estimation without compromising itssteady-state selectivity.

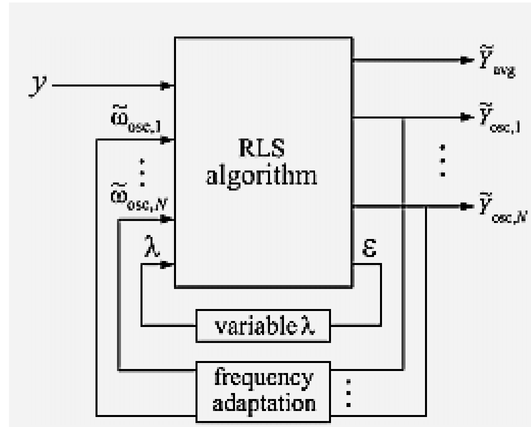


Fig.7. Block diagram of the modified RLS estimator for multiple oscillationmodes.

**Modification for Multiple Oscillation Modes**: The investigated control method has been derived under the assumption ofa single oscillatory frequency component in the input signal. Abrief description of how the proposed algorithm can be extendedfor multi-area system with multiple oscillation modes will bebriefly presented here for future reference.
The RLS described inthe sections (including variable forgetting factor andfrequency adaptation for each considered oscillation mode) canbe 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 verifiedvia PSCAD/EMTDC simulation using the well known two-areafour-machine system in Fig. 7. The implemented system is rated20/230 kV, 900 MVA and the parameters for the generators andtransmission system together with the loading of the system aregiven.

## VI. CONCLUSION

An adaptive POD controller by E-STATCOM has beendeveloped in this paper. For this, a modified RLS algorithm hasbeen used for estimation of the low-frequency electromechanical oscillation components from locally measured signalsduring power system disturbances. The estimator enables afast, selective and adaptive estimation of signal components atthe power oscillation frequency.

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