International Journal of Engineering In Advanced Research Science and Technology
ISSN: 2278-2566

VOLUME-2
ISSUE-5
OCT-2016
PAGE NO:12-18

AN ADAPTIVE POWER OSCILLATION DAMPING CONTROLLER BY STATCOM WITH ENERGY STORAGE

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ABSTRACT— This paper manages the configuration of a versatile poweroscillation damping (POD) controller for a static synchronouscompensator (STATCOM) furnished with vitality stockpiling. This isachieved utilizing a sign estimation strategy in light of a modifiedrecursive minimum square (RLS) calculation, which permits a fast,selective, and versatile estimation of the low-recurrence electromechanicaloscillations from privately measured signs duringpower framework aggravations. The proposed technique is viable inincreasing the damping of the framework at the frequencies of interest,also on account of framework parameter instabilities and at variousconnection purposes of the compensator. To start with, the investigation of the impactof dynamic and receptive force infusion into the force systemwill be completed utilizing a basic two-machine framework model. Acontrol system that advances dynamic and responsive force injectionat different association purposes of the STATCOM will be derivedusing the improved model. Little flag investigation of the dynamicperformance of the proposed control procedure will be conveyed out.The adequacy of the proposed control technique to give poweroscillation damping regardless of the association purpose of thedevice and within the sight of framework parameter vulnerabilities willbe checked through reenactment and exploratory results.

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

I.INTRODUCTION

This paper manages the configuration of a versatile poweroscillation damping (POD) controller for a static synchronouscompensator (STATCOM) furnished with vitality stockpiling. This isachieved utilizing a sign estimation strategy in light of a modifiedrecursive minimum square (RLS) calculation, which permits a fast,selective, and versatile estimation of the low-recurrence electromechanicaloscillations from privately measured signs duringpower framework aggravations. The proposed technique is viable inincreasing the damping of the framework at the frequencies of interest,also on account of framework parameter instabilities and at variousconnection purposes of the compensator. To start with, the investigation of the impactof dynamic and receptive force infusion into the force systemwill be completed utilizing a basic two-machine framework model. Acontrol system that advances dynamic and responsive force injectionat different association purposes of the STATCOM will be derivedusing the improved model. Little flag investigation of the dynamicperformance of the proposed control procedure will be conveyed out.The adequacy of the proposed control technique to give poweroscillation damping regardless of the association purpose of thedevice and within the sight of framework parameter vulnerabilities willbe checked through reenactment and exploratory results..

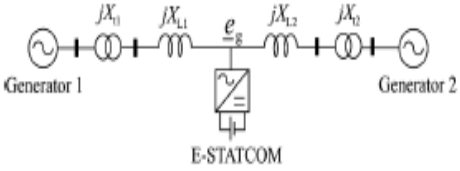

Fig. 1. Simplified two-machine system with E-STATCOM

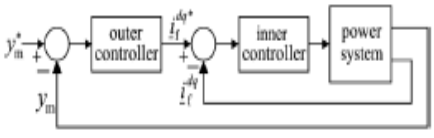

Fig. 2. Block diagram of the control of E-STATCOM

signals from locally measured signals. Finally, the effectivenessof the proposed control strategy will be

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validated via simulationand experimental verification.

II. SYSTEM MODELING FOR CONTROLLER DESIGN

A simplified power system model, such as the one depictedin Fig. 1, 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.The synchronous generators are modeled as voltage sourcesof constant magnitude and dynamic rotor anglesbehind a transient reactance . The transmissionsystem consists of two transformers represented bytheir equivalent leakage reactance and a transmissionline with equivalent reactance .Thelosses in the transmission system are neglected for simpler analyticalexpressions. 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]. For analysis purpose, the electricalconnection point of the converter

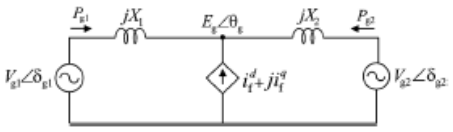

Fig. 3. Equivalent circuit for two-machine system with E-STATCOM.

$$\Delta P_{g1,P} \approx -\Gamma_P P_{inj}, \quad \Delta P_{g2,P} \approx -(1-\Gamma_P)P_{inj}$$
$$\Delta P_{g1,Q} \approx \left[\frac{V_{g1}V_{g2}\sin(\delta_{g10}-\delta_{g20})a(1-a)}{E_{g0}^2}\right] Q_{inj}$$
$$\Delta P_{g2,Q} \approx -\left[\frac{V_{g1}V_{g2}\sin(\delta_{g10}-\delta_{g20})a(1-a)}{E_{g0}^2}\right] Q_{inj} \quad (2)$$

respectively. In the notation in Fig. 2, the superscript " " denotesthe corresponding reference signals.In this paper, the outer control loop is assumed to be aPOD controller, and the detail of the block will be describedin Section III. 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. 3, for analysis purpose.The level of power oscillation damping provided by theconverter depends on how much the active power output from

II. POD CONTROLLER DESIGN

The derivation of the POD controller from locally measuredsignals will be made in this section.A. Derivation of Control Input SignalsConsidering the simplified two-machine system in Fig. 1,the active power output from each generator should change inproportion to the change in its speed to provide damping [9].From (2), it can be observed that the effect of the power injectedby 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. 3, a controlinput signal that contains information on the speed variation ofthe generators can be derived. When the E-STATCOM is notinjecting any current, the variation of the locally measured signals,and at different E-STATCOM connection pointsusing the dynamic generator rotor angles and is givenby

$$\theta_g = \delta_{g2} + \tan^{-1}\left[\frac{(1-a)V_{g1}\sin(\delta_{g1}-\delta_{g2})}{(1-a)V_{g1}\cos(\delta_{g1}-\delta_{g2})+aV_{g2}}\right] \quad (4)$$

$$P_{tran} = \frac{V_{g1}V_{g2}\sin(\delta_{g1}-\delta_{g2})}{X_1+X_2}. \quad (5)$$

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 [14]

$$\frac{d\theta_g}{dt} \approx \Gamma_P\omega_{g0}\Delta\omega_{g1} + (1-\Gamma_P)\omega_{g0}\Delta\omega_{g2} \quad (6)$$

$$\frac{dP_{tran}}{dt} \approx \left\{\frac{V_{g1}V_{g2}\cos(\delta_{g10}-\delta_{g20})}{X_1+X_2}\right\}\omega_{g0}[\Delta\omega_{g1}-\Delta\omega_{g2}]$$

B. Estimation of Control Input Signals

As described in the Introduction, effective power oscillationdamping for various power system operating points andE-STATCOM locations require fast, accurate, and adaptive estimationof 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 activeand reactive power injection, respectively. The aim of thealgorithm is therefore to estimate the signal components

International Journal of Engineering In Advanced Research Science and Technology
ISSN: 2278-2566

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thatconsist of only the low-frequency electromechanical oscillationin the measured

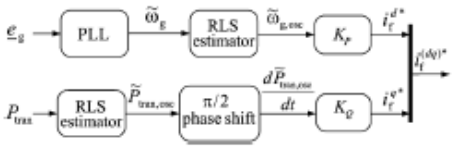

Fig. 4. Block diagram of the POD controller.

are excited by the disturbance. For simplicity, let us assume thatthere exist a single oscillatory component in the input signal.Therefore, the input signal consists of an average componentand an oscillatory component which can be modeledas

A. Derivation of Control Input Signals

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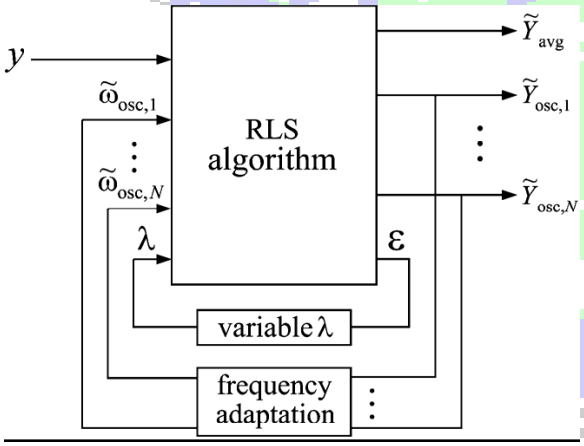

IV. STABILITY ANALYSIS OF SYSTEM MODEL

The mathematical model of the system in Fig. 3 is developedin this section to investigate the performance of the POD controllerusing active and reactive power injection. Using the expressionsin (6)–(7) for and , the injected currentsare controlled aswhere the constant is as defined in (3). Linearizing aroundan initial steady-state operating point, the small-signal dynamicmodel of the two-machine system with the E-STATCOM in perunit is developed as in(16)where represents the rotor angle differencebetween the two generators and other signals as definedpreviously.

$$i_f^d \approx K_P\omega_{g0}\left[\Gamma_P\Delta\omega_{g1} + (1-\Gamma_P)\Delta\omega_{g2}\right] \quad (1$$

$$i_f^q \approx K_Q\omega_{g0}\left\{\frac{V_{g1}V_{g2}\cos(\delta_{g10}-\delta_{g20})}{X_1+X_2}\right\}\left[\Delta\omega_{g1}-\Delta\omega_{g2}\right]$$

Assuming no mechanical damping and the initialsteady-state speed of the generators set to , the constants are

$$\frac{d}{dt}\begin{bmatrix}\Delta\omega_{g1}\\ \Delta\delta_{g12}\\ \Delta\omega_{g2}\end{bmatrix} = \begin{bmatrix}\beta_{11} & \beta_{12} & \beta_{13}\\ \omega_{g0} & 0 & -\omega_{g0}\\ \beta_{31} & \beta_{32} & \beta_{33}\end{bmatrix}\begin{bmatrix}\Delta\omega_{g1}\\ \Delta\delta_{g12}\\ \Delta\omega_{g2}\end{bmatrix} + \begin{bmatrix}\frac{1}{2H_{g1}} & 0\\ 0 & 0\\ 0 & \frac{1}{2H_{g2}}\end{bmatrix}\begin{bmatrix}\Delta T_{m1}\\ \Delta T_{m2}\end{bmatrix}$$

$$\begin{bmatrix}\beta_{11}\\ \beta_{12}\\ \beta_{13}\\ \beta_{31}\\ \beta_{32}\\ \beta_{33}\end{bmatrix} = \begin{bmatrix}\frac{\omega_{g0}\left(K_P E_{g0}\Gamma_P^2 + K_Q\Gamma_Q\right)}{2H_{g1}}\\ \frac{V_{g1}V_{g2}\cos(\delta_{g10}-\delta_{g20})}{2H_{g1}(X_1+X_2)}\\ \frac{\omega_{g0}(K_P E_{g0}\Gamma_P(1-\Gamma_P)-K_Q\Gamma_Q)}{2H_{g1}}\\ \frac{\omega_{g0}(K_P E_{g0}\Gamma_P(1-\Gamma_P)-K_Q\Gamma_Q)}{2H_{g2}}\\ \frac{V_{g1}V_{g2}\cos(\delta_{g10}-\delta_{g20})}{2H_{g2}(X_1+X_2)}\\ \frac{\omega_{g0}\left(K_P E_{g0}(1-\Gamma_P)^2 + K_Q\Gamma_Q\right)}{2H_{g2}}\end{bmatrix} \quad (1$$

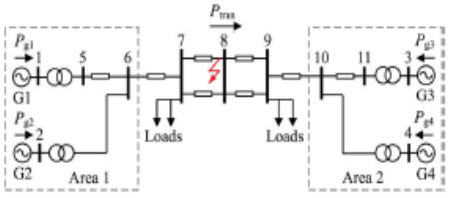

Fig. 7. Simplified two-area four machine power system.

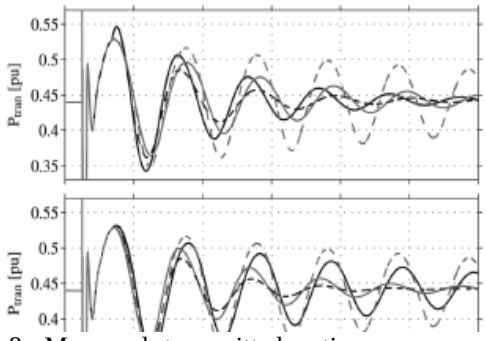

Fig. 8. Measured transmitted active power output following a three-phase

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E-STATCOMconnected at bus 7 (top), bus 8 (middle), and bus 9 (bottom).POD by only (black solid), only (gray solid), both , (blackdashed), and no POD (gray dashed).

Fig. 9. Single-line diagram of the laboratory setup.

(a) (b)

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 in detail in [9]. The system is initially operating in steadystatewith a transmitted active power, 400 MW fromarea 1 to area 2. A three-phase fault is applied to the system onone of the transmission lines between bus 7 and bus 8. The faultis cleared after 120 ms by disconnecting the faulted line. Due tothe applied disturbance, a poorly damped oscillation is obtainedafter the fault clearing.With the POD controller structure described in Fig.plots).

VI. EXPERIMENTAL VERIFICATION

To validate the results obtained via simulation for the PODcontroller performance by E-STATCOM, the obtained experimentalresults will be presented in this section.A. Laboratory SetupThe schematic of the laboratory setup is shown in Fig. 9,while Fig. 10 shows a photograph of the actual transmissionsystem model. The system consists of a 75-kVA, 400-V synchronousgenerator connected to a stiff ac grid through a transmission-line model. A voltage source converter (VSC) systemcan be connected at various locations of the transmission line.

1) VSC System: The VSC system consists of a two-level converterconnected to the transmission line model though a seriesreactor with 2 mH, 6.2 m and shunt capacitorwith 60 uF. The VSC is controlled from a computer witha dSpace 1103 board, which can be programmed using C-codeorMATLAB/Simulink. The dc-link of theVSC is connected to a

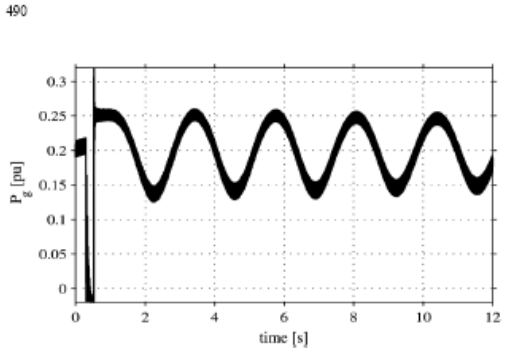

Fig. 11. Measured transmitted active power from the generator. A three-phase fault is applied and cleared after 250 ms.

dc machine rated 700 V and 60 A. The dc machine is equippedwith field control and the terminal dc voltage is controlled to650 V for all of the experiments. The dc machine will act as the

energy source providing active power injection capability to theVSC. Therefore, the VSC with the dc machine is considered asan E-STATCOM.

2) Network Model: The network model is a down-scaledversion of an actual Swedish 400 kV transmission systemwith the model rated at 400 V, 50 Hz. The transmission-linemodel consists of six identical sections (with parameters2.05 mH, and 46 F), eachcorresponding to a portion of 150 km of the actual line [16].As shown in Fig. 9, faults can be applied to the transmission

B. Experimental Verification of Modified RLS EstimatorIn order to create a power oscillation in the system, athree-phase fault has been applied in the middle of the transmissionline. The fault clearing time is 250 ms.The measuredoutput power from the generator as shown in Fig. 11 isthen used as an input to test the performance of the algorithmto estimate the low-frequency electromeachieved. The frequency adaptation ensures a correct extractionof the magnitude and phase of the oscillatory component which 400 MW fromarea 1 to area 2. A three-phase fault is applied to the system onone of the transmission lines between bus 7 and bus 8. The faultis cleared after 120 ms by disconnecting the faulted line. Due tothe applied disturbance, a poorly damped oscillation is obtainedafter the fault clearing.With the POD controller structure described in Fig.plots). 400 MW fromarea 1 to area 2. A three-phase fault is applied to the system onone of the transmission lines between bus 7 and bus 8. The faultis cleared after 120 ms by disconnecting the faulted line. Due tothe applied disturbance, a poorly damped oscillation is obtainedafter the fault clearing.With the POD controller structure described in Fig.plots).

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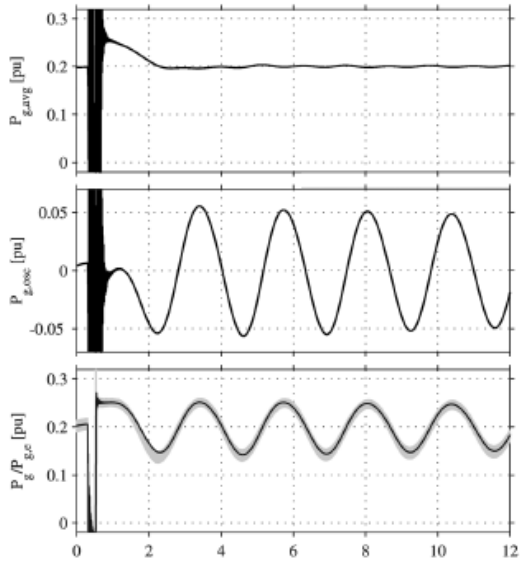
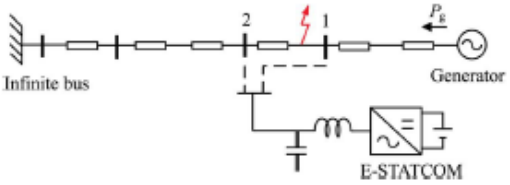


C. Experimental Verification of POD Controller by E-STATCOM

As described in Section III, the outputs of the POD controllerare active and reactive current references to be injected to thegrid by the E-STATCOM. The current controller implemented

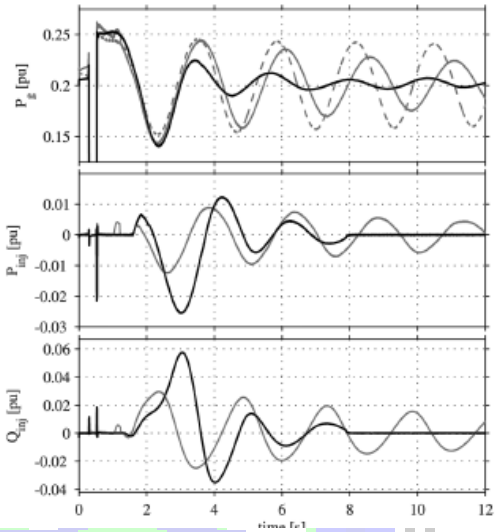


VII. CONCLUSION

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 electromechanicaloscillation components from locally measured signalsduring power system disturbances. The estimator enables afast, selective and adaptive estimation of signal components atthe power oscillation frequency. The dynamic performance ofthe POD controller to provide effective damping at various connectionpoints of the E-STATCOM has been validated throughsimulation as well as experimental verification. The robustnessof the control algorithm against system parameter changeshas also been proven through experimental tests. Furthermore,using the frequency variation at the E-STATCOM connectionpoint as the input signal for the active power modulation, it hasbeen shown that active power injection is minimized at pointsin the power system where its impact on POD is negligible.This results in an optimal use of the available energy source.

APPENDIX

Here, the relation between the change in active power outputfrom the generators and the active and reactive power injectedby the E-STATCOM will be derived. With the notations givenin Fig. 3, the power output of Generator 1 is given by



REFERENCES

[1] N. G. Hingorani and L. Gyugyi, Understanding FACTS.Concepts andTechnology of Flexible AC Transmission Systems.NewYork,NY,USA: IEEE, 2000.

[2] G. Cao, Z. Y. Dong, Y. Wang, P. Zhang, and Y. T. Oh, "VSC basedSTATCOM controller for damping multi-mode oscillations," in Proc.IEEE Power and Energy Soc. General Meeting—Conversion and Deliveryof Electrical Energy in the 21st Century, Jul. 2008, pp. 1–8.

[3] M. Zarghami and M. L. Crow, "Damping inter-area oscillations inpower systems by STATCOMs," in Proc. 40th North Amer. PowerSymp., Sep. 2008, pp. 1–6.

[4] Z. Yang, C. Shen, L. Zhang,M. L. Crow, and S. Atcitty, "Integration ofa statcom and battery energy storage," IEEE Trans. Power Syst., vol.16, no. 2, pp. 254–260, May 2001.

[5] A. Arulampalam, J. B. Ekanayake, and N. Jenkins, "Application studyof a STATCOM with energy storage," Proc. Inst. Electr. Eng.—

Gener.,Transm. andDistrib., vol. 150, pp. 373–384, July 2003.

[6] N. Wade, P. Taylor, P. Lang, and J. Svensson, "Energy storage forpower flow management and voltage control on an 11 kV UK distributionnetwork," Prague, Czech Republic, CIRED paper 0824, Jun. 2009.

[7] A. Adamczyk, R. Teodorescu, and P. Rodriguez, "Control of full-scaleconverter based wind power plants for damping of low frequency

system oscillations," in Proc. IEEE PowerTech, Trondheim, Norway,Jun. 2011, pp. 1–7.

[8] H. Xie, "On power-system benefits, main-circuit design, control ofStatcoms with energy storage," Ph.D. dissertation, Dept. Electr. EnergyConversion, Royal Inst. Technol., Stockholm, Sweden, 2009.

[9] P. Kundur, Power System Stability and Control. New York, NY,USA: McGraw-Hill, 1994.

[10] K. Kobayashi, M. Goto, K. Wu, Y. Yokomizu, and T. Matsumura,"Power system stability improvement by energy storage typeSTATCOM," in Proc. IEEE Power Tech Conf., Bologna, Italy, Jun.2003, vol. 2, DOI 10.1109/PTC.2003.1304302.

[11] L. Zhang and Y. Liu, "Bulk power system low frequency oscillationsuppression by FACTS/ESS," in Proc. IEEE PES Power Syst. Conf.Exp., Oct. 2004, pp. 219–226.

[12] A. Arsoy, L. Yilu, P. F. Ribeiro, and F. Wang, "Power converter andSMES in controlling power system dynamics," in Proc. Ind. Appl.Conf., Oct. 2000, vol. 4, pp. 2051–2057.

[13] M. Beza and M. Bongiorno, "A fast estimation algorithm for low-frequencyoscillations in power systems," in Proc. 14th Eur. Conf. PowerElectron. Appl., Sep. 2011, pp. 1–10.

[14] M. Beza, "Control of energy storage equipped shunt-connected converterfor electric power system stability enhancement," LicentiateThesis, Dept. Energy and Environment, Chalmers Univ. of Technol.,Gothenburg, Sweden, 2012, .

[15] L. Ängquist and M. Bongiorno, "Auto-normalizing phase-locked loopfor grid-connected converters," in Proc. IEEE Energy Conv. Congres