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Advanced Tuning of POD Controllers for Electric Power Systems using FACTS

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Abstract: In this work, real-time evaluation and steps towards implementation of three different types of power oscillation damping controllers (POD) for fast power electronic devices such as FACTS (flexible AC transmission systems) have been done. The performance of classical POD controllers (lead-lags and phasor estimators) are compared with an advanced adaptive approach. The prerequisite for achieving optimal results in damping of electromechanical oscillations is the availability of remote signals through wide-area monitoring and control (WAMC) platforms discussed here. Achieved results are demonstrated on a dedicated real-time hardware platform.

Keywords: Modeling, operation and control of power systems, Power system oscillations, flexible AC transmission systems, adaptive control, model identification, Kalman Filter.

1. INTRODUCTION

Generators in an interconnected power systems produce alternating current and are synchronized to operate at the same frequency. In a synchronized system, the power is naturally shared between generators. Alternating current generators remain in synchronism because of the self-regulating properties of their interconnection. In case of a disturbance, a generator deviates from its synchronous speed, power is transferred from the other generators in the system in such a way that the speed deviation is reduced. The moments of inertia of the generators and the control loops closed via the excitation systems also come into account. It typically results in speed over-corrections and the whole system starts naturally swinging in the same manner as a set of interconnected pendulums. As a result, any interconnected power system can hardly be operated without supplementary control guaranteeing satisfactory damping of power oscillations. To improve the damping of these electro-mechanical oscillations, fast acting power electronic devices, such as FACTS devices, can be employed using the presented feedback control laws. Optimally tuned for nominal operating conditions, the conventional controllers – usually linear time-invariant (LTI) lead-lags, see e.g. Sadikovic [2005] or so called phasor POD developed by Angquist [2000] – are simple and often a very effective solution to improve the damping of selected oscillatory modes. However, they only work within a limited operating range. In case of contingencies, the new operating conditions can still cause poorly damped or unstable oscillations since the set of the controller's parameters found for one operating condition may no longer be adequate for another one. One solution to this problem has been based on a lately developed algorithm for on-line detection of electromechanical oscillations based on Kalman filtering techniques proposed by Korba [2003]. The algorithm, developed for a wide-area monitoring platform productized recently, see Zima [2005], has been employed to improve damping of electromechanical oscillations of a power system model discussed in Leirbukt [2006]. It gives the information about the actual dominant oscillatory modes with respect to the frequency and damping as well as about the amplitude of the oscillation obtained through on-line analysis of signals measured at appropriate places in the power system. The approach has been tested in non-linear simulations in Sadikovic [2006]. The actual work has dealt with real-time implementation of the adaptive algorithm making use of the hardware platform described in Majumder [2006]. One of the major challenges with adaptive algorithms is their implementation and verification of the closed-loop performance in real time. To carry out such a validation exercise access to practical power systems is required wherein the controller can be plugged in and tested for satisfactory performance. However, unless the utilities are convinced *apriori* they are not going to allow such testing on system due to potential risks. The other option, therefore, is to build a prototype of the power system in the laboratory. Although this might be a feasible option for smaller systems, this is not possible for large scale systems. The solution is to build a hardware platform that can emulate the behavior of large scale power systems in real time and to interface the controller (analog domain) with the system emulator and to carry out hardware-in-loop simulations in real time this way.

2. ADAPTIVE CONTROL

In general, the power system dynamics is non-linear and varies with the operating point of the power system. The technique employed here to track the model parameters is based on Kalman Filtering techniques (KF) which provides a unifying framework for a complete family of recursive least-squares filters. The solution is computed recursively, applying without modification to time-varying or time-invariant environments. The tuning procedure, experience and the set of standard equations has been described in Korba [2007]. Properly tuned, one gets at any sampling time k the optimal dynamic model of the power system behavior, which is required for the subsequent controller design procedure. The basic idea is to design a controller which shifts the actual poles of the open-loop system towards the origin of the z-plane used by Malik [1993] for tuning power system stabilizers. The implemented pole shifting procedure is based on a method incorporating a self-tuning feature with regard to the limits imposed on the control signal. In order to achieve the maximal closed-loop damping subject to the control signal limits, the pole shifting factor varies then with the actual operating conditions.

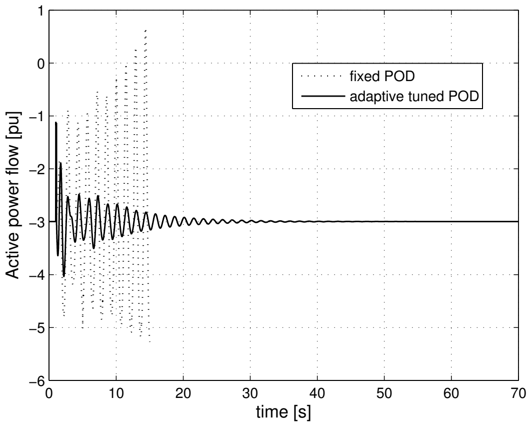

Fig. 1. Power flow in the controlled line after a fault.

3. REAL-TIME IMPLEMENTATION

The real time station (RTS) is a PC based computer running on a real time operating system RedHawk RT-Linux having a 3.2 GHz dual-Xeon processor. Both the processors share a common memory. The computational tasks are distributed as follows: CPU1 of the dual-CPU processor handles the differential equations describing the dynamic behavior of the generators, associated excitation systems, loads and other dynamic components like the FACTS devices. The CPU2 simultaneously solves the network equations and interface the generators with the network. Once the control algorithm is formulated it can be implemented in the rapid prototyping controller (RPC). The key is to ensure that the computational time for the RPC is well within the sampling period. The efficacy of the designed controller is proved in real time by implementing it on the RPC.

4. RESULTS AND RELATED WORK

The work done on the wide-area monitoring system in the past, see e.g. Korba [2003], Zima [2005], Leirbukt [2006], has indicated that the next logical step would be to use the newly available remote phasor measurements (with a relatively high time domain resolution – so far up to 50Hz sampling frequency) in a closed loop control. In Majumder [2006], the above described hardware set up has been tested to validate the real-time performance of a robust linear time-invariant controller. Here, performance of fixed and the discussed adaptive controllers were investigated. The robust controller has been designed for the nominal operating conditions (all generators and power lines in operation). Both type of controllers have shown very good performance in a number of simulations with different contingencies. However, it has been easy to demonstrate that fixed POD controllers can easily be driven out of the operating range, see Fig.1. As a result, they loose their stabilizing effect on the power system. On the other hand, the adaptive controller quickly adjusts its parameters to the new operating conditions and stabilizes the power system again. This feature has been the main motivation for dealing with the adaptive controllers in our work.

5. CONCLUSION AND FUTURE WORK

The presented adaptive controller for FACTS has been able to stabilize the power system models subject to many different types of (a priori unknown) disturbances. Not surprisingly, its operating range has been much wider compared to any fixed POD controller. The price to be paid for this is a higher computational effort put on the hardware. However, the first experiments have proven its feasibility.

REFERENCES

P. Korba, *"Real-time Monitoring of Electromechanical Oscillations in Power Systems: First Findings"*, IEE Proceedings on Generation, Transmission and Distribution, Vol.1 No. 1, pp. 80–88, 2007.

M. Zima, M. Larsson, P. Korba, C. Rehtanz, G. Andersson, *"Design Aspects for Wide-Area Monitoring and Control Systems"*, Proc. of the IEEE, Vol. 93, No. 5, pp. 980–996, 2005.

P. Korba, M. Larsson, C. Rehtanz, *"Detection of oscillations in power systems using Kalman filtering techniques"*, Proc. of IEEE Conference on Control Applications, Vol.1, pp. 183–188, 2003.

A. B. Leirbukt, P. Korba, J.O. Gjerde, K. Uhlen, L. K. Vormedal, L. Warland, *"Wide-Area Monitoring Experiences in Norway"*, Power Systems Conference and Exposition (PCSE), Atlanta, 2006.

R. Majumder, B. C. Pal, C. Dufour, P. Korba, *"Design and Real-time Implementation of FACTS Controller for Damping Inter-area Oscillation"*, IEEE Trans. on Power Systems, Vol. 21, No. 2, pp. 809–816, 2006.

G.P. Chen, O.P. Malik, G.S. Hope, Y.H. Qin, G.Y. Xu, *An adaptive power system stabilizer based on the self-optimizing pole shifting control strategy*, IEEE Transactions on Energy Conversion, Vol. 8, No. 4, pp. 639–645, December 1993.

C. Gama, L. Angquist, G. Ingestrom, M. Noorozian *Commisiong and operative experience of TCSC for Damping Power Oscillations in the Brazilian North-South Interconnection*, CIGRE Session 14-104, Paris, France, 2000.

R. Sadikovic, P. Korba, G. Andersson *Application of FACTS Devices for Damping of Oscilations*, IEEE PowerTech, St. Petersburg, Russia, 2005.

R. Sadikovic, P. Korba, G. Andersson, *Selft-tuning Controller for Damping of Power System Oscillations using FACTS* , IEEE Power Engineering Society General Meeting, Montreal, Canada, 2006.