Real-Time Implementation of Synchrophasor-based Wide-Area Power Oscillation Damping Control System

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***Abstract*—The modern power grid is increasingly being used under operating conditions of increasing stress for which it was not designed. The increasing penetration levels of variable energy sources such as wind present significant power grid stability issues. One of the these stability issues is the phenomenon of low frequency, electro-mechanically induced, inter-area oscillations. Simulations have demonstrated the potential of Wide Area Measurement Signals (WAMS) -based Power Oscillation Damping (POD) in achieving improved electromechanical mode damping compared to traditional, local signal based, Power System Stabilizers (PSS). This paper takes an established Phasor-based oscillation damping method and combines it with modern PMU technology to implement a hardware prototype of a real-time oscillation damping control system using remote PMU signals sent over a communications network. The developed prototype is tested in a real-time Hardware-in-the-loop approach in conjunction with the Klein-Rogers-Kundur two-area four-machine test system.**

Keywords*—IEEEtran, journal, synchrophasor, PMU, damping control, Wide Area measurement and control

I. Introduction

THE goal of this paper is to demonstrate the flexibility in oscillation damping controller design that is provided by using synchrophasors. The Phasor Power Oscillation Damping algorithm originally developed by Ängquist and Gama [1] is run on a National Instruments Compact Reconfigurable Input / Output (cRIO) real-time controller. A slightly modified, SIMULINK model of the four-machine, two-area network developed by Klein-Rogers and Kundur [2] is run on the eMEGASIM [3] platform from OPAL RT. This allows interfacing an externally generated control signal with the simulated model. The flexibility of the developed controller is also demonstrated by extracting various data from the synchrpohasor input and using each as a damping input to the controller. A brief analysis of the performance of each input is also presented.

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A. Background

As modern power systems grow in size, both in terms of power transfer capacity and geographic spread, they are increasingly being used for purposes that the power system was not designed for. Examples of these 'new' uses include conditions of increasing stress such as power trading between countries. These interconnections, which link synchronous generators, often separated by vast physical distances, create conditions where small disturbances can excite oscillations that may or may not settle. When the generators of one area oscillate at a low frequency (typically 0.2–2.5Hz) against the generators of another interconnected, but distinct area, 'inter-area' oscillations may start.

Although the purpose of system interconnection was to increase stability, the present situation of the power system incorporates renewable energy sources and power trading corridors, both of which impact system stability. More modern solutions to the problems of inter area and intra oscillations use Power System Stabilizers (PSS) [4]. While a PSS provides excellent damping to intra area modes with good local observability, its performance with intra-area modes may not be satisfactory [5].

1) Methodology: This paper presents a Wide Area Power Oscillation Damper (WAPOD)[1] prototype using commercially available micro-controller hardware, based entirely on PMU measurements received over a TCP/IP network. A previously developed damping algorithm [1] will be implemented on a general purpose micro-controller and will be run in real-time. The inputs to the controller will come from one or multiple PMU's, each monitoring data at different points in the power system. The power system model used in this thesis is the two-area four machine model, originally proposed by Klein, Rogers and Kundur [2]. To prove the real-world applicability of the developed controller, all tests are carried out in real-time, with conditions such as noise and network transport delay present.

[1]Historically, damping stabilizers have been termed WAPOD where the P represents a measurement of active power through the line. Active power here would be used as a controller input signal. Although this term is not accurate when other quantities are used as control inputs or feedback signals, the term is used here to maintain consistency with existing literature.

II. Setup Preparation

III. Testing & Results

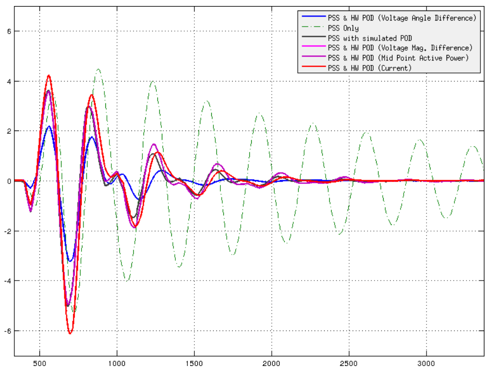

Fig. 1. Result Comparison

IV. Additional Inputs

V. Challenges

A. Time Delays

B. Analogue Limits and Noise

C. Loop Rates and FPGA Resources

VI. Conclusion

This work has demonstrated the feasibility of using wide-area power system data in the design of an oscillation damping controller. The real-time simulation results prove that the design goals of the controller were met. The flexibility of synchrophasor data was demonstrated and the wide range of inputs possible from this were also tested.

Appendix A
Proof of the First Zonklar Equation

Appendix one text goes here.

Appendix B

Appendix two text goes here.

Acknowledgment

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