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The preferred citation for this publication is

S. P. Kerr, W. R. Kerr and T. Xu. *Wide-area Oscillation Identification and Damping Control in Power Systems*. Foundations and Trends® in Electric Energy Systems, vol. 2, no. 2, pp. 133–197, 2018.

ISBN: 978-1-68083-449-9

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Volume 2, Issue 2, 2018

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Foundations and Trends® in Electric Energy Systems, 2018, Volume 2, 4 issues. ISSN paper version 2332-6557. ISSN online version 2332-6565. Also available as a combined paper and online subscription.

# Contents

# Wide-area Oscillation Identification and Damping Control in Power Systems

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ABSTRACT

Low-frequency oscillation (LFO) is a phenomenon inherent to power systems and should be carefully considered and dampened to improve the dynamic stability of power systems. With the development of wide area synchronous phasor measurement technology, the measurement results of phasor measurement units (PMUs) and wide-area measurement system (WAMS) can be applied in system identification and the wide area damping controller design to suppress LFO. In this paper, the identification methods and controller design methods of wide area damping control are reviewed. The basic framework for the application of PMU/WAMS results in power system identification and control is introduced first. Both the output response identification and the input-output identification are introduced in the identification section. The offline controller design and adaptive controller design methods are introduced. Practical cases in China Southern Grid and China Central Grid are reviewed as engineering application examples.

Chao Lu, Jingyi Zhang, Xinran Zhang and Yi Zhao (2018), "Wide-area Oscillation Identification and Damping Control in Power Systems", Foundations and Trends® in Electric Energy Systems: Vol. 2, No. 2, pp 133–197. DOI: 10.1561/3100000003.

# 1

## Introduction

In power systems, equilibrium is maintained between electromagnetic and mechanical torques of each connected synchronous generator. The change in electromagnetic torque of a synchronous machine following a perturbation or disturbance can be resolved into a synchronizing torque component and a damping torque component. Non-oscillatory instability will be caused by insufficient synchronizing torque, whereas the lack of damping torque results in low-frequency oscillations (Prasertwong *et al.*, 2010).

Low-frequency oscillation (LFO) is a phenomenon inherent to power systems (Wang *et al.*, 2014). There are two primary types of LFO involved in power systems. One associated with a single generator or more generators within one area is called local-mode oscillation, while the other related to a group of generators among different areas is called inter-area oscillation. Typically, the frequency range is 1–2 Hz for local LFO and 0.1-1 Hz for inter-area LFO (Kundur, 1994). LFO may endanger the dynamic stability of power systems if there is no proper control to damp these oscillations. Inter-area oscillations also limit the amount of power transfer on the tie-lines between the areas containing coherent generator groups. Therefore, it is very critical to design damping controllers to stabilize the oscillations.

Recently, based on the synchronous phasor measurement and modern communication technology, WAMS is an integrated application system that offers real-time control and operation service to power systems. Research on WAMS was initiated in 1995 by the U.S. Department of Energy to develop advanced tools for wide-area measurement, control, and operation in the Western North American power system (WECC). Because WAMS is able to accurately provide both individual and sequential voltage and current phasors, it has been extensively used in power system applications, such as power system monitoring (Cai *et al.*, 2013), power system state estimation (Wang *et al.*, 2012), power system protection (Su *et al.*, 2010), and power system control (Zhang *et al.*, 2013a).

Wide-area damping control (WADC) has been extensively studied in recent years to suppress inter-area oscillations in power systems (Zhang *et al.*, 2014). In addition, the fast development of the wide-area measurement system (WAMS) has yielded new opportunities for the damping control of inter-area power systems. Meanwhile, modal analysis and model identification are essential parts of the design of damping controllers. The development of WAMS has also brought with it abundant and accurate data, providing good hardware support for dynamic identification.

The structure of WADC applied in power systems is shown in Figure 1.1. In this WADC, PMU acts as the sensor to measure the power system variables needed for a WADC controller. Receiving control commands from the WADC controller, power system stabilizer (PSS) or high-voltage direct current (HVDC) system, flexible alternate current transmission system (FACTS), etc. can act as actuators to damp the power system oscillations through the controlled plant (power system). Sensors and actuators communicate with the WADC controller through a communication network.

In the past two decades, various WAMS-based WADC technologies have been proposed and developed, and some of them have been successfully applied to real transmission systems in different countries. This paper aims to present a comprehensive review on WAMS-based WADC technologies to provide reference and guidance for researchers and utilities on the deployment of WADC to better accept large-scale

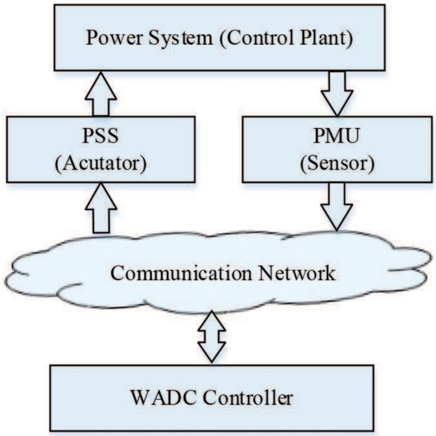


**Figure 1.1:** Structure of a WADC system

penetration of renewable energy resources. Typical analysis and design issues related to WAMS-based WADC technologies are also summarized and discussed in the paper.

There are four main steps in dynamic identification and damping controller design based on WAMS, including output response identification, feedback signal and input placement selection, input-output model identification, and controller design. We will introduce the framework of our dynamic identification and damping controller design and feedback signal and input placement selection in Section 2. Modal analysis with output response identification is a necessary part of the framework of WADC and is introduced in Section 3 in detail. Then, the system model between the input and feedback signal should be identified or built, with an input-output model identification method, which is discussed in Section 4. There are two main types of WADC design methods, including off-line methods and adaptive methods. Off-line WADC design methods are summarized in Section 5. Adaptive WADC design methods are summarized in Section 6. Two typical engineering applications of WADC in China Southern Grid and Central China Grid are introduced in Section 7; Section 8 concludes this work.

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