This article has been accepted for inclusion in a future issue of this journal. Content is final as presented, with the exception of pagination.

A Dynamic Mode Decomposition Framework for Global Power System Oscillation Analysis

Emilio Barocio, *Member, IEEE*, Bikash C. Pal, *Fellow, IEEE*, Nina F. Thornhill, *Senior Member, IEEE*, and Arturo Roman Messina, *Fellow, IEEE*

***Abstract*—A global multiscale method based on a dynamic mode decomposition (DMD) algorithm to characterize the global behavior of transient processes recorded using wide-area sensors is proposed. The method interprets global dynamic behavior in terms of both, spatial patterns or shapes and temporal patterns associated with dynamic modes containing essentially single-frequency components, from which the mode shapes, frequencies and growth and decay rates of the modes can be extracted simultaneously. These modes are then used to detect the coherent and dominant structures within the data. The technique is well suited for fast wide-area monitoring and assessment of global instability in the context of modern data fusion-based estimation techniques. Results of the application of the proposed method to large, high-dimensional data sets are encouraging.**

***Index Terms*—Dynamic mode decomposition, inter-area oscillations, mode-shape.**

I. Introduction

POWER system dynamic monitoring for a near real-time control has received increased importance in the past 5–10 years because of two primary reasons. Firstly the analysis of the causes and mechanisms of several large blackouts identified the lack of fast and dynamic monitoring [1]. Secondly the phasor measurement technology (PMUs) for deployment over wide area power system is now available commercially. A successful wide-area monitoring of low-frequency oscillation requires adaptive global identification methods, which can accurately identify and track the evolving dynamics of critical system modes [2], [3].

The dynamic monitoring of systems should be robust, and resilient against uncharacteristic variation of signal information. The tools must operate in real-time to quickly quantify the risks to system shut down such as blackouts. In the past few large power system collapse it has been observed that slowly growing power oscillations of low frequency have triggered the final events. These are known as inter-area modes as they are manifested across several large utilities. Naturally fasts monitoring of these oscillations is way to commit control to avert such situations.

Identifying damping factors and the frequency of oscillations has been very popular to quantify the stability margin in small signal sense [4]. Both, model and data driven tools, are reported. The recently concluded IEEE Task Force on modal identification [3] summarizes recent work on this topic.

Inter area oscillations monitoring targeting temporal amplitudes and phases of inter-area mode and energy of oscillations are useful attributes to assess the proximity of the system to instability [5]–[13]. Because of their global nature, modal frequencies and modal speeds in particular, are directly associated with global system behavior and may therefore be useful to detect and visualize the stressed part of the system. In addition, the level of energy associated with the oscillations as a measure of stability margin is a useful indicator as it is robust against noise in the measured signal.

Recently, several multi-scale dynamic feature extraction methods have been used to objectively identify and extract dominant patterns exhibited by power system transient processes. Of these methods, proper orthogonal decomposition (POD) and principal component analysis (PCA) have been applied to identify dynamically coherent generators and mode shapes using ensembles of model simulations and measured data [5]–[7]. The simplicity of the model structure allows for direct numerical analysis of large data sets collected using strategically located sensors.

Over the last few years, data-driven methods for modal identification based on the use of the Koopman operator have been developed [8]–[10]. These methods use Arnoldi-like techniques and enable complex oscillatory processes to be represented by several single-frequency nonlinear modes from which oscillations and interacting generators could be identified. The application of this approach, however, is challenging due to both, the high dimensionality of the parameter space and the computational complexity.

In this paper, a physically-motivated dynamic mode decomposition (DMD) algorithm is introduced to monitor the spatial and temporal dynamics of nonlinear transient phenomena. Distinct from previous power system identification methods, the proposed framework allows the multi-scale spatial and temporal dynamics in observed data to be identified directly from observational data [14]–[18].

Methods for interpreting the nonlinear mathematical structure of the spatio-temporal model in terms of temporal and structural components are discussed and a physical interpretation is provided.

Manuscript received December 18, 2013; revised May 26, 2014 and August 21, 2014; accepted October 29, 2014. This work was supported by the Marie Curie FP7-IAPP Project "Using real-time measurements for monitoring and management of power transmission dynamics for the smart grid- REAL-SMART", Contract No. PIAP-GA 2009-251304. Paper no. TPWRS-01599-2013.

E. Barocio, B. C. Pal, and N. F. Thornhill are with Imperial College London, London, NE 68902, U.K. (e-mail: ebarocio@imperial.ac.uk; b.pal@imperial.ac.uk; n.thornhill@imperial.ac.uk).

A. R. Messina is with CINVESTAV, Guadalajara, AL 36849, Mexicao (e-mail: aroman@gdl.cinvestav.mx).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TPWRS.2014.2368078