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Damping inter-area oscillation by generation rescheduling based on wide-area measurement information

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ABSTRACT

Inter-area oscillations are inherent to power systems which can be caused due to oscillation of two coherent groups of generators against each other with low or negative damping. Poorly damped oscillations can pose various problems such as limiting transfer capabilities and in more severe cases can lead to uncontrolled islanding causing system blackout. In this paper, for damping inter-area oscillation a new method based on the wide area measurement system (WAMS) and using generation rescheduling (GR) is proposed. The proposed algorithm consists of three tasks; identification of inter-area mode, determination the most effective generators for rescheduling and enhancing damping of inter-area mode by GR. In this approach, first by means of Independent Component Analysis (ICA) and modified Random Decrement (RD) techniques and using on-line power and rotor angle oscillation data provided by WAMS, the frequency and damping of the inter-area mode is identified. In the case of low damping of oscillation, by using mode shape of the inter area mode, generation rescheduling is applied for improvement of damping. In this paper, a non-model based method is adopted for estimating mode shape from the measured data like generator rotor speeds. The proposed approach is applied on a two area small system and IEEE 39-bus test system and the results demonstrate effectiveness of the method for enhancing oscillation damping.

Introduction

Inter-area oscillations are inherent to power systems which can be created when two coherent groups of generators with weak connection start to oscillate against each other with low or negative damping. These types of oscillations commonly referred to as inter-area mode can be excited by events such as random variation of load demand, fault or network switching. They are usually stable but typically have small damping ratios. As electrical power systems are being operated closer to their limits, poorly damped oscillations can pose various problems such as limiting transfer capacities and in more severe cases can lead to system instability causing a wide-scale blackout [1].

Model based approaches for evaluating system stability margin are increasingly problematical because of uncertainty in the parameters defining various components of the system.

In recent years, introduction of wide-area measurement systems that collect data using phasor measurement units (PMUs) from different locations with time synchronized through global positioning systems provides an attractive control strategy for damping inter-area oscillation. By introducing suitable wide-area signals transmitted by WAMS, the power system control devices can be used to perform wide-area damping control for overall stability enhancement of interconnected system [2–5].

Many parametric methods have been applied to estimate power-system electromechanical modes by PMU acquired data. These methods are classified into two categories: ringdown analyzers; and mode meters [6]. A ringdown analysis tool operates specifically on the ringdown portion of the response; typically the first several cycles of the oscillation (5–20 s). The most widely studied ringdown analysis algorithm is termed Prony analysis [7]. Other ringdown analysis algorithms have been successfully applied to power-system applications including the Matrix-Pencil method and the Hankel Total Least Squares (HTLS) [8].

Alternatively, a mode-meter is applied to any portion of the response: ambient; transient; or combined ambient/transient. Ultimately, a mode meter is an automated tool that estimates modal properties continuously, and without reference to any exogenous system input. Ambient-based mode estimation can be conducted in the time domain or frequency domain. Time-domain algorithms operate directly on the sampled data while frequency-domain methods require the estimation of the power spectral density function. Methods applicable to ambient operation available in

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literature include Yule-walker algorithm in [9], subspace methods CVA (Canonical Variate Algorithm) and N4SID (numerical algorithm for subspace state space system identification) were first introduced in [10,11] respectively, Frequency Domain Decomposition (FDD) method [12] and the methods based on Least Mean Squares (LMS) [13–15]. Independent Component Analysis and Random Decrement (ICA–RD) [1] and wavelet transform and Random Decrement [16,17] are the most recent mode meter methods.

On the other hand, damping of inter-area oscillations is one of the major challenges to the electric power system operators. In [18], an adaptive damping controller design method by integrating online recursive closed-loop subspace model identification (SMI) with model predictive control theory is proposed. In [19], in view of the low frequency, low damping ratio and long duration characteristics of the inter-area oscillation mode, based on the extension of the stable region by the eigenvalue shifted factor a mixed H_2/H_∞ multi-objective robust control strategy based on the non-convex stable region is proposed. These oscillations are the manifestation of consequences of small disturbances in weakly interconnected power system. With ever-increasing power exchange between utilities over the existing transmission network in the open power trading regimes, the problem has become even more challenging [20]. Basically, the damping methods of inter-area oscillations can be classified into the following two general categories.

1. Device based methods using controlling equipments such as Power System Stabilizers (PSSs) and Flexible AC Transmission Systems (FACTS) devices.
2. Operation based methods changing system operating conditions such as generation rescheduling (GR), load shedding and changing network structure.

The conventional method to deal with inter-area oscillations problem is to add damping controllers, such as Power System Stabilizers [21–26], HVDC and FACTS modulation controls [27–30]. These devices indeed provide effective long-term solutions and have been widely used. From the system operation perspective, however, use of the damping controllers may not always be sufficient to solve the small-signal security problem, for the following reasons [31].

- Implementation of a damping controller usually requires lengthy design, manufacture, installation, and commission procedures. Therefore, it often cannot meet the short-term solution requirements for problems found in the operational studies.
- Frequently, limitation of a power transaction due to inter-area oscillation may occur only for a short period of time. So, it may not be the most efficient way to mitigate such oscillation by installing new controllers.
- Even with appropriate damping controllers in place, there are always situations for which specific operating conditions fall beyond what the controllers are designed for and, therefore, additional remedial measures are necessary to accommodate the operating conditions.

In this paper, based on the wide area measurement system (WAMS) and using GR, a new approach for damping inter-area oscillation is proposed. The proposed approach consists of three tasks: 1-identification the frequency and damping ratio of the inter-area mode, 2-determination the most effective generators for rescheduling, and 3-damping inter-area mode by rescheduling procedure.

The paper is organized as follows: Section 'Overview of the proposed method' present an overview of the proposed algorithm. Sections 'Identification of inter-area modes' and 'Determination of effective generators' describe used method for estimation of inter-area modes and effectiveness of generators in them respectively. Section 'Global structure of the proposed approach' explains the proposed algorithm for identifying and damping inter-area modes. Section 'Simulation studies' introduces test systems with a discussion of the critical modes in these systems. Section 'Conclusion' illustrates the application of the algorithm to test systems and Appendix A provides a summary of the results.

Overview of the proposed method

Fig. 1 shows conceptual frame work of the proposed algorithm for identification and damping inter-area oscillation between two oscillating areas. This approach works based on the WAMS and the outcome of a prior study which show a potential of inter-area oscillation on the tie line connecting two areas *A* and *B*. In order to make the proposed approach more applicable in real operational environment of power systems, it mainly relies on the ambient data. The proposed algorithm consists of three tasks as follows.

1. Mode identification: by continuous capturing and processing power oscillations on the tie line and phase angles of generators terminal voltage using WAMS, the possibility of inter-area oscillation and its corresponding frequency and damping are estimated.
2. Recognizing effective generators: once a critical mode with low damping is identified, in order to improve oscillation damping, the damping procedure will come into effect for recognizing the most effective generators for rescheduling.
3. Generation rescheduling: between effective generators, GR will be carried out based on the participation factors of generators with respect to the critical mode. The procedure of GR is a continuous and step by step process; it will stop when damping ratio of the critical mode reaches to a desired value.

Identification of inter-area modes

The proposed approach is a two steps algorithm in which in the first step frequency of inter-area mode is identified and in the second step damping ratio of the identified mode will be estimated. Fig. 2 shows the global structure of the two step approach.

Step 1: identifying inter-area mode by ICA technique

In this step, ICA technique is utilized for developing identification algorithm for estimating inter-area mode. The principle of ICA is based on the blind source separation in which from several observed mixture without any prior knowledge of the observed mixtures, independent sources (signals) can be recovered [32]. More detailed information about principle of ICA can be found in [32–34].

Eq. (1) shows decomposition of a matrix of time measurement signal (*X*) into common and independent non-Gaussian sources (*S*) referred to as independent components (ICs).

$$\underbrace{\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix}}_{X} = \underbrace{\begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix}}_{A} \underbrace{\begin{pmatrix} s_1 \\ s_2 \\ \vdots \\ s_n \end{pmatrix}}_{S} \tag{1}$$

where the rows of *X* are time series realized as a linear combination of signals from the various sources in *S*, in the specific ratios contained in *A*. The concept of non-Gaussianity relates to the probability density function (PDF) of the elements in a row of *S* which, if the signals are stationary, may be estimated directly from the elements of the row.