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Wide area damping of electromechanical low frequency oscillations using phasor measurement data

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ABSTRACT

A wide area controller using modern multi-band power system stabilizer (PSS) is proposed to damp low frequency oscillations (LFOs) in the presence of wind power penetration. The proposed scheme is perfected in two stages. In the first stage, as the online stage, the generation re-dispatch is utilized to improve the damping of LFOs. In the second stage, as the real-time stage, the modern multiband PSSs are tuned in a wide area basis using ambient synchro-phasor measurements. A hybrid subspace identification approach based on estimation of signal parameters via rotational invariance technique (ESPRIT) and robust project approximation subspace tracking (PAST) technique is developed for online estimation of electromechanical modal properties using ambient phasor measurement data. The estimated modal information is then utilized for optimal wide area tuning of multi-band PSSs. Performance of the proposed scheme is then compared with local and global conventional PSSs. The proposed wide area damping controller is simulated over the IEEE-39 Bus test systems.

1. Introduction

The rotor angle small signal stability problem involves the study of the electromechanical LFOs inherent in power systems. Insufficient damping of oscillations is a major challenge in dynamic rotor angle stability problem. Different issues such as fast acting automatic voltage regulators (AVRs), frequency dependency of load, and new power generation technologies may contribute to a decrease in damping. As an example, with increasing penetration of doubly fed induction generators (DFIG) wind farms, the system inertia is decreased and it may deteriorate dynamic stability of the entire power system [1]. Although few studies have utilized DFIGs to damp inter-area oscillations [2], a sudden change in load or wind speed may cause large imbalance between load and generation. This power imbalance may cause salient frequency deviation and unwanted load shedding or equipment outage [3]. The overall impact of DFIG wind farms on dynamic stability depends on the DFIG installation location and penetration level. Even with selecting the proper insertion point, it's too risky to rely on such an uncertain resource for damping oscillations, due to intermittent nature of wind. It is noted that, among all the developed LFO dampers, PSS is the most cost-effective method for improving the small signal stability [4,5]. Conventional PSSs (CPSSs) have been utilized as the first countermeasure for LFO damping. However, CPSSs lack sufficient damping of global modes with frequency range of 0.01–0.05 Hz [6]. In addition, simultaneous damping of local, inter-area, and global modes is not possible using CPSSs. Therefore, a modern multi-band stabilizer named PSS4B has been proposed in [7]. The new multi-band PSS has three parallel bands, each providing damping of different frequency range of LFOs. It is demonstrated that, utilizing both CPSS and PSS4B together with an accurate wide area tuning process can provide a robust damping for all oscillatory modes particularly inter-area modes [8]. Also the combination of PSS and other Flexible Transmission AC Systems such as TCSC may be has been proposed for damping inter-area oscillations [9,10].

Tuning of modern multiband power system stabilizer may be interpreted as an optimization task. In this regard, different analytic and evolutionary algorithms have been utilized for tuning power system stabilizers. In [11] a steepest descent parameter optimization algorithm is employed to seek the optimal PSS design parameters. In [12] dynamic programming has been utilized to tune the parameters of modern power system stabilizers using local signals. In [13] three metaheuristics (Gravitational Search Algorithm, Bat Algorithm and Particle Swarm Optimization) have been combined with the Steepest Descent Method for the tuning of PSS4B stabilizers.

The particle swarm optimization and co-evolutionary algorithms have been combined in [14] to tune the PSS4B in a multimachine power system. In [15] based on the reduced network equivalents, the Differential Evolution is utilized to minimize the weighted sum of speed deviations under different scenarios. In [16], the optimization techniques proposed for design power system stabilizer has been reviewed.

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Wide-area global dampers utilize wide area signals and could be tuned using the eigenvalue or modal analysis of full or reduced dynamic model of system. These LFO dampers are suitable for inter-area oscillatory modes; however, modal analysis may be formidable especially for a large-scale power system. Due to computational burden of model-based wide area damping, the modal information could be extracted from local or global ambient measurements without any information about the dynamic state space model of power system [8,17,18].

Observability brought by integration of phasor measurement units (PMUs) into the power systems has made it possible to monitor oscillations through continuous assessment of critical modes of the system [19]. Hence, identification techniques could be used for tracking frequency and damping of oscillations using ambient synchro-phasor measurements [20,21]. Different approaches such as Prony analysis [22], autoregressive moving average (ARMA) methods [23], subspace identification methods [24], and frequency domain decomposition [25] have been used to get the mode oscillation parameters and mode shapes using synchro-phasor data. The ESPRIT and robust PAST are two subspace identification methods that have been used for mode estimation of dynamic systems [26]. The gap this paper intends to fill is the wide area tuning of modern multi-band PSSs for simultaneous and robust damping of local, inter-area, and global oscillatory modes.

The major contribution of the present paper is presenting a two stage damping control in which the modal information are extracted using phasor measurements. In other words the combination of generation re-dispatch and PSS4B as the damping control is the major contribution of this paper. Also the modal information of oscillations are extracted using the combination of ESPRIT and robust PAST methods.

In this paper, a hierarchical two-stage strategy is proposed for simultaneous damping of critical modes. In the first stage, which is performed off-line, a generation re-scheduling method based on participation analysis is proposed to improve the damping of dominant oscillatory modes. In the second stage, an adaptive wide-area LFO damper based on modern multi-band PSSs is proposed. In this stage a hybrid stochastic subspace identification (SSI) scheme including adaptive ESPRIT technique and robust PAST is developed for online estimation of LFOs. The estimated modal information is then used for optimal wide area tuning of PSSs. In addition, the parameters of multi-band PSSs are optimized using an evolutionary algorithm in a wide area basis. The rest of this paper is organized as follows. In Section 2 the impact of DFIG wind farms on small signal stability is investigated. The overall structure of the proposed hierarchical wide area damping control is presented in Section 3. Afterward, in Sections 4 and 5 the two main components of the proposed method, i.e. LFO estimation and wide-area tuning method are discussed. The simulation results over the IEEE 39-bus test system are given in Section 6. Finally, the conclusion of the paper is provided in Section 7.

2. DFIG impact on small signal stability

In order to investigate the impact of DFIGs penetration on external network, the wind farms are modeled as a single equivalent machine. DFIG model used in [27], consists of four main components. The types of effects that DFIGs penetration has on small signal stability depend on the insertion point of the DFIGs in the network [1]. As shown in Fig. 1, the IEEE 39 bus system with three specified areas, which have been determined employing slow coherency technique, is studied to investigate the impacts of DFIG on small signal stability. In this study, all of the synchronous generators are represented by a six-order model and equipped with an IEEE type G1 governor (i.e. IEEE-G1) and an IEEE type T1 AVR (i.e. IEEET1). It should be noted that the generator G1 (as the equivalent of the external grid) is not equipped with any PSSs. The static and dynamic data of IEEE-39 bus system could be found in [28]. In order to show the effects of DFIGs on the small signal stability, two different scenarios are simulated.

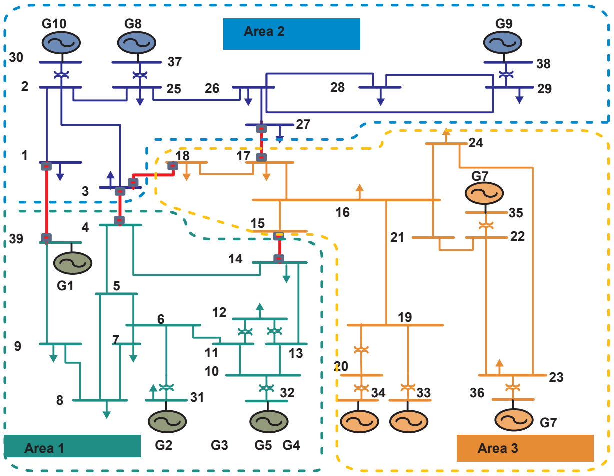

Fig. 1. Single line diagram of IEEE 39-bus system with three specified area.

In the first scenario, it is assumed that 300 MW of the G4 power generation is provided by a DFIG. In the second scenario, it is assumed that 300 MW of the G9 generation power is provided by exactly the same DFIG. In both scenarios, a three phase short-circuit fault is applied at bus 19 and cleared after 50 ms. To demonstrate the impact of DFIGs penetration on inter-area and local modes, the power flow of line 19-16 and the rotor angle of G5 are monitored as shown in Fig. 2.

Based on Fig. 2, a beneficial impact on small signal stability is achieved by inserting the DFIG at bus 34, yet the oscillation damping is significantly deteriorated with the presence of DFIG at bus 38. Moreover, in small power systems, replacing conventional power plants with DFIGs will significantly reduce the system inertia. Therefore, in this condition a sudden change in load or wind speed may lead to large imbalance between load and generation. One of the advantages of modern multi-band PSSs is to create additional damping in such situations.

3. Proposed hierarchical method

In this section, the overall structure of the proposed wide area LFO damper is presented. As illustrated in Fig. 3, the proposed scheme has two main stages named HLI (online stage) and HLII (real-time stage). The details of the proposed two-stage wide area LFO damper are described as follows:

- Step 0: all the required data measured by PMUs are transmitted to the central control system (CCS).
- Step 1: based on the received synchro-phasor data, the oscillatory

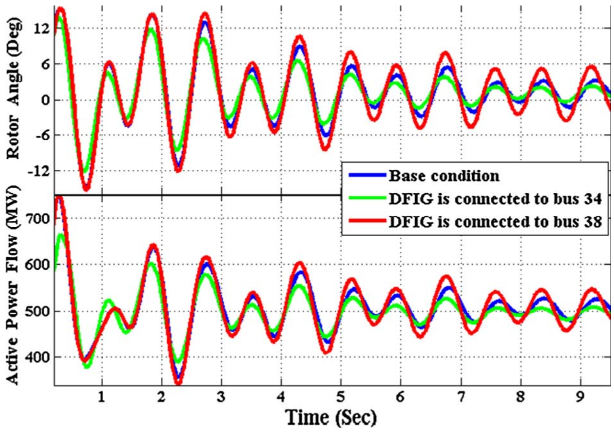

Fig. 2. Effects of DFIGs penetration with respect to insertion point.