Low Frequency Oscillations Damping in Power Networks Through PSS and Robust Wide-Area Damping Controller

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by

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Chapter 7

Conclusions and Future Scope

Modern power system need large penetration of Renewable Energy Sources (RESs) to make generations environment friendly. However, these sources of energy lack rotating inertia. This may lead to emergence of new prominent modes of low-frequency oscillations. Therefore, an attempt was made in this work to suggest effecting measures for damping low-frequency oscillations under RESs and Inverter-Based Resources (IBRs) penetration.

Chapter-2 presented a methodology for optimal placement of Power System Stabilizer (PSS) supplemented with Wide-Area Damping Controller (WADC) in a multi-machine power network to effectively damp prominent modes of inter-area oscillations.

In Chapter-3, replacement of synchronous generator with Doubly Fed Induction Generator (DFIG) based Wind Turbine System (WTS) was considered to study its impact on prominent modes of low-frequency oscillation. A robust duel-channel H_∞ WADC was proposed to significantly reduce these oscillations.

Chapter-4 of thesis proposed optimal location of Battery Energy Storage System (BESS) based on the residue indices of prominent modes of oscillations. Impact of BESS on low-frequency oscillations was studied and a fixed–structure H_∞ scheme-based WADC was proposed.

Chapter-5 proposed a robust H_∞mixed sensitivity scheme based WADC to damp low-frequency oscillation for BESS integrated power networks.

Chapter-6 presented the impact of IBRs controlled through Virtual Synchronous Generation (VSG) technique on low-frequency oscillations and proposed a multi-stage mixed H_2/H_∞ decentralized WADC to damp these oscillations.

Effectivness of proposed controllers were tested on test systems, and simulation results were validated on Real Time Digital Simulator (RTDS).

7.1 Summary of important findings

Based on the research presented in this thesis, the subsequent major conclusions are drawn as follows:

1. The simulation results demonstrate that the Wide-Area Damping Controller (WADC) supplemented with the optimal placement of Power System Stabilizer (PSS) offers superior damping performance compared to placing PSS without WADC.

2. The high penetration of Wind Turbine System (WTS) significantly deteriorates the damping of critical oscillation modes and introduces unstable oscillatory modes that threaten the small signal stability of the system. The proposed controller was found to be effective not only in damping critical modes of oscillations of WTS integrated power system but also in improving system stability margin.

3. Apart from reduction in inertia, interaction of closed-loop control modes between WTS and Synchronous Generators (SGs) results in new oscillation modes that are effectivelly damped by proposed robust WADC.

4. This study reveals that the Battery Energy Storage System (BESS) active power control loop demonstrates superior damping performance compared to the reactive power control loop in mitigating dominant inter-area oscillations under varying system operating conditions.

5. This study observes that power system inter-area oscillation modes are influenced by the closed-loop control mode interactions between SG and BESS, as well as changes in system operating conditions. The control mode parameters of BESS significantly affect the damping performance of inter-area oscillation modes in the system. Furthermore, the proposed controller's effectiveness was assessed by comparing it with an ESS-based stabilizer and an existing WADC.

6. Simulation results demonstrate that the dynamic interaction between VSG-controlled IBRs and the power network introduces new oscillation modes that affect LFO

damping. In contrast, grid-following IBR control does not introduce new modes. Increasing the inertia constant of the IBR's active control loop reduces damping performance and raises LFO frequency, while increasing the damping coefficient enhances damping and decreases LFO frequency. The proposed SDC scheme notably enhances system LFO damping performance and effectively mitigates IBR power oscillations under diverse operating conditions.

7.2 Future scope

The thesis work presented can be further extended in the following directions:

1. Future research may address the design of robust WADC under packet drop and loss of communication considerations for remote data transfer and test the efficacy of the controller under cyber threats. Issues such as noise and malicious communication in remote data transfer may also be considered.

2. A robust centralized mixed H_2/H_∞ control scheme-based WADC could be designed for multiple IBRs controlled via Grid Forming technique.

3. Coordinated robust control schemes may be developed that simultaneously manage multiple energy sources, including wind, solar, and energy storage systems, in conjunction with HVDC links. This involves designing algorithms that can dynamically adjust the power flow and damping control to maintain grid stability under varying operating conditions.

4. Future research should integrate grid-forming inverters into HVDC and renewable-integrated power systems, focusing on developing robust control algorithms to provide essential voltage and frequency support for stable and efficient grid operation.

5. Future work may design robust WADC that incorporates advanced communication models, including random delays and network congestion, which can affect performance in practical applications. Strategies like delay compensation, predictive control, and fault tolerance should also be explored to improve WADC robustness against unpredictable communication behaviors.

6. Future work will focus on exploring the practical aspects of deploying the proposed controllers in real-world grids. This includes conducting a cost analysis, assessing infrastructure requirements, and addressing regulatory challenges associated with implementing the proposed controllers.