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Robust power oscillation damper design for DFIG-based wind turbine based on specified structure mixed H_2/H_∞ control

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ABSTRACT

As the integration of a doubly fed induction generator (DFIG)-based wind power generation into power systems tends to increase significantly, the contribution of DFIG wind turbine is highly expected. Since the active and reactive power outputs of DFIG can be independently modulated, the stabilizing effect of DFIG on the inter-area power system oscillation is a challenging issue. This paper proposes a new robust control design of power oscillation damper (POD) for a DFIG-based wind turbine using a specified structure mixed H_2/H_∞ control. The POD structure is a practical 2nd-order lead–lag compensator with single input. Normally, H_∞ control mainly enforces the closed-loop stability while noise attenuation or regulation against random disturbances is expressed in H_2 control. As a result, the mixed H_2/H_∞ control gives a powerful multi-objective control design so that both closed-loop stability and performance of designed controller can be guaranteed. Here, the linear matrix inequality is applied to formulate the optimization problem of POD based on a mixed H_2/H_∞ control. The POD parameters are optimized so that the performance and robustness of the POD against system disturbances and uncertainties are maximal. The firefly algorithm is automatically applied to solve the optimization problem. Simulation study in a two-area four-machine interconnected power system shows that the DFIG with robust POD is superior to conventional POD in terms of stabilizing effect as well as robustness against various power generating and loading conditions, unpredictable network structure, and random wind patterns.

1. Introduction

Interconnections in power systems not only provide an enhancement of system reliability, but also increase the economical efficiency. Nevertheless, they occasionally cause the inter-area power oscillation with low frequency and poor damping [1]. The stability of the inter-area oscillation modes is deteriorated by the heavy load condition in tie-lines especially due to the electric power exchange. Furthermore, the increase of system uncertainties due to a deregulated environment with complex power contracts, various generating and loading conditions as well as unpredictable network structure, etc., makes the stabilization of inter-area oscillation more difficult [2].

Nowadays, the integration of wind power generation into power systems increases considerably. As the sharing of wind power generation increases, the contribution of wind power for power system control and stabilization is highly expected. Especially, the ability of wind power generation for damping of power system oscillations is a very challenging issue. As an example, in the new Spanish grid code for wind power, the ability of power oscillation damping is included [3].

Among of wind turbines, the doubly-fed induction generator (DFIG) wind energy system is extensively used nowadays. In Ref. [4], a modelling of DFIG-based wind turbine generation system for real time electromagnetic simulation study is proposed. With the developed real-time model, new controller designs or protective devices can be easily implemented and tested in a hardware-in-the-loop configuration. In Ref. [5], the second-order sliding model control of DFIG in real time simulation is represented. The power extraction maximization of the proposed sliding mode control is superior to traditional techniques. The active and reactive power outputs of DFIG can be controlled independently by the power converters based on vector control [6], flux magnitude and angel control [7]. As a result, the DFIG-based wind turbine not merely enhances the energy transfer efficiency but also provides the damping of power system oscillations. In Ref. [8], the power oscillation damper (POD) is added to the wind turbine controller with

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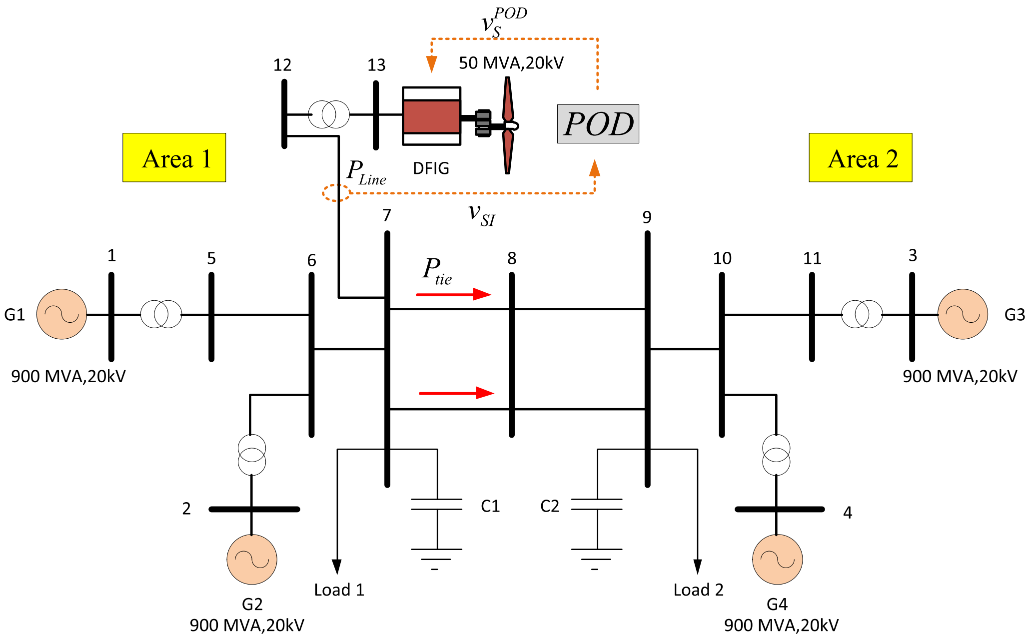

Fig. 1. Two-area four-machine interconnected power system with DFIG.

the same function as a power system stabilizer (PSS) from the synchronous generator. The PODs with various inputs such as the angle variation [9], the slip of DFIG [10] etc. are presented. The DFIG wind turbine equipped with POD with all the inputs shows the good damping performance. In Ref. [11], the optimization of DFIG control parameters is proposed based on the minimizing of some criteria. A mixed control of Eigen-structure assignment and a multi-objective nonlinear optimization method for the POD based on the conventional PSS is presented in Ref. [12]. In Ref. [13], the DFIG with active and reactive power loops is presented. In Ref. [14], the mixed active and reactive control strategy of DFIG based on Lyapunov method is proposed. The PODs proposed for DFIG in these works show good stabilizing effect. Nevertheless, there are several system uncertainties in actual power systems such as various wind power patterns, generating and loading conditions, unpredictable network structures, and system parameters variation etc. The POD designed without considering such uncertainties may fail to stabilize the power oscillation. The POD with high robustness against system uncertainties is significantly anticipated.

In fact, it is desirable to follow several objectives such as stability, disturbance attenuation and reference tracking, and consider the practical constraints, simultaneously. Pure H_∞ synthesis cannot adequately capture all design specifications. Normally, H_∞ synthesis mainly enforces closed-loop stability and meets some constraints and limitations, while noise attenuation or regulation against random disturbances is more naturally expressed in H_2 synthesis. As a result, the mixed H_2/H_∞ control synthesis gives a powerful multi-objective control design addressed by the linear matrix inequalities techniques [15].

This paper focuses on the robust control design of a POD equipped with DFIG wind turbine for stabilization of inter-area oscillation in interconnected power systems. The POD structure is a practical 2nd-order lead–lag compensator with single input. The optimization of POD parameters is carried out by a specified structure mixed H_2/H_∞ control based on linear matrix inequality (LMI). The parameters of POD are optimized so that the damping performance and robust stability margin against system uncertainties are satisfied. The firefly algorithm is applied to solve the optimization problem. Simulation result shows the robustness and stabilizing effect of the proposed POD is much superior to those of the conventional POD.

2. Study system and modelling

2.1. Study system

The two-area four-machine power system as depicted in Fig. 1 is used as the study system [1]. Each synchronous generator is represented by a 6th-order model. It is equipped with an automatic voltage regulator (AVR) type 3 and a turbine governor type 2 [16]. The DFIG wind turbine equipped with POD is placed at bus 7 to supply electrical power to the system. In this study, it assumed that the power flow in two tie-lines (P_{tie}) between bus 7 and bus 8 are in heavy condition and the system disturbances such as faults, etc., occasionally occur. These situations cause the inter-area oscillation with poor damping. To damp out this oscillation mode, the DFIG is used. The DFIG parameters are given in Table 1.

Table 1
DFIG parameters.

Parameters	Value
Power rating	50 MVA
Frequency rating	60 Hz
Stator resistance (r_s)	0.01 p.u.
Stator reactance (x_s)	0.10 p.u.
Rotor resistance (r_r)	0.01 p.u.
Rotor reactance (x_r)	0.08 p.u.
Magnetizing reactance (x_u)	3.00 p.u.
Inertia constants (H_m)	3 kWs/kVA
Gearbox ratio	1/89
Number of poles	4
Blade length	75 m
Number of blade	3
Pitch angle time constant (T_p)	3
Pitch control gain (K_p)	10
Power control time constant (T_e)	0.01
Voltage control gain (K_e)	50