Abstract

With the growth in requirement for a high reliability of power supply, stability of the power system and the minimum requirement for control systems becomes more and more significant. The most popular way to solve the problem of stability is to install power system stabilizers (PSSs) on synchronous generators in related power systems. The conventional methods for designing PSS are generally based on the compensation approach for the phase and eigenvalue of the generator model. In recent decades, H-norm based robust PSS has been developed because of the system uncertainty of power grids. In another aspect, wind power has evolved into a significant renewable energy source and increased at an outstanding rate. Stability problems of power system with large wind farms became more and more challenging. Some wind plant modelling methods, for which PSSs are not taken into consideration, have been developed and widely used in practical applications.

The present study is concerned with a comprehensive power system stability analysis based on an improved H-norm robust controller design method and a novel modelling approach for doubly fed induction generator (DFIG) wind turbines. Initially, one improved lemma, enhanced with LMI regional pole placement, is developed for linear matrix inequality (LMI) based H_2/H_∞ robust output feedback controller design. Robust PSSs are designed based on the approach and they are tested in both single and multi-machine systems. A novel DFIG wind turbine model is then built up and tested with the robust PSS in both single and multi-machine systems to see the oscillations damping ability. Finally, based on the robust PSS, a large multi-machine power system with wind parks is selected for a comprehensive stability analysis.

Simulated examples and case studies are employed in this study to demonstrate the effect of new PSSs. The simulation results clearly suggest that the proposed PSS can solve the stability problem of damping oscillations in power systems with large wind parks.

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List of publications based on this study

Conference papers

Peng, Y., Nouri, H., Zhu, Q. M., and Cheng, L., 2011(a), Robust controller design survey for damping low frequency oscillations in power systems, *Asia-Pacific Power and Energy Engineering Conference (APPEEC 2011)*, 27--29, March, 2011, Wuhan, China.

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Peng, Y., Nouri, H., and Zhu, Q. M., 2013(b), LMI based controller design for doubly-fed induction generator wind turbine systems, *The 48th International Universities' Power Engineering Conference*, September, 2013, Dublin, Ireland.

Journal papers

Peng, Y., Zhu, Q. M., and Nouri, H., 2013, Improved mixed H_2/H_∞ power system stabilizer design using robust output feedback controller, submitted to Journal of Electrical Engineering.

Nouri, H., Peng, Y., and Zhu, Q. M., 2013, Power system small signal stability analysis of large DFIG wind parks in modern power grids, to be submitted.

Contents

Abbreviations

Abbreviations	Descriptions
AC	Alternating Current
ARE	Algebraic Riccati Equation
AVR	Auto-Voltage Regulator
CIGRE	International Council on Large Electric Systems
CPSS	Conventional Power System Stabilizer
DC	Direct Current
DFIG	Doubly Fed Induction Generator
EE	Energy to Energy
EMF	Electromotive Force
EP	Energy to Peak
FACTS	Flexible Alternating Current Transmission System
FMAC	Flux Magnitude and Angular Control
FRS	Feasibility Radius Saturation
FSIG	Fixed Speed Induction Generator
GEVP	Generalized Eigenvalue Problem
GWEC	Global Wind Energy Council
HVDC	High Voltage Direct Current

Abbreviations	**Descriptions**
IE	Impulse to Energy
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
IMOFC	Improved Mixed H_2/H_∞ Output Feedback Controller
LFO	Low Frequency Oscillation
LMI	Linear Matrix Inequality
LOEC	Linear Optimal Excitation Controller
NEC	Nonlinear Excitation Controller
PID	Proportional Integral Derivative controller
PP	Peak to Peak
PSS	Power System Stabilizer
PSS/E	Power System Simulation for Engineering
PTI	Power Technology International
PWM	Pulse Width Modulation
SAVNW	Name of the New England Power System
SDRE	State-dependent Riccati Equation
SMIB	Single Machine Infinite Bus
STATCOM	Static Synchronous Compensator
SVC	Static Var Compensator

VSC	Voltage Source Converter

Symbols

Symbols	**Descriptions**
Δ	Deviation of the parameter (can be put before any symbol)
c_{dc}	DC capacity of the DFIG wind turbine
D_{pg}	Damping torque factor for synchronous generators
E_d	Internal electromotive force on *d* axis
E_q	Internal electromotive force on *q* axis
E'_d	Internal transient electromotive force on *d* axis
E'_q	Internal transient electromotive force on *q* axis
E''_q	Post-transient electromotive
E_{fd}	Electromotive force of exciter winding
i_d	Synchronous generator stator current on *d* axis
i_L	DFIG inductance current
i_q	Synchronous generator stator current on *q* axis
i_r	DFIG rotor current
I_{ds}	DFIG stator current on *d* axis
I_{qs}	DFIG stator current on *q* axis

Symbols	**Descriptions**
I_{dr}	DFIG rotor current on *d* axis
I_{qr}	DFIG rotor current on *q* axis
K_A	Gain of exciter
K_E	Self-excitation factor of exciters
K_F	Rotor feedback factor
K_{P1}, K_{I1}	Controller parameter of the outer PID controller of DFIG
K_{P2}, K_{I2}	Controller parameter of the inner PID controller of DFIG
L	DFIG converter inductance
L_s	DFIG stator inductance
L_r	DFIG rotor inductance
L_m	DFIG mutual inductance
M_e	Electrical torque of synchronous generator
M_m	Mechanical torque of synchronous generator
Q_{ref}	DFIG reference input of reactive power
R_s	DFIG stator resistance
R_r	DFIG rotor resistance

Symbols	**Descriptions**
s	Operator for Laplace transform
s_s	Slip of DFIG
S_E	Saturation factor of exciters
T_0	Transient time constant of DFIG
T_b	Time constant of DFIG pitch angle control system
T'_{d0}	Open circuit time constant on d axis
T''_{d0}	Special time constant used in five-winding generator model
T'_{q0}	Open circuit time constant on q axis
T_A	Time constant of regulators
T_E	Exciter time constant
T_F	Time constant of rotor feedback section
T_j	Time constant of the one-mass drive train of DFIG
T_J	Inertia coefficient of synchronous generator
T_T	DFIG rotor side mechanical torque
T_w	Blade input mechanical torque
u_a	Voltage from the grid side controller of DFIG

Symbols	**Descriptions**
u_r	Reference voltage input to the exciter
u_{rw}	Voltage from the rotor side controller of DFIG
u_s	Output voltage from power system stabiliser
u_{sw}	DFIG stator voltage
u_{td}	Terminal voltage of synchronous generator on *d* axis
u_{tq}	Terminal voltage of synchronous generator on *q* axis
U_{dc}	DFIG DC capacitor voltage
U_{dcref}	Reference input of DFIG DC capacitor voltage
U_{ds}	DFIG stator voltage on *d* axis
U_{qs}	DFIG stator voltage on *q* axis
U_{dr}	DFIG rotor voltage on *d* axis
U_{qr}	DFIG rotor voltage on *q* axis
U_t	Terminal voltage of the generator
U_{REF}	Reference voltage input
x_l	Leakage reactance
x_d	Stator reactance on *d* axis

Symbols	**Descriptions**
x_q	Stator reactance on *q* axis
x'_d	Stator transient reactance on *d* axis
x''_d	Post-transient reactance on *d* axis
x'_q	Stator transient reactance on *q* axis
X'_i	DFIG transient reactance
Z_T	Impedance of transformer
Z_L	Impedance of transmission line
β	Pitch angle of DFIG
ω	Angular speed
ω_0	Synchronous speed of synchronous generator
ω_{ref}	Reference input of the DFIG speed
ω_s	Synchronous speed of the DFIG
δ	Power angle
ψ_{ds}	DFIG stator flux on *d* axis
ψ_{qs}	DFIG stator voltage on *q* axis
ψ_{dr}	DFIG rotor flux on *d* axis

Symbols	**Descriptions**
ψ_{qr}	DFIG rotor flux on *q* axis
Ψ_d	Synchronous generator flux linkage on *d* axis
Ψ_q	Synchronous generator flux linkage on *q* axis
$\otimes$	Kronecker Product