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Performance of a grid-connected wind generation system with a robust susceptance controller

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ABSTRACT

Wind turbine driven induction generators are vulnerable to transient disturbances like wind gusts and low voltages on the system. The fixed capacitor at the generator terminal or the limited support from the grid may not be able to provide the requisite reactive power under these abnormal conditions. This paper presents a susceptance control strategy for a variable speed wound-rotor induction generator which can cater for the reactive power requirement. The susceptance is adjusted through a robust feedback controller included in the terminal voltage driven automatic excitation control circuit. The fixed parameter robust controller design is carried out in frequency domain using multiplicative uncertainty modeling and H_∞ norms. The robustness of the controller has been evaluated through optimally tuned PID controllers. Simulation results show that the robust controller can effectively restore normal operation following emergencies like sudden load changes, wind gusts and low voltage conditions. The proposed robust controller has been shown to have adequate fault ride through capabilities in order to be able to meet connection requirements defined by transmission system operators.

1. Introduction

Large penetration of wind power to the grid is, though, very desirable it has its associated disadvantages. Simple connection of an induction generator to the grid may give rise to unacceptable voltage rise at the bus, not delivering the maximum available power at the desired efficiency. Wind turbines mostly do not take part in voltage and frequency control and if a disturbance occurs, the wind turbines are sometimes disconnected and then reconnected when normal operation has been resumed [1]. Variation of wind speed from time to time due to gusts and disturbances like faults on the asynchronous as well as the synchronous part of the system may pose serious control problems [2]. Transients arising in either system may propagate into the other causing malfunctions in the controls. Voltage collapse has been reported following transient short circuits in the connecting networks with large wind farms [3].

The transient performance can normally be enhanced for by blade pitch control on the turbine side. Pitch control for power output and speed fluctuations has been reported in [4,5]. Braking resistor control for fault ride through has been proposed in [6]. Voltage, current and power control on the generator side is reported in [7,8]. Adaptive control strategies [9] and robust controllers [10] have been reported in the literature for maximum power point tracking. Fuzzy-logic based power and efficiency maximization as well as robust speed control have also been reported [11,12]. While some of these are open-loop strategies, the PI controllers used in some of these studies depend on feedback of terminal voltage, current and speed of the machine. In the PI designs, departure from the nominal operating point degrades controller performance significantly due to nonlinearity of the system. In general, control designs considering the entire system dynamic model is lacking.

This study proposes a susceptance control strategy for transient control of a variable speed wind generation system with a wound-rotor type of induction machine. A fixed parameter robust damping controller has been proposed which acts along with an automatic susceptance control circuit driven by changes in terminal voltage. The robust design uses the uncertainty modeling and the controller function is arrived at through frequency response methods. Simulation studies demonstrate the effectiveness of the robust controller in restoring normal operation following severely depressed voltage conditions.

2. The system model

Fig. 1 shows the variable speed wind turbine-generator system considered in this study. The system consists of a horizontal axis turbine-generator connected to the power grid through back-to-

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Nomenclature

d–q	subscripts for direct and quadrature axes
R_s, R_r	stator, rotor resistance
x_s, x_r	stator, rotor reactance
x_m	mutual reactance
ψ_{ds}, ψ_{qs}	d, q axes stator flux linkage
ψ_{dr}, ψ_{qr}	d, q axes rotor flux linkage
i_{ds}, i_{qs}	d, q axes stator current
i_{dr}, i_{qr}	d, q axes rotor current
v_{ds}, v_{qs}	d, q axes stator voltage
ω_e	generator rotor angular speed
ω_o	base angular speed
V_s	generator terminal voltage
V_{sr}	generator terminal reference voltage
P_m, P_e	input, output power of generator
H	inertia constant of generator
K_{sE}, T_{sE}	gain, time constant of exciter circuit
T_w	washout block time constant

back converters and the transmission lines. The integrated local load and the proposed control circuits are shown to be connected at the generator terminal. A wound-rotor induction generator is considered in the study. It is assumed that a variable susceptance control circuit is installed at the AC side of the system along with the local load. The variable susceptance can be obtained by controlling firing angle of the thyristors in the static VAR system. The SVC system contains a fixed capacitor (FC) needed for normal excitation of the induction generator. If additional capacitor excitation is required the thyristor switched capacitor (TSC) is switched in. A reduction in capacitance is achieved by switching in the thyristor controlled reactor (TCR) into the circuit. The models for the different components of the wind turbine-generator system are given in the following.

2.1. The wind turbine model

The mechanical power output of a wind turbine is related to the wind speed V_ω by [2]:

$$P_m = \frac{1}{2}\rho A C_p V_\omega^3 \tag{1}$$

Here, ρ is the air density and A is the swept area by the turbine blades. The power coefficient C_p is a function of both tip speed ratio (λ) and the blade pitch angle (β). The tip speed ratio which is the ratio of linear speed at the tip of blades to the speed of wind is expressed as:

$$\lambda = \frac{\omega_m R}{V_w} \tag{2}$$

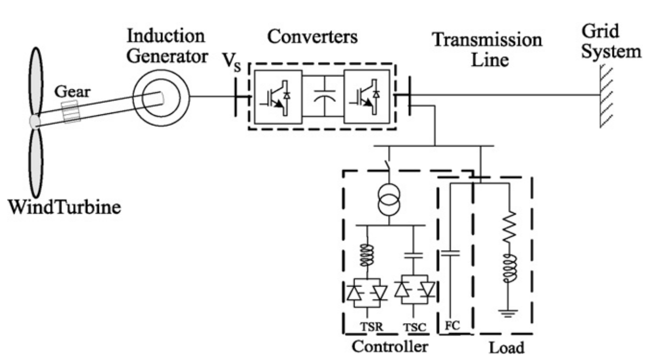

Fig. 1. Wind generator-infinite bus system.

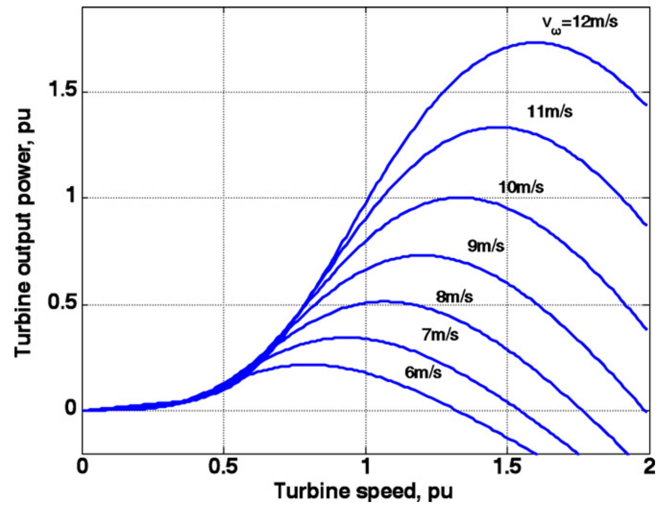

Fig. 2. Speed vs. power output characteristics of a wind turbine.

where R and ω_m are the radius and the mechanical angular velocity, respectively, of the wind turbine rotor. Expressions of C_p as a function of λ and β employed in [13] are:

$$C_p(\lambda, \beta) = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{-21/\lambda_i} + 0.0068\lambda$$
$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{3}$$

Fig. 2 shows the power–speed characteristics curves of a typical wind turbine for various wind velocities. For a given wind speed V_w and pitch angle β, the power coefficient C_p is constructed for a set of values of λ (usually in the range 0–14) using relationship (3). For a certain value of C_p and λ mechanical power is calculated through (1) and (2) gives the corresponding rotor speed. The plots in Fig. 2 are for zero blade pitch angle.

Wind speed changes continuously and its magnitude are random over any interval. For simulation of randomly changing wind speed, probability distribution of the random number should be known. The average wind speed is usually considered constant for some intervals (say about 10 min). The fluctuations during such intervals can be considered to be combination of constant and sinusoidal variation around the mean speed, V_m. A typical formula is [14]:

$$V_\omega = V_m\left[1 - 0.2\cos\left(\frac{2\pi t}{20}\right) - 0.5\cos\left(\frac{2\pi t}{600}\right)\right] \tag{4}$$

The wind gust can be simulated by varying the magnitude and frequency of the sinusoidal fluctuation.

2.2. The induction machine model

The induction machine model can be derived from the generalized induction motor model of Krause [15]. The voltage current relations along the d–q axes of the stator and rotor circuits, respectively, are:

$$\frac{1}{\omega_o}\dot{\psi}_{ds} - \frac{\omega_e}{\omega_o}\psi_{qs} + R_s i_{ds} = v_{ds}, \qquad \frac{1}{\omega_o}\dot{\psi}_{qs} + \frac{\omega_e}{\omega_o}\psi_{ds} + R_s i_{qs} = v_{qs} \tag{5}$$

$$\frac{1}{\omega_o}\dot{\psi}_{dr} - s\psi_{qr} + R_r i_{dr} = v_{dr}, \qquad \frac{1}{\omega_o}\dot{\psi}_{qr} + s\psi_{dr} + R_r i_{qr} = v_{qr} \tag{6}$$

The flux linkages and currents are related through:

$$\psi_{ds} = x_s i_{ds} + x_m i_{dr}, \qquad \psi_{qs} = x_s i_{qs} + x_m i_{qr} \tag{7}$$

$$\psi_{dr} = x_r i_{dr} + x_m i_{ds}, \qquad \psi_{qr} = x_r i_{qr} + x_m i_{qs} \tag{8}$$