Energy 33 (2008) 1438–1452

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Comparative study on the performance of control systems for doubly fed induction generator (DFIG) wind turbines operating with power regulation

L.M. Fernandez [a], C.A. Garcia [a], F. Jurado [b,*]

[a] Department of Electrical Engineering, University of Cádiz, 11202 EPS Algeciras (Cádiz), Spain
[b] Department of Electrical Engineering, University of Jaén, 23700 EPS Linares (Jaén), Spain

ARTICLE INFO

Article history:
Received 10 October 2007

Keywords:
DFIG
Wind farm generation control
Wind power production
Wind turbine control system

ABSTRACT

As a result of the increasing wind power penetration on power systems, the wind farms are today required to participate actively in grid operation by an appropriate generation control. This paper presents a comparative study on the performance of three control strategies for DFIG wind turbines. The study focuses on the regulation of the active and reactive power to a set point ordered by the wind farm control system. Two of them (control systems 1 and 2) are based on existing strategies, whereas the third control system (control system 3) presents a novel control strategy, which is actually a variation of the control system 2. The control strategies are evaluated through simulations of DFIG wind turbines, under normal operating conditions, integrated in a wind farm with centralized control system controlling the wind farm generation at the connection point and computing the power reference for each wind turbine according to a proportional distribution of the available power. The three control systems present similar performance when they operate with power optimization and power limitation strategies. However, the control system 3 with down power regulation presents a better response with respect to the reactive power production, achieving a higher available reactive power as compared with the other two. This is a very important aspect to maintain an appropriate voltage control at the wind farm bus.

© 2008 Elsevier Ltd. All rights reserved.

1. Introduction

Nowadays, the most widely used wind turbine in wind farms is based on doubly fed induction generator (DFIG) due to noticeable advantages: the variable speed generation, the decoupled control of active and reactive powers, the reduction of mechanical stresses and acoustic noise, and the improvement of the power quality [1].

Until relatively recently, the wind farms equipped with DFIG wind turbines have commonly operated entirely delivering the available energy to the grid. Hence, the wind turbines have autonomously maximized the energy captured from the wind, without exceeding the generator limits and operating with the unity power factor (zero reactive power). However, the wind farms production has been voluntarily reduced by disconnecting wind turbines from the grid at special occasions, especially during low consumption periods and strong winds [2]. During these conditions, the system operators recommended the reduction of wind farm production in order to maintain the stability and reliability of the power systems with high wind power penetration.

The increase of wind power penetration on power systems has led to a gradual substitution of conventional power plants by the current wind farms. Therefore, the wind farms are today required to participate actively in the power system operation as conventional power plants. Thus, the power system operators have revised the grid connection requirements for wind turbines and wind farms [3–5], demanding an operational behavior with several control tasks similar to those of conventional power plants. One of these control tasks is the capability of generation control, both active and reactive powers of a wind turbine. In this case, the system operator defines the operating requirements to be followed by the wind farms ensuring a reliable and safe power system operation. The wind farms require therefore a centralized control system that computes the power references (active and reactive powers) for each wind turbine when trying to adjust the wind farm production in the connection point to the settings specified by the power system operator.

Most of the control strategies for DFIG wind turbines referred in literature [6–10] are based on producing the maximum power for the best conditions of economic exploitation, when all the produced energy can be delivered to the grid. In this case, the

* Corresponding author. Tel.: +34 953 648 518; fax: +34 953 648 586.
E-mail address: fjurado@ujaen.es (F. Jurado).

0360-5442/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.energy.2008.05.006

Nomenclature

A	rotor area of the wind turbine (m^2).
e'	internal voltage of the induction generator (p.u).
H	inertia (s).
i	current (p.u.).
P	active power (p.u.).
Q	reactive power (p.u.).
R	resistance (p.u.).
s	slip.
T	torque (p.u.).
u	voltage (p.u.).
v	wind speed (m/s).
X	reactance (p.u.).
θ	pitch angle (deg.).
λ	tip speed ratio.
ρ	air density (kg/m^3).
ω	frequency (p.u.).

Indexes

c	converter
d, q	direct and quadrature components.
e	electrical.
g	generator.
m	mutual.
mec	mechanical.
r	rotor.
s	stator.
wt	wind turbine.
σ	leakage.

wind turbine operates with optimum power efficiency for a wide range of wind speeds, without exceeding the rated power and with the desired power factor or generation voltage.

However, as commented before, the wind turbines are today demanded to regulate both active and reactive powers according to the power set points ordered by the wind farm control system, which are defined considering the generation capability (related to the wind speed) and the grid power needs. Therefore, the present article focuses on the study of the control systems for DFIG wind turbines when regulating power.

The control of DFIG wind turbines operating with power regulation ordered by a centralized wind farm control system has been described in previous works [11–14]. Two control approaches can be distinguished in these works. The first approach, illustrated in [11], is based on controlling the active power with the blade pitch angle, the rotational speed by the quadrature component of rotor current, and the reactive power with the direct component of rotor current. The second approach, used in [12–14], is based on controlling the active power with the quadrature component of the rotor voltage, the rotational speed by the blade pitch angle and the reactive power with the direct component of the rotor voltage.

The main purpose of this work is to perform a comparative study of these control systems for DFIG wind turbines when regulating power, both the active and reactive powers, by means of simulations of DFIG wind turbines integrated in a wind farm with centralized control system. Furthermore, a novel control strategy is proposed in this work, whose performance is compared with the previous controls.

The paper is organized as follows. Section 2 describes the modeling of a DFIG wind turbine. Three control systems for DFIG wind turbines are explained in Section 3. The model and the control systems for DFIG wind turbines used in this work have been validated in Section 4 by comparison with the DFIG wind turbine model included in the Sim Power Systems library of MATLAB/Simulink®. Section 5 presents the wind farm control system that computes the power references for each wind turbine when the wind farm regulates its production to the settings ordered by the system operator. The performance of the wind turbine control systems is assessed and discussed in Section 6, and finally the conclusions are established.

2. DFIG wind turbine

DFIG wind turbine uses a wound rotor induction generator coupled to the wind turbine rotor through a gearbox. The wound rotor induction generator presents the stator winding coupled directly to the grid and a bidirectional power converter feeding the rotor winding. The power converter is made up of two back-to-back IGBT bridges linked by a dc bus. This power converter decouples the electrical grid frequency and the mechanical rotor frequency, enabling the variable speed generation. The wind turbine includes blade pitch angle control in order to limit the power extracted from the wind. Fig. 1 shows the DFIG wind turbine configuration.

2.1. Modelling assumptions

In this paper, the behavior of a DFIG wind turbine has been simulated by means of widely used models in the literature. The work focuses on comparing several control systems for grid-connected DFIG wind turbines when they regulate power. In this case, the characteristic frequencies of a grid-connected DFIG wind turbine are between 0.1 and 10 Hz. Therefore, fundamental frequency simulations (also known as electromechanical transient simulations) can be used to represent the dynamic response [6]. In this approach, only the fundamental frequency component of voltages and currents is taken into account and higher harmonics are neglected. This allows the use of a load flow representation of the power system. Furthermore, also some of the differential equations associated with generators are cancelled as well as short time constants, enabling the use of a larger time step. Simulation speed is increased substantially.

A quasi-static approach is used to describe the rotor. This means that an algebraic relation is assumed between the wind speed at hub height and the mechanical power extracted from the wind. More advanced methods, such as the blade element impulse method, require detailed knowledge of aerodynamics and of the wind turbine blade characteristics [15]. These data will often not be available and the impact on the control and grid interaction is assumed to be rather limited.

Regarding the drive train model, a two-mass model has been adopted in this work as the most commonly used [15]. In this model, one lumped mass accounts for the low-speed shaft (which includes hub and blades) and the other one accounts for the high-speed shaft (which includes the rotor of the generator).

In fundamental frequency simulations, the following assumptions are applied to the generator:

- Magnetic saturation is neglected.
- Flux distribution is sinusoidal.
- Any losses apart from copper losses are neglected.

متن کامل مقاله
دریافت فوری

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات