Electric Power Systems Research 86 (2012) 84–97

Contents lists available at SciVerse ScienceDirect

Electric Power Systems Research

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

Improved control strategy of DFIG-based wind power generation systems connected to a harmonically polluted network

Heng Nian [a,*], Yu Quan [a], Jiabing Hu [b]

[a] College of Electrical Engineering, Zhejiang University, Hangzhou 310027, China
[b] College of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China

ARTICLE INFO

Article history:
Received 1 April 2011
Received in revised form 6 September 2011
Accepted 6 December 2011
Available online 4 January 2012

Keywords:
Coordinated control
Doubly fed induction generator (DFIG)
Harmonically distorted voltage
Proportional integral plus resonant (PI–R)
Wind energy

ABSTRACT

This paper presents a coordinated control strategy for the grid-side converter (GSC) and rotor-side converter (RSC) of a doubly fed induction generator (DFIG) wind power generation system connected to a harmonically polluted network. Two improved control schemes are presented for both RSC and GSC, respectively. During voltage harmonics, the RSC is controlled to eliminate the torque and stator reactive power oscillations. The oscillations of the stator output active power or the harmonic components of the stator currents are then compensated by GSC to achieve either constant active power output or sinusoidal output current from the overall DFIG system. In order to provide accurate control of the fundamental and harmonic currents of both GSC and RSC, a current control scheme consisting of a proportional integral (PI) controller and a resonant (R) compensator in the fundamentally synchronous reference frame is presented. The effectiveness of the proposed coordinated control strategy is verified by the simulation results on a commercial 1.5-MW DFIG wind power generation system under harmonically distorted grid voltage conditions.

1. Introduction

Wind energy has been considered to be the main energy resources for low carbon society due to its clean and renewable capability. In various types of wind power generation systems, wind turbine based on doubly fed induction generator (DFIG) has become increasingly popular due to its advantage of variable speed operation with the excitation converter rated at only the slip power of the generator rating [1]. Under ideal grid voltage supply, the control strategy and operation performance of DFIG systems have been well studied in [2–6]. In the papers, the numerous advantages are primarily achieved via the control of a rotor-connected back-to-back voltage source converter, which is typically rated at around 25–30% of the generator rating. However, since the stator of a DFIG is directly connected to the grid via a step-up transformer and the power rating of its excitation converter is limited, the operation of DFIG systems is quite sensitive to the grid disturbances.

As the power penetration from the DFIG-based wind turbines into the grid was largely increased, the control and operation of DFIG under grid disturbances has been researched widely during the last few years. Of all grid disturbances, the steady-state and transient responses of DFIG-based wind turbines under unbalanced grid voltage conditions have been well investigated [7–12]. In [9,10], a rotor current control strategy containing a main controller implemented in the positive dq^{+} reference frame and an auxiliary controller implemented in the negative dq^{-} reference frame, was proposed to eliminate the impact of unbalanced supply voltage. And in [11,12], another current control scheme consisting of a proportional integral (PI) controller and a resonant (R) compensator, which can avoid decomposing the positive and negative-sequence components, is presented. And the oscillations of the stator active, reactive powers, and electromagnetic torque caused by unbalanced grid voltage can be restrained well with the control of the proposed control strategy.

Practically, both transmission and distribution networks can also have voltage harmonic distortions [13]. For instance, standards IEEE-519-1992 [14] and ER G5/4-1 [15] have, respectively, recommended different practices and requirements for harmonic control in electrical power systems. Both of them allow individual voltage harmonics, especially 5th and 7th components, to exist up to 3% in the voltage level of 6.6 kV, 11 kV and 20 kV. As indicated in [16–18], if voltage harmonics were not taken into account by the DFIG control system, not only torque and output power oscillations would appear, but also copper and iron losses in the generator would increase. As a result, the

* Corresponding author. Tel.: +86 571 87951784; fax: +86 571 87951625.
E-mail address: nianheng@zju.edu.cn (H. Nian).

0378-7796/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsr.2011.12.006

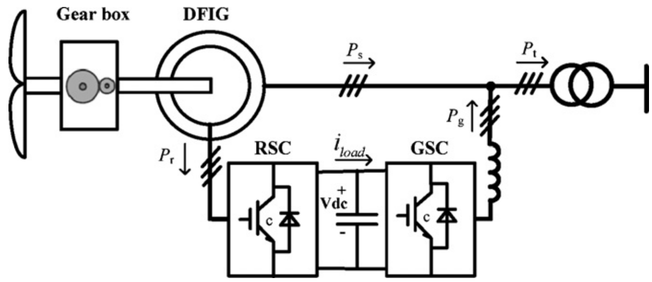

Fig. 1. Schematic diagram of a DFIG-based wind generation system.

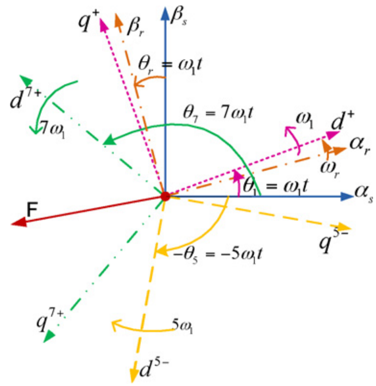

Fig. 2. Relationships between the $(\alpha_s\beta_s)$, $(\alpha_r\beta_r)$, the dq^+, the dq^{5-} and the dq^{7+} reference frames.

DFIG-based wind turbine without the consideration of the distorted voltage control might have to be disconnected from the grid when grid voltage harmonic distortions happen. However, harmonic standards recommend that the wind turbines should have the ability to withstand a certain voltage harmonics without tripping. As a result, aimed at the higher reliability and operation performance, an improved control strategy of DFIG system is necessitated under distorted grid voltage conditions.

Research on the control and operation for DFIG under distorted grid voltage conditions has been studied in [19]. Sinusoidal stator current, sinusoidal rotor current, eliminating torque or power oscillations can be selected as the control target of DFIG. However, the control strategy required in the each target is independent and interacting, such as the rotor current, the torque or power oscillations will be deteriorated if the sinusoidal stator current is selected. In [20], the improved control strategy was implemented of the grid-side converter (GSC) to achieve the steady GSC power output or the sinusoidal GSC output current. Practically, DFIG system including RSC and GSC should be considered as a whole, it is necessary to investigate the operation performance of the entire DFIG system under the distorted grid voltage. Especially, considering that the output performance of the DFIG system will be assessed by the grid, the GSC can be operated as the auxiliary controller to compensate the power oscillations or the harmonic current, and DFIG can be controlled to achieve the stable torque to improve the reliability of the mechanical transmission system. Thus, the grid-on operation ability of the overall DFIG system will be increased.

In this paper, a coordinated control strategy of the RSC and GSC is proposed to provide enhanced control and operation capability of the DFIG-based wind turbine when the network is harmonically polluted. Based on the dynamic modeling and improved control for DFIG (RSC) and GSC under 5th and 7th harmonic voltage, the control targets of the overall system are identified as: (1) sinusoidal system output current and constant electromagnetic torque; (2) steady output power of DFIG system and constant electromagnetic torque. The control schemes corresponding to the different control targets are proposed, which are composed of a PI regulator and a harmonic resonant compensator tuned at sixth the grid frequency. Finally, the proposed control scheme is verified by detailed simulation study on a 1.5-MW commercial DFIG system under distorted grid voltage conditions.

2. Modeling of a DFIG system during GRID harmonics

A simplified diagram of a wind-turbine DFIG system is shown in Fig. 1. The stator of the DFIG is connected to the grid through a step-up transformer, while the rotor is connected to a back-to-back voltage-sourced PWM converter. Rotor-side converter (RSC) is connected to the DFIG's rotor winding to control the power flow from the stator to the grid. Grid-side converter (GSC) is directly connected to the grid so as to achieve the stable dc link voltage and provide the limited reactive power support to the grid. Under balanced and distorted grid voltage conditions, the fundamental and the harmonics at the frequencies of $-5\omega_1$ and $7\omega_1$ are taken into consideration in this paper. Detailed modeling of both the RSC and GSC have been studied [19,20], and thus, only a brief description is given in this section.

2.1. DFIG (RSC) model

Under the distorted grid voltage conditions, the distorted grid voltage can be decomposed into a fundamental frequency component and a set of harmonic frequency components. In order to describe the electromagnetic components in the DFIG system, the spatial relationship between some related reference frames is given in Fig. 2. Based on the grid-voltage orientation, Fig. 2 shows the relationship between the