Electrical Power and Energy Systems 82 (2016) 363–372

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Dynamic performance improvement of DFIG-based WT using NADRC current regulators

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ARTICLE INFO

Article history:
Received 6 July 2014
Received in revised form 14 March 2016
Accepted 16 March 2016
Available online 1 April 2016

Keywords:
Doubly-fed induction generator-based wind turbine (DFIG-based WT)
Dynamic performance
Fault ride-through (FRT)
Nonlinear adaptive disturbance rejection control (NADRC)
Rotor side converter (RSC)

ABSTRACT

In this paper, to improve the dynamic performance of DFIG-based WT, a NADRC technology is proposed. The proposed NADRC can actively estimate and compensate the plant internal dynamics and external disturbances in real time. Therefore, it improves the tracking performance of the rotor current without any overshoot and steady-state error, and enhances the fault ride-through capability of DFIG-based wind turbine. Compared with the proportional PI control, the proposed NADRC during grid fault can significantly suppress the peak values of stator and rotor currents and DC-link voltage, and decrease the oscillation time of electromagnetic torque. Moreover, the proposed NADRC has a characteristic of one-parameter tuning by using the parameterization technique of controller, and parameter tuning of NADRC is only determined by the rise time of the system step response. A series of simulations for various cases on a 1.5-MW DFIG-based wind turbine are implemented, and the results validate the stability of the proposed NADRC and the strong robustness against the plant internal dynamics and external disturbances.

Introduction

MW doubly fed induction generator (DFIG) is becoming more and more popular in wind-power generation system [1,2]. Compared with the fixed speed induction generator (FSIG) and permanent magnet synchronous generator (PMSG) which are equipped with full-sized converters, the power control of DFIG can be implement with a back-to-back converter which connects between the rotor and the grid, and it is sized for a power around 30% of the rated power of the turbine [3,4]. Due to its advantageous characteristic, most of the grid-connected wind power generators commonly use DFIG. In addition, to maintain grid stability during the grid fault, the grid code requires the grid-connected wind turbines (WTs) to remain connected to the grid and provide a certain reactive power. Therefore, the development of high-performance control scheme increasingly becomes research focus.

Nowadays, to control the rotor current of DFIG-based WT, the control strategy of the rotor side converter (RSC) mainly uses the stator flux vector orientation [5,6]. In addition, some other control methods are also mentioned in the literatures, e.g., stator voltage vector orientation [7,8], air gap flux vector orientation [9], scalar control [10,11], grid voltage vector orientation [12], direct torque control [13], direct power control [14,15], and hysteresis current vector control [16,17]. However, for the strong nonlinear wind power system, these control methods that depend on accurate mathematical model of the plant can deteriorate the controller performance.

Recently, with the rapid developments of power electronic technology and modern control theories, the nonlinear control methods have been widely concerned, and some control algorithms have also been presented [3,18,19]. To some extent, these control methods have improved the control performance of DFIG-based WT system. However, some of which are too complicated to be implemented practically in industrial application, and strongly depend on the proper design of control parameters.

In this paper, a nonlinear adaptive disturbance rejection control (NADRC) technology is proposed for the rotor current control of DFIG-based WT, in which the grid disturbance, parameter variation, and cross-coupling term are treated as a generalized disturbance and compensated in real time. The NADRC is a novel control method that proposed by Han [20] and further developed by Gao [21], which recently has been successfully used in the following engineering control fields, e.g., electro-mechanical control systems [22], servo control of machining process [23], trajectory tracking and coordination control of robotic system [24,25], high

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http://dx.doi.org/10.1016/j.ijepes.2016.03.026
0142-0615/

precision motion control [26], speed control of motor system [27,28] and power converter [29].

The proposed NADRC current regulator in this paper consists of two parts. The first one is a nonlinear extended state observer (NESO), which estimates and compensates the generalized disturbance in real time, achieving better performance and disturbance compensation via the estimation of internal dynamic and external disturbance. The second one is a nonlinear state error feedback control law (NSEFCL), which makes the error reach zero much more quickly in finite time. With the accurate estimations of internal dynamic and external disturbance, the proposed NADRC technology can successfully drive the rotor current to track the reference signal, and suppress the performance degradation caused by the grid disturbance and parameter uncertainty. More importantly, the one-parameter tuning feature in its true sense makes the control method practical and easy to implement in industrial applications.

DFIG-based WT system modeling

Fig. 1 shows the schematic diagram of a grid-connected DFIG-based WT system, which consists of WT, drive train, wound-rotor induction generator with back-to-back PWM converter and control systems. The DFIG stator windings are directly connected to the grid through a step-up transformer, and the rotor windings are connected to the grid via a partial scale power back-to-back converter. The control system includes two subsystems, one is WT control system that usually adopts maximum power point tracking (MPPT) control below the rated wind speed and constant power control above the rated wind speed to make full use of wind power [30].The other is DFIG control systems based on vector control techniques, which include the rotor side controller that independently regulates the active and reactive power of DFIG, and the grid side controller that regulates the DC-link voltage and reactive power according to the power factor requirement [8].

Modeling of WT and drive train

The WT that consists of three blades and hub captures wind energy, and converts it into mechanical energy. Through the drive train, the mechanical energy drives the DFIG rotor. The mechanical torque T_m produced by the WT can be given by [17]

$$T_m = \frac{\pi \rho R^2 C_p(\lambda, \beta) v_w^3}{2\omega_t} \tag{1}$$

where ρ is the air density, R is the WT radius, v_w is the wind speed, ω_t is the WT angular frequency, C_p is the WT power coefficient, λ is the blade tip speed ratio, which has $\lambda = \omega_t R / v_w$, and β is the blade pitch angle.

The power coefficient C_p is a function of the tip speed ratio λ and the blade pitch angle β. The calculations of the power coefficient are rather complicated, which requires the use of blade element theory and knowledge of aerodynamics. The numerical approximations based on given values of λ and β have been developed. Hence, the approximate function can be given by

$$\begin{cases} C_p(\lambda, \beta) = 0.22\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{-12.5/\lambda_i} \\ \lambda_i = \frac{1}{\frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}} \end{cases} \tag{2}$$

The drive train which is consisted of WT shaft, gearbox, and rotor shaft of DFIG is commonly treated as two masses connected together by spring and damper [17]. The drive train model treats the wind turbine as one mass, and the gearbox with the rotor of DFIG as the other mass. The dynamic equations describing the two-mass drive train can be written as

$$\begin{cases} \frac{d\omega_t}{dt} = \frac{1}{2H_t}(T_m - K_{sh}\theta_t) \\ \frac{d\theta_t}{dt} = \omega_b(\omega_t - \omega_r) \\ \frac{d\omega_r}{dt} = \frac{1}{2H_g}(K_{sh}\theta_t - T_e) \end{cases} \tag{3}$$

where ω_r is the rotor angular frequency of DFIG, ω_b is the system base angular frequency which is equal to the synchronous angular frequency, H_t, H_g are the inertia constants of the WT and the generator rotor, respectively, K_{sh} is the shaft stiffness, θ_t is the shaft twist angle, and T_e is the DFIG electromagnetic torque.

Modeling of DFIG

The Park model is usually used for DFIG, in which it is assumed that the stator and rotor windings of DFIG are placed

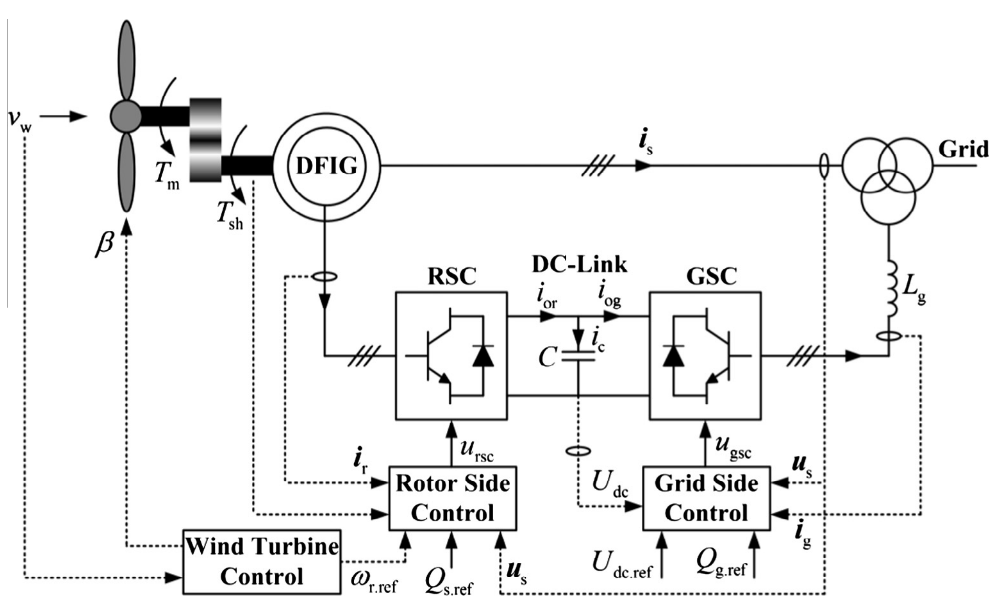

Fig. 1. Schematic diagram of a grid-connected DFIG-based WT system.