Electrical Power and Energy Systems 44 (2013) 375–382

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

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

# Dynamic modeling and robust power control of DFIG driven by wind turbine at infinite grid

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ARTICLE INFO

*Article history:*
Received 27 December 2008
Received in revised form 18 March 2011
Accepted 2 June 2011
Available online 26 September 2012

*Keywords:*
Wind turbine
Doubly fed induction generator
Power control
Robust control
Sliding mode control

ABSTRACT

In this paper, a dynamic modeling and power control scheme for doubly-fed induction generator (DFIG) for variable speed wind power generation is proposed. A detail dynamic model of a DFIG-based, wind turbine and grid-connected system is presented in the *d–q*-synchronous reference frame. A robust controller based on sliding mode controller (SMC) is applied in order to control the power flowing between the stator of the DFIG and the power network. To improve the controller performance in steady state the integral sliding mode controller (ISMC) is used. Also, ISMC is used to achieve the controller robustness. Its respective performance is compared in terms of power reference tracking, sensitivity to perturbations in sub-synchronous and super-synchronous modes and robustness against machine parameters variations. Moreover, the proposed ISMC performance is compared with the conventional proportional–integral control.



## 1. Introduction

The renewable energy systems and specially wind energy have been attracted due to the increasing concern about $CO_2$ emissions. The wind energy systems using a doubly-fed induction generator (DFIG) can operate with variable speed and in the four quadrant active and reactive power capabilities. Many researchers investigated the performance improvements of DFIG driven by wind turbine at deferent conditions [1–3]. These features give DFIG advantage as compared with fixed speed induction generators which are presented in Refs. [4,5]. The stator of DFIG is connected directly to the grid and the rotor links the grid by a bi-directional converter. The rotor converter controls the flow of active and reactive power between DFIG and AC supply. Some investigations using PI controllers that generates reference currents from active and reactive power errors to the inverter or a cascade PI controllers that generate a rotor voltage are presented in Refs. [6,7]. The problem in the use of PI controller is the tuning of the gains and the cross-coupling on DFIG terms.

Recently, the variable structure control strategy using the sliding-mode has been focused on many studies and research for the control of the wind generation systems [8–12]. The sliding-mode control can offer many good properties, such as good performance against unmodeled dynamics, insensitivity to parameter variations, external disturbance rejection and fast dynamic response [13]. These advantages of the sliding-mode control may be employed in the active and reactive power control of DFIG connected to utility grid.

The design of SMC consists of two main steps. Firstly, selecting a sliding surface that models the desired closed loop performance. Secondly, designing a control law such that the system state trajectory is forced toward the sliding surface. The system state trajectory in the period of time before reaching the sliding surface is called the reaching phase. The system dynamics in the reaching phase is still influenced by uncertainties. Ideally, the switching of the control should occur at infinitely high frequency to eliminate the deviation from sliding manifold. In practice, the switching frequency is not infinitely high due to the finite switching time. Thus, undesirable chattering appears in the control effort. Chattering is highly undesirable because it excites unmodeled high frequency plant dynamics and this can cause unforeseen instability [13]. Different studies tried to solve this problem by combining fuzzy or neural controller with the sliding mode [14,15].

This paper presented a system consists of wind turbine, DFIG and constant grid. A robust ISMC is used to control the flow of active and reactive power between the DFIG and the grid. The proposed controller generates the references rotor currents using the DFIG equations in synchronously rotating coordinate system. Also the controller calculates the rotor voltages required to guarantee active and reactive power reach their desired reference values. The proposed ISMC performance is compared with the conventional proportional integral control. Simulation results are presented for validating the proposed controller.

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http://dx.doi.org/10.1016/j.ijepes.2011.06.038

**Nomenclature**

| | |
|---|---|
| *DFIG* | double-fed induction |
| *SMC* | sliding mode controller |
| *ISMC* | integral sliding mode controller |
| *WECS* | wind energy conversion system |
| *VSC* | voltage-source converter |
| *APISMC* | active power integral sliding mode control |
| *RPSMC* | reactive power sliding mode control |
| $V_{ds}$, $V_{qs}$ | stator direct and quadrature voltages referred to synchronously rotating coordinate (V) |
| $V_{dr}$, $V_{qr}$ | rotor direct and quadrature voltages referred to synchronously rotating coordinate (V) |
| $I_{ds}$, $I_{qs}$ | stator direct and quadrature currents referred to synchronously rotating coordinate (A) |
| $I_{dr}$, $I_{qr}$ | rotor direct and quadrature currents referred to synchronously rotating coordinate (A) |
| $L_s$, $L_r$ | per phase stator and rotor self inductance respectively (H) |
| $L_m$ | mutual inductance (H) |
| $R_s$, $R_r$ | per phase stator and rotor resistances (Ω) |
| $\varphi_{ds}$, $\varphi_{qs}$ | stator direct and quadrature flux (Wb) |
| $\varphi_{dr}$, $\varphi_{qr}$ | rotor direct and quadrature flux (Wb) |
| $\omega$, $\omega_r$, $\omega_s$ | mechanical speed, rotor speed and synchronous speed (rad/s) |
| $p$ | number of poles pairs of the machine |
| $T_e$, $T_L$ | electromagnetic torque and load torque respectively (N m) |
| $J$ | moment of inertia of the machine (kg-m$^2$) |
| $f$ | friction coefficient (N-m s$^{-1}$) |
| $g$ | the rotor speed per unit |
| $e$, $\dot{e}$ | error signal and its derivative |
| $e_p, \dot{e}_p$ | error signal of the active power and its derivative |
| $e_q, \dot{e}_q$ | error signal of the reactive power and its derivative |
| $\sigma$ | sliding surface |
| $\sigma_p$ | sliding surface for the active power control |
| $\sigma_q$ | sliding surface for the reactive power control |

## 2. System description

Fig. 1 shows a wind energy conversion system (WECS) connected to an infinite grid. The proposed WECS consists of a wind turbine driving a double fed induction generator (DFIG). Two voltage-source converters (VSCs) control the system power flow. The converter on the rotor side, controls the active and the reactive power flow between the DFIG and the grid. The converter on the grid side controls the DC-link voltage and the reactive power to the grid from the converter. The active power transmitted to the grid is the algebraic sum of stator power $P_s$ and rotor power $P_r$, assuming the power converter is loss less, $P_s \pm P_r = P_g$, $P_g$ is the active power flow to the grid.

In general an induction machine has three operating modes, namely the motor, the generator and the brake modes. The power flowing in the rotor of a slip-ring induction machine (i.e. of the wound rotor type) has three main components. These are (a) the electromagnetic power transferred between the stator and the rotor through the air gap which is known as the air gap power $P_{gap}$; (b) the mechanical power $P_m$ transferred between the rotor and the shaft; (c) the slip power $P_r$ which is transferred between the rotor and any external electrical source or load (e.g. a converter) through the rotor slip-rings and/or consumed in the rotor winding as copper losses ($P_r = P_c + P_{cur}$, where $P_c$ is the converter output/input power and $P_{cur}$ is the rotor copper losses). the slip power $P_r = sP_{gap}$, where $s$ is the slip. The different operating modes of a slip-ring induction machine is summarized in Table 1 [16].

Depending on the DFIG operating modes $P_r$ may be either drawn from the grid or supplied to the grid. For sub-synchronous mode when rotor angular speed $\omega$ is less than the mains angular frequency $\omega_g$, the power flows from the grid to the rotor; otherwise the rotor power is supplied to the grid. Hence the net DFIG generated power is $P_s \pm P_r$. The reactive power $Q_s$ is determined by the machine excitation requirement and the desired grid power factor. The control objective is to ensure that the phase shift between the grid voltage and machine supplied current is at the desired value for a given power developed by the turbine that is determined by the wind speed. As is known for wind speeds within the range from cut-in to rated level, the mechanical power generated by the wind turbine varies according to the turbine shaft speed [17].

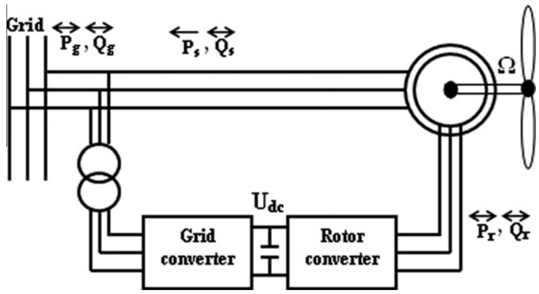


**Fig. 1.** DFIG system used.

## 3. Modeling of the DFIG

The DFIG is used to produce electrical power at constant frequency whatever wind and shaft speed conditions. We used the classical *d*–*q* manetization of the induction generator in the Park reference frame [18,19]. The equations for a DFIG are identical with a squirrel-cage induction generator, except that the rotor voltages are not zeros.

$$V_{ds} = R_s I_{ds} + \frac{d}{dt}\varphi_{ds} - \omega_s \varphi_{qs} \tag{1}$$

$$V_{qs} = R_s I_{qs} + \frac{d}{dt}\varphi_{qs} + \omega_s \varphi_{ds} \tag{2}$$

$$V_{dr} = R_r I_{dr} + \frac{d}{dt}\varphi_{dr} - \omega_r \varphi_{qr} \tag{3}$$

$$V_{qr} = R_r I_{qr} + \frac{d}{dt}\varphi_{qr} + \omega_r \varphi_{dr} \tag{4}$$

where

$$\varphi_{ds} = L_s I_{ds} + L_m I_{dr}$$

$$\varphi_{qs} = L_s I_{qs} + L_m I_{qr}$$

$$\varphi_{dr} = L_r I_{dr} + L_m I_{ds}$$

$$\varphi_{qr} = L_r I_{qr} + L_m I_{qs}$$

The mechanical equation is:

$$T_e = T_l + f\omega + J\frac{d\omega}{dt} \tag{5}$$