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An improved control scheme for grid connected doubly fed induction generator considering wind-solar hybrid system

Adikanda Parida *, Debashis Chatterjee [1]

Department of Electrical Engineering, Jadavpur University, Kolkata, India

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ABSTRACT

This paper proposes a wind-solar hybrid generation scheme, along with an improved control strategy for grid connected wind energy conversion system (WECS) considering parameter uncertainty. In the proposed scheme, a photo voltaic (PV) supplemented rotor power management scheme (RPMS) has been developed for doubly fed induction generator (DFIG) with stator connected to grid. The topology of RPMS is implemented in isolation with the grid during entire period of DFIG operation. The proposed scheme ensures an increased output power delivered to the grid during low wind speeds. The DFIG control scheme require accurate information for the rotor position and speed at all operating conditions, which is estimated in the proposed method without any significant dependency on machine parameters. The control strategy proposed in this paper is implemented with a 2.5 kW DFIG using dSPACE DS1104 module with PC interface, which produced satisfactory results.

Introduction

The wind energy shares a considerable segment amongst all the generations in the world energy scenario. At present doubly fed induction generators with suitable control scheme, provides a low cost alternative with high dynamic performance for power ranges from kW to MW for the purpose of wind energy conversion. The precise control of DFIG requires accurate information of rotor position angle and rotor speed. The rotor speed sensorless option for the control of DFIGs are more preferred due to its improved reliability, lower capital cost investment and lower maintenance. Moreover mounting of speed sensors require additional space which may not be available in some of the systems. The dual converter based controllers with sensorless estimation of rotor speed and position has been widely addressed [1–16,18–21]. The earlier control schemes are complex to coordinate and incapable to maintain the grid connectivity of DFIG at low wind speeds. Also the earlier proposed rotor speed and position estimation algorithms [1–5] are based on open loop methods, where the estimation is implemented with the use of differentiators. This can introduce error due to noise in the input signals for computation of rotor speed and position. Similar type of controller with MRAS based rotor speed and position algorithms are proposed in [6–10]. But these are directly sensitive to magnetizing inductance variations which affects the stability and reliability of the controller. The control algorithm proposed in [11] suffers from problems associated with integration at low frequency for the rotor side variables around synchronous speed. The rotor speed and position estimation techniques presented in [12–16] are based on hysteresis controllers where the adjustable model parameter is directly sensitive to the machine magnetizing inductance. A current based direct power control strategy for DFIG has been proposed in [18]. The dual converter based controllers are proposed in [19–21] under various grid disturbances. Almost all of the already proposed controllers are derived in such a way that the rotor side converter (RSC) of the machine is fed from another converter connected to grid known as grid side converter (GSC). Thus, the grid disturbances can directly affect the control of both these converters and thereby reducing grid connectivity options under these situations. Moreover, none of these techniques address the problem of grid connectivity improvement options under low wind speeds situations.

In this paper a novel wind-solar hybrid power generation scheme for grid connected DFIG has been developed considering improved connectivity option in the subsynchronous range. The continuity of supply to grid during low wind speed conditions with enhanced output power is the major advantage of the proposed scheme. The proposed scheme is implemented with only rotor side converter, thus RSC controller is working in isolation with the grid. The dc power input to the controller is provided from a PV panel along with storage battery of appropriate size. The PV panel supplements the rotor power during low wind speeds to generate

* Corresponding author. Tel.: +91 9436633939.
E-mail addresses: adikanda_2003@yahoo.co.in (A. Parida), debashisju@yahoo.com (D. Chatterjee).
[1] Tel.: +91 3324146100.

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Nomenclature

$\lambda^s_{\alpha s}, \lambda^s_{\beta s}$	α–β axis components of stator flux in stationary reference frame
$v^s_{\alpha s}, v^s_{\beta s}$	α–β axis components of stator voltages in stationary reference frame
$i^s_{\alpha s}, i^s_{\beta s}$	α–β axis components of stator currents in stationary reference frame
$i^s_{\alpha r}, i^s_{\beta r}$	α–β axis components of rotor current transformed into stator reference frame
$i^r_{\alpha r}, i^r_{\beta r}$	α–β axis components of measured rotor currents in rotor reference frame
L_m, L_s, L_{ls}, L_{lr}	magnetizing, stator self, stator leakage and rotor leakage inductances of DFIG
R_s	stator resistance
T_e, p	electromagnetic torque, number of poles
ω_e, ω_r	angular velocity of stator magnetizing flux, rotational speed of rotor
θ_r	rotor position angle
σ_s	stator leakage factor
K_p, K_i	proportional constant and Integral constants of PI-controller
τ_s	time constant of the delay introduced by sampling
ω_o	electrical frequency of the machine

Subscripts

(r, s)	rotor or stator quantities

constant output power to be fed to the grid. The proposed control algorithm needs correct information regarding rotor speed and position for stability and reliability of the system. The proposed method, effectively estimates the said quantities under variable wind speed condition including near synchronous speed. The estimation process is almost independent of machine parameter variations. The proposed model for rotor position and speed estimation is stable under all loading conditions while catching the actual value of rotor speed including starting on fly. The method is simple and can be easily implemented for practical applications.

Architecture of the proposed controller

The schematic of the proposed system is shown in Fig. 1. The rotor power is controlled by a rotor side converter only, replacing the widely used dual converter scheme connected to grid. A suitable PV module assists the rotor power management system (RPMS) to maintain a constant voltage across dc-link capacitor (C_d). The diode connected in series with the solar panel protects the PV module from voltage surges and prevents reverse current flow during low irradiation periods.

The dc-bus voltage (V_{dc}) is compared with the reference dc voltage (V^*_{dc}) and the error signal is fed to a hysteresis controller which generates switching pulses for the IGBT based dc chopper circuit with help of a suitable pulse driver circuit. When $V_{dc} > V^*_{dc}$, the IGBT2 charges the battery2 for future usage and the excess energy after charging can be dumped to another auxiliary load through a switch shown in Fig. 1. The selection of capacitor and battery can be flexible as it is based on the local wind profile. When both wind and solar power is not available, the stored energy in battery2 can be utilized to provide rotor power through IGBT3.

The proposed system shown in Fig. 1 can operate in the following modes.

Mode 1: Wind power is low (subsynchronous rotor speed) and solar power is sufficient.

In this mode, the rotor power needed is supplied directly from solar panel. If the requirement of rotor power P2 is more than solar energy generated, battery1 can supply the balance power. If solar energy generated is more than rotor power P2 needed, the excess power will stored in battery1 and then in battery2.

Mode 2: Both wind and solar powers are low.

In this mode, the rotor power P2 needed is supplied from battery1 and battery2.

Mode 3: Wind power is large and solar power is low.

In this mode, the rotor goes to supersynchronous region and rotor power P2 will be extracted from the rotor. This power is directly stored both in battery1 and battery2.

Mode 4: Both wind power and solar power are high.

In this case, both the rotor power and solar power gets stored in battery1 and battey2. If the generated power is large, the dc-bus voltage will rise which enable the switch SW shown in Fig. 1 to connect to auxiliary load to utilize the excess power.

a. Generation of reference signals.

The DFIG generates power at constant voltage and constant frequency at the stator terminals irrespective of the shaft speed. In the proposed scheme, a stator flux oriented control strategy has been adopted for this purpose. For stator flux orientation with stator flux λ_s oriented along synchronously rotating d-axis, $\lambda_s = \lambda_{ds}$, thus $\lambda_{qs} = 0$. Where, $\lambda_{ds}, \lambda_{qs}$ are the d–q components of the stator flux in synchronous reference frame.

The stator flux can be expressed as [22],

$$\begin{bmatrix} \lambda_{ds} \\ \lambda_{qs} \end{bmatrix} = L_s \begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} + L_m \begin{bmatrix} i_{dr} \\ i_{qr} \end{bmatrix} \tag{1}$$

Where, i_{ds}, i_{qs} and i_{dr}, i_{qr} are the d–q stator and rotor currents in synchronous reference frame. Therefore, reference value of rotor currents (i^*_{dr}, i^*_{qr}) in synchronous reference frame can be computed using (1) as,

$$i^*_{qr} = -(L_s/L_m)i_{qs}, \quad i^*_{dr} = (1/L_m)\lambda_{ds} - (L_s/L_m)i_{ds} \tag{2}$$

The rotor voltage equations in synchronous reference frame is given by [23],

$$\begin{bmatrix} v_{dr} \\ v_{qr} \end{bmatrix} = Rr \begin{bmatrix} i_{dr} \\ i_{qr} \end{bmatrix} + (d/dt) \begin{bmatrix} \lambda_{dr} \\ \lambda_{qr} \end{bmatrix} + \omega_{slip} \begin{bmatrix} -\lambda_{qr} \\ \lambda_{dr} \end{bmatrix} \tag{3}$$

The d–q axis rotor voltage references (V^*_{dr}, V^*_{qr}) can be expressed with the stator flux orientation of d-axis utilizing (1) and (3) as,

$$V^*_{dr} = V'_{dr} - (\omega_{slip})\sigma L_r i_{qr} \tag{4}$$

$$V^*_{qr} = V'_{qr} + (\omega_{slip})\left(\left(L^2_m/L_s\right)i_{ms} + \sigma L_r i_{dr}\right) \tag{5}$$

Where ω_{slip} is the slip speed, $\sigma = \left(1 - \frac{L^2_m}{L_s L_r}\right)$ is the leakage factor, i_{ms} is the magnetizing current and V'_{dr}, V'_{qr} are the control outputs of PI controllers PI_1 and PI_2 respectively as shown in Fig. 1. The PI controller outputs V'_{dr}, V'_{qr} are used to generate rotor d–q axes voltage reference using (4) and (5).

The control of rotor-side PWM converter requires the measurement of the stator voltage and current and rotor current.

b. Power flow.

The DFIG power flow diagram is shown in Fig. 2a for existing conventional scheme of rotor side converter connected to grid and in Fig. 2b for the proposed scheme. Different power