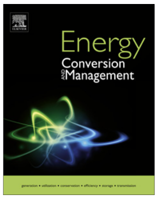
Energy Conversion and Management 78 (2014) 584–594

Contents lists available at ScienceDirect

Energy Conversion and Management

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



# An improved sensorless decoupled power control scheme of grid connected variable speed wind turbine generator

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ARTICLE INFO

*Article history:*
Received 18 February 2013
Accepted 8 November 2013
Available online 12 December 2013

*Keywords:*
Doubly fed induction generator (DFIG)
Sensorless control
Phase-locked loop (PLL)
Three-level converter
Space-vector-based hysteresis current control (SVBHCC)

ABSTRACT

This paper proposes an improved sensorless control for a variable speed-constant frequency generation system based on a doubly fed induction generator (DFIG). The rotor position and speed estimation method is based on a modified phase-locked-loop (MPLL). Using the measured stator voltages and rotor currents, the proposed algorithm can directly generates the rotor position and speed by simple arithmetic operations using the PLL basis. The speed is estimated independently of the machine parameters and the algorithm avoids using differentiation, which results in a substantial improvement in control robustness and improves its immunity to noise. This paper also presents the design of a space-vector-based hysteresis current control (SVBHCC) technique applied to a three level neutral-point-clamped (NPC) inverter to enhance the control system performance and achieve high power quality. The algorithm allows a systematic application of zero-voltage vectors that leads in reducing the average switching frequency. Furthermore, the space-vector-based approach reduces the interference between the commutations of the three phases. Simulation results confirm the effectiveness and validity of the proposed control approach.

## 1. Introduction

The doubly fed induction generator (DFIG) is very attractive for variable speed generations especially for wind energy generations [1]. Advantages of the DFIG-based variable speed wind turbines are numerous. Firstly, the maximal mechanical power attainable from the wind can be extracted and converted to fixed-frequency electric power by adjusting the machine speed and the electrical torque [2]. Secondly, only a fraction of the nominal electric power flows through the power converter thus reduces its loss and cost. Moreover, the stator side active and reactive power can be independently controlled [2,3].

Different topologies of the interfacing converter can be used in wind energy conversion system. Multilevel converters especially three-level converters are a good alternative to the conventional two-level voltage source converters (VSC) [4,5]. However, the control complexity increases [6]. The traditional current control strategies are mostly proportional-integral (PI) based on a linearized model, which are difficult to obtain and may not give satisfactory performance under parameter variations, load disturbances and a large-scale wind changes [7,8].

As an alternative, hysteresis-based control schemes have been known for a long time as a simple and effective way for implementing current control of switching converters. The variable switching frequency, the strong load dependency of the average switching frequency, and the possibilities for limit cycle operation with high frequency switching are well known disadvantages of basic hysteresis controllers [7]. Nevertheless, the hysteresis current control schemes can be relevant for many applications with different improvements in the control strategy. A complete overview including introduction, modeling and different control methods for DFIGs is presented in [9].

It seems that rotor position or speed sensors installed on the rotor shaft are required for the transformation of the rotor current space vector between different reference frames in the vector control system [9–11]. The use of such sensors implies additional wiring, extra cost, extra space, and careful mounting which weakness the robustness of the induction machines [12].

During the last years, sensorless control of a DFIG-based wind turbines has been the focus of significant research efforts [12–30]. The earliest speed estimation method was proposed in [13]. In [14], the angle between the rotor current vector and the field axis is estimated using the inverse tangent functions. The rotor position estimation approaches presented in [15–19] are based on the fundamental model of the machine, where the rotor position is directly obtained from the measured voltages and currents by reference frame transformation. The problems with these methods

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http://dx.doi.org/10.1016/j.enconman.2013.11.015

reside in the open-loop character of the estimators and the effect of the controller is dependent on the information accuracy of the system parameters. Furthermore, some noise is introduced in the speed signal through differentiation.

In order to deal with the open-loop estimators problems, closed-loop model reference adaptive system (MRAS) observers are proposed in [2,20–31]. The MRAS algorithm is simple to compute but it is slightly sensitive to parameters variation, especially at a very low speed. Moreover, the designing approaches are established in the stationary reference frame, which gives a sinusoidal form to the involved variables. Hence, the controller parameters choice is very sensitive and the observer might become inaccurate or even unstable in digital implementation [21,22]. In [28], the proportional-integral (PI) control is replaced by a hysteresis controller.

Another kind of closed-loop observer based on phase-locked loop is introduced in [13,30,31]. The method proposed in [13] is based on the calculation of the air–gap–flux in the rotor reference frame by direct measurement of the rotor voltages and currents to estimate the rotor load angle $\delta$. The use of voltage controlled oscillator (VCO) with high gain ensures the convergence of the slip frequency to the desired value. The scheme proposed in [30,31] is based on a rotor position phase-locked loop (PLL). This scheme suffers from the dependency on the magnetization inductance (Lm). Added to this, the overall sensorless control system requires the stator currents measurements, which are not necessary in the DFIG vector control.

In this paper, a sensorless decoupled power control strategy for a DFIG-based wind turbine is proposed. The rotor position and speed estimation can be achieved by means of a closed-loop observer based on modified phase-locked-loop (MPLL) as an improvement of the method proposed in [30,31]. The principles of the method were originally discussed for application to permanent-magnet synchronous motor (PMSM) drive [32]. In case of a DFIG, both the stator and rotor currents can be measured. This is an important advantage of the DFIG compared to the other types of electrical machines. With the measured stator voltages and rotor currents, the proposed algorithm can directly generate the rotor position and speed by simple arithmetic operation using the phase-locked loop (PLL) basis. A linearized closed-loop observer model is derived to validate the observer gain selection.

The attractiveness of the proposed strategy comes from its simplicity and ability to actively estimate the rotor position and speed simultaneously without using differentiation. Conversely to others, the proposed method does not require any estimated or intermediate quantities like rotor or stator fluxes. This allows some independence and increases the robustness of the method against machine parameters variations. Furthermore, the frequency response proves that the whole modified-PLL system acts as a low-pass filter, which effectively participates in the enhancement of the immunity against noise in the electrical measurements.

The paper also presents an improved space-vector-based hysteresis current control (SVBHCC) strategy for three-level NPC inverter to overcome the deficiency of the traditional hysteresis current control and enhance the decoupled power control system performance. The SVBHCC algorithm brings the rotor currents errors into stationary ($\alpha$, $\beta$) space-vector reference frame. According to the error vector position, an appropriate voltage vector among the 27 vectors of three-level NPC will be applied to force the rotor current towards the reference one. The proposed space-vector based approach ensures that zero voltage vectors are systematically applied.

The following contributions are believed to be new. First, the design approaches and analysis of the proposed method in dynamic and steady-state modes including both bellow and above synchronous speeds are thoroughly investigated for a DFIG-based wind turbine application. Good behavior is verified for different cases by using Bode-diagram of the loop gain transfer function. Second, the developed sensorless control strategy involves the same input variables for both SVBHCC and MPLL, without requisite to estimate rotor or stator fluxes. Only stator voltages and rotor currents are needed. This substantially reduces the cost and enhances the overall control system reliability. Hopefully, these features make the control strategy practical and easy to implement in commercial wind turbines.

## 2. Wind energy conversion system modeling

A typical grid connected DFIG-based wind conversion system is illustrated in Fig. 1. It consists of a wind turbine, a gearbox, a DFIG and back-to-back three-level converters. The DFIG wind power system employs two PWM-converters can achieve high performance, such as fast dynamic response, decreased total-harmonic-distortion (THD) and high efficiency. PWM converters between the grid-side and the rotor-side also allow for power flow in both directions [19,33]. By decoupling the power system electrical frequency and the rotor mechanical frequency, the converter system permits a variable speed operation of the wind turbine [33].

### 2.1. Modeling of the turbine

In the wind turbine integration studies, it is common to define the wind turbine mechanical power output as [33,34].

$$P_a = \frac{1}{2}\pi \cdot \rho \cdot R^2 \cdot V_w^3 \cdot C_p(\lambda, \beta) \tag{1}$$

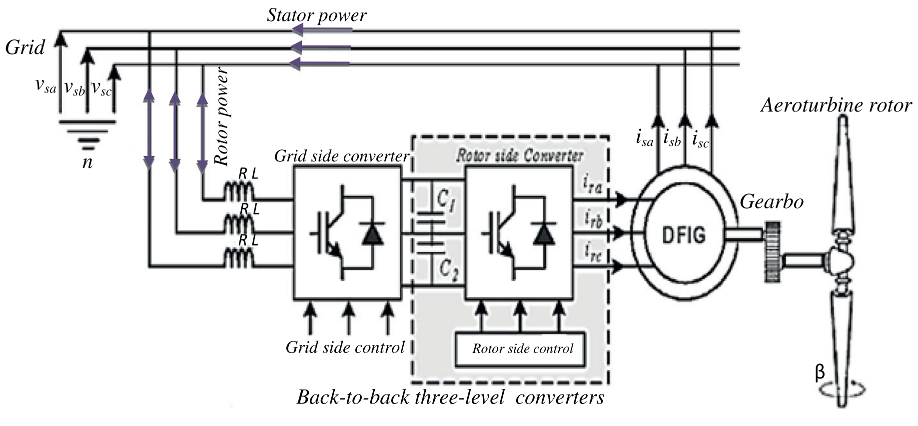

**Fig. 1.** Simplified diagram of the wind conversion system.