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A novel voltage and frequency controller for standalone DFIG based Wind Energy Conversion System

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ABSTRACT

This paper presents a new speed-sensorless control strategy for a stand-alone doubly-fed induction generator supplying energy to an isolated load. The method is based on the root mean square (rms) detection scheme. The generated stator voltage is controlled via rotor currents. Amplitude of stator voltage and its frequency are controlled simultaneously. The output signals from the voltage controllers are the reference signals for the rotor current amplitude and frequency of the stator voltage is regulated with the help of frequency control loop. This developed direct voltage control method is applicable for both the balanced and unbalanced load and also for standalone and grid connected mode. The control pulses for the rotor side converter is supplied by the hysteresis controller which is operated on the error signal calculated between actual and reference rotor currents. This paper also provides the brief idea about the voltage and frequency control on modern Autonomous DFIG based Wind Energy Systems via single phase mathematical model of standalone DFIG system. A short state-of-the-art review on mechanical position/speed sensorless control schemes for autonomous DFIG based WESs is presented, which helps the present researcher and students working in this area. These include stator flux oriented control techniques; direct voltage control techniques; MARS observer based techniques for autonomous DFIG-based variable-speed WESs. Simulation results obtained from a 2MVA DFIG system, prototype in MATLab/Simulink, are presented and discussed in this paper.

Contents

1. Introduction

From the past two decades, wind energy is a very crucial renewable energy source. In earlier period, the technology used in WECS was based on squirrel-cage induction generators (SCIG), running at constant speed, directly connected to grid, Fig. 1(a). The fixed speed Wind Energy Conversion Systems (WECSs) employ a number of gearbox stages operate only in a narrow range around the

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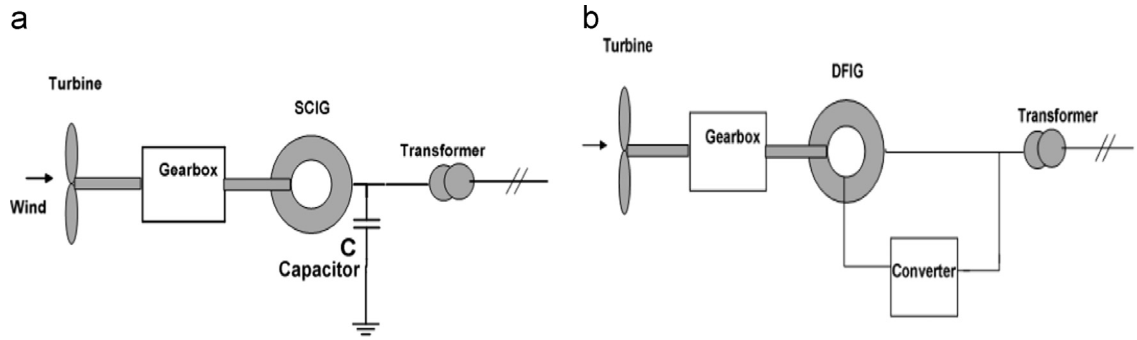

Fig. 1. (a) Scheme of a fixed speed concept with SCIG system and (b) scheme of a variable speed concept with DFIG system.

synchronous speed, always draws reactive power from the grid are directly connected to the grid through a transformer [1]. Presently, the technology moves towards variable speed WECS. Also the controlling of the WESC becomes very important as the power level increases. The variable speed WECSs have been used with an arrangement is well-known as the DFIG concept, Fig. 1(b), which belongs to a variable speed wind turbine with a wound rotor induction generator and power electronics converter on the rotor side.

This concept gives a wide speed operational range, depending on the size of the power electronics converter. Typically, the speed ranges from +30% to −30% around the synchronous speed [2]. The rating of the power electronic converter is only 25–30% of the generator capacity, which makes this concept attractive and popular from an economic point of view [3]. A number of publications and research works have been reported on the grid connected operation of DFIG based WECSs [3–10]. The grid connected DFIG based WECS is comparatively older and is extensively used today. However, scanty attention has been paid toward the issues of stand-alone DFIG based WECSs. In case, the users are at a distant away from the grid and cannot use the energy provided by grid, a stand-alone generating system can be used. A stand-alone generating system must be capable to supply the users with regulated voltage and frequency [13,14,23]. In these cases, wound rotor induction machine (WRIM) offers more useful characteristics working at variable speed while regulating the generated voltage and frequency [13–43]. The stand alone and the grid connected operation of the DFIG based WECS is very different to each other and needs different controllers. There are only some techniques in the literature about the speed-sensorless control of the slip-ring machines [3,50]. But, these techniques will not be discussed in this paper because they associated to the grid connected mode of operation. In grid connected mode, active and reactive powers are controlled, which results in failure to regulate output voltage and frequency in stand-alone mode. It makes the WECS useless after the grid outage; thus, the control techniques for stator voltage amplitude and frequency control were developed. A method described in [37] is only one recognized sensorless control for stand-alone DFIG. The predicted speed is given by synchronization of predicted and measured stator flux, with stator flux estimation related to the stator and rotor currents. To control the amplitude of the stator voltage, a magnetizing current control is used. The assumption is that the magnetizing current is applied only from the rotor side. But it is true only for resistive load [25]. It was tested only for resistive load. Also the high-frequency harmonics in stator voltage, produced by pulse width modulation converter, are limited (by reducing the rotor current ripples) by the additional extremely large chokes connected to the rotor. The given method is based on the flux control rather than a stator voltage control. The flux and voltage are sinusoidal in case of linear load; but, in the case of nonlinear load, stator voltage is distorted more than flux, and these additional distortions are not completely taken into account during the flux control method. Therefore, another technique is presented by Iwanski and Koczara in [18–32]. It is sensorless direct voltage control technique. The method uses a phase-locked loop (PLL) for the synchronization of the actual output voltage vector with the reference vector. The method based on the stator voltage vector control represented in the synchronously rotated polar coordinates. The generated stator/load voltage is controlled by rotor currents. Amplitude of stator voltage and its frequency are controlled separately. The method is applicable for both the stand alone and the grid connected operation.

There are two basic methods of standalone generator voltage control: stator flux oriented control [12–16] and direct voltage control (DVC) [18–32]. The direct voltage control DVC is much simpler than the stator flux oriented control. In the DVC control, any information from mechanical sensors or estimators on the rotor speed or position angle is not needed. In [23,25], the authors proposed dq0 transformation to regulate output or stator voltages and need to tune the two PI controllers. For unbalance loads, extended method is given [24–26], which uses positive and negative sequence controllers, but this needs lots of calculation. So in this paper, a novel control strategy to control the voltage and frequency of a WRIM working as a variable speed stand-alone generating system supplying a balance and unbalanced *R–L* load is proposed. This technique based on the root mean square (rms) detection. The control of load side converter is beyond the scope of this paper and only a diode rectifier is used for the purpose. Because the stand-alone system requires initial energy for excitation, so here a dc battery is connected for short duration of time and after that filtering capacitors are solving this problem. Here we need one (for balanced load) and three (for unbalanced load) PI controllers for each of the three phases. This proposed technique is simple and easy to implement than any other technique used for control of voltage and frequency in standalone DFIG based WECS. This paper is organized as follows: Section 2 discusses the basics of wind turbine concept with the modeling of standalone DFIG based WECS and a short state-of-the-art review on mechanical position/speed sensorless control schemes for standalone DFIG based WESs is presented, these include stator flux oriented control techniques; direct voltage control techniques; MARS observer based techniques for autonomous DFIG-based variable-speed WESs. Section 3 discusses the proposed technique for voltage and frequency control of the stator voltage. Section 4 presents the simulation results with their discussions. Section 5 presents the conclusions and future scope.

2. Standalone DFIG based WECS

The power generated by a WT can be expressed as [11,53]

$$P = 0.5\rho\pi R^2 V^3 C_P(\lambda, \beta) \tag{1}$$

where ρ is the air density in kg/m^3, R the turbine rotor radius, V the wind speed, and C_p is the turbine power coefficient that represents the power conversion efficiency of a wind turbine. The