Renewable Energy 81 (2015) 903–917

Contents lists available at ScienceDirect

Renewable Energy

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

Observer backstepping control of DFIG-Generators for wind turbines variable-speed: FPGA-based implementation

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A R T I C L E I N F O

Article history:
Received 19 March 2014
Accepted 3 April 2015
Available online 24 April 2015

Keywords:
DFIG-Generator
Backstepping control
Adaptative control
Wind turbine
MPPT
FPGA

A B S T R A C T

In this paper, we present a new contribution for the control of Wind-turbine energy systems, a nonlinear robust control of active and reactive power by the use of the Adaptative Backstepping approach based in double-fed asynchronous generator (DFIG-Generator).

Initially, a control strategy of the MPPT for extraction of maximum power of the turbine generator is presented. Thereafter, a new control technique for wind systems is presented. This control system is based on an adaptive pole placement control approach integrated to a Backstepping control system. The stability of the system is shown using Lyapunov technique. Using the FPGA to implement the order gives us a better rapidity. A Benchmark was realized by a prototyping platform based on DFIG-generator, FPGA and wind-turbine; the experimental results obtained show the effectiveness and the benefit of our contribution.

1. Introduction

Today, wind energy has become a viable solution for the production of energy, in addition to other renewable energy sources. While the majority of wind turbines are fixed speed, the number of variable speed wind turbines is increasing [1]. The *Doubly-Fed Asynchronous Generator* (*DFIG*) with Backstepping control is a machine that has excellent performance and is commonly used in the wind turbine industry [2,3]. There are many reasons for using the Doubly-Fed Asynchronous Generator (DFIG) for wind turbine a variable speed, such as reducing efforts on mechanical parts, noise reduction and the possibility of control of active power and reactive.

The wind system using DFIG generator and a “back-to-back” converter that connects the rotor of the generator and the network has many advantages. One advantage of this structure is that the power converters used are dimensioned to pass a fraction of the total system power [5,6]. This allows reducing losses in the power electronics components. The performances and power generation depends not only on the DFIG generator, but also the manner in which the two parts of “back-to-back” converter are controlled.

The power converter machine side is called “Rotor Side Converter” (RSC) and the converter Grid-side power is called “Grid Side Converter” (GSC). The RSC converter controls the active power and reactive power produced by the machine. As the GSC converter, it controls the DC bus voltage and power factor network side.

The speed performance of new components and the flexibility inherent of all programmable solutions give today many opportunities in the field of digital implementation for control systems. This is true for software solutions as microprocessor or DSP (Digital Signal Processor). However, specific programmable hardware technology such as Field Programmable Gate Array (FPGA) can also be considered as an especially appropriate solution in order to boost performances of controllers [1–3]. Indeed, these generic components combine low cost development, thanks to their reconfigurability, use of convenient software tools and more and more significant integration density [4,5].

The *FPGA* technology is now used by an increasing number of designers in various fields of application such as signal processing [6], telecommunication, video, embedded control systems, and

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http://dx.doi.org/10.1016/j.renene.2015.04.013
0960-1481/

electrical control systems. This last domain, i.e. the studies of control of electrical machines, will be presented in this paper. Indeed, these components have already been used with success in many different applications such as Pulse Width Modulation (*PWM*), control of induction machine drives and multimachine system control.

This paper presents the realization of a platform for *adaptative Backstepping* control of *Wind turbine system based in DFIG-Generator* using *FPGA* based controller. This realization is especially aimed for future high performance applications. In this approach, not only the architecture corresponding to the control algorithm is studied, but also architecture and the *ADC* interface and *RS232 UART* architecture.

The adaptive backstepping approach offers a choice of design tools for accommodation of uncertainties nonlinearities. And can avoid wasteful cancellations. However, the not adaptive backstepping approach is capable of keeping almost all the robustness properties of the mismatched uncertainties. The not adaptive backstepping is a rigorous and procedure design methodology for nonlinear feedback control. The principal idea of this approach is to recursively design controllers for machine torque constant uncertainty subsystems in the structure and "step back" the feedback signals towards the control input. This approach is different from the approach of the conventional feedback linearization in that it can avoid cancellation of useful nonlinearities in pursuing the objectives of stabilization and tracking. A nonlinear backstepping control design scheme is developed for the speed tracking control of DFIG that has exact model knowledge. The asymptotic stability of the resulting closed loop system is guaranteed according to Lyapunov stability theorem.

The Backstepping control is a systematic and recursive design methodology for nonlinear feedback control. Applying those design methods, control objectives such as position, velocity can be achieved.

A nonlinear backstepping control design scheme is developed for the speed tracking control of DFIG that has exact model knowledge. The asymptotic stability of the resulting closed loop system is guaranteed according to Lyapunov stability theorem.

In this paper, we present a technique to control two power converters which is based on the backstepping control. We analyze their dynamic performances by simulations in Matlab/Simulink environment. We start by modeling of the wind turbine, and then a tracking technique operating point at maximum power point tracking (MPPT) will be presented. Thereafter, we present a model of the DFIG in the dq reference, and the general principle of control of both power converters which is based on backstepping technique, Finally, the principle of the implementation on the FPGA target and source program Xilinx System Generator, and the test benchmark for the experimental validation of the proposed model in my lab work.

Considering the complexity of the diversity of the electric control devices of the machines, it is difficult to define with universal manner a general structure for such systems. However, by having a reflexion compared to the elements most commonly encountered in these systems, it is possible to define a general structure of an electric control device of machines which is show in Fig. 1:

2. Modelling of the wind-turbine

The model of the turbine is modeled from the following system of equations [7,8]:

$$P_{incident} = \frac{1}{2}\cdot\rho\cdot S\cdot v^3 \tag{1}$$

$$P_{extracted} = \frac{1}{2}\cdot\rho\cdot S\cdot C_p(\lambda,\beta)\cdot v^3 \tag{2}$$

$$\lambda = \frac{\Omega_t\cdot R}{v} \tag{3}$$

$$C_p^{\max}(\lambda,\beta) = \frac{16}{27}\approx 0.593 \tag{4}$$

$$C_p(\lambda,\beta) = c_1\cdot\left(c_2\cdot\frac{1}{A} - c_3\cdot\beta - c_4\right)\cdot e^{-c_5\frac{1}{A}} + c_6\cdot\lambda \tag{5}$$

$$\frac{1}{A} = \frac{1}{\lambda + 0.08.\beta} - \frac{0.035}{1+\beta^3} \tag{6}$$

$$C_{al} = \frac{P_{eol}}{\Omega_t} = \frac{1}{2}\cdot\rho\cdot S\cdot C_p(\lambda,\beta)\cdot v^3\cdot\frac{1}{\Omega_t} \tag{7}$$

$$J = \frac{J_{tur}}{G^2} + J_g \tag{8}$$

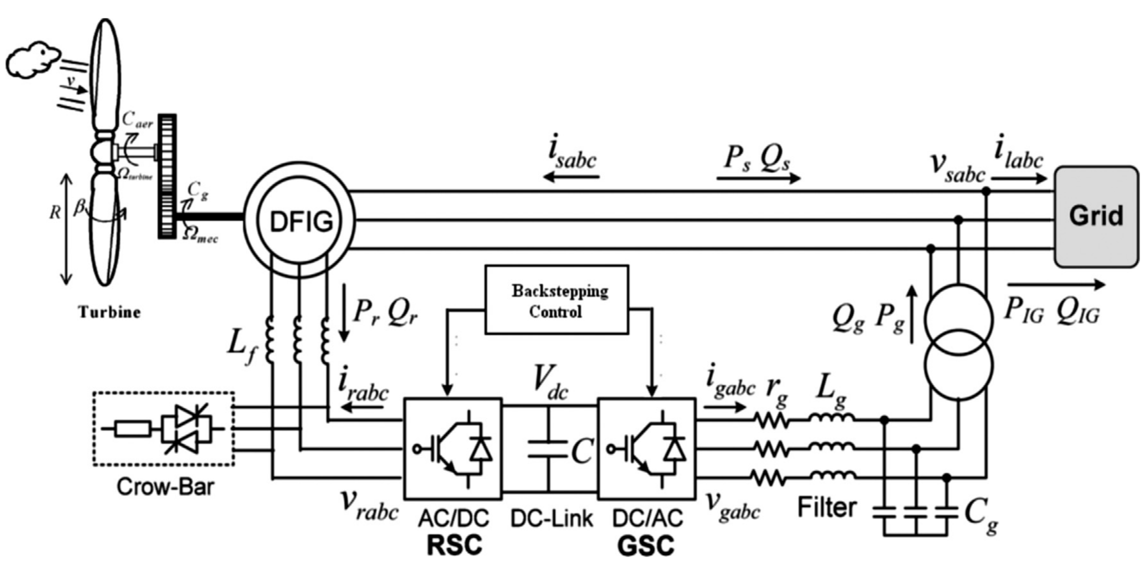

Fig. 1. Architecture of the control.