Computers and Mathematics with Applications 68 (2014) 2112–2123

Contents lists available at ScienceDirect

Computers and Mathematics with Applications

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

A wind energy generator for smart grid applications using wireless-coded neuro-fuzzy power control[☆]

C.E. Capovilla[a], I.R.S. Casella[a], A.J. Sguarezi Filho[a], J.L. Azcue-Puma[b,*], R.V. Jacomini[a], E. Ruppert[b]

[a] Universidade Federal do ABC - UFABC - Santo André, Brazil
[b] Universidade Estadual de Campinas - Unicamp - Campinas, Brazil

ARTICLE INFO

Article history:
Available online 13 August 2013

Keywords:
DFIG
Power control
Wind energy
Smart grid
Wireless communication
ANFIS

ABSTRACT

Wind energy is the major driver to obtain an optimized and efficient use of renewable energy in smart grids. To provide balanced supply, demand, and storage of energy in a much more efficient manner than is done today, smart grids require the employment of an advanced communication infrastructure associated to a robust power control and real-time monitoring systems.

Towards this objective, we present a wireless-coded power control scheme for doubly fed induction generators operating at variable speed. The proposed system employs adaptive neuro-fuzzy control, quaternary phase shift-keying modulation, and low-density parity check coding techniques to improve the system robustness and reliability in different propagation conditions for remotely transmitting the power control references from the control center to a given aerogenerator.

1. Introduction

Smart grids are an evolution of conventional power grids that use the infrastructure for generation, transmission, and distribution of energy in a more efficient way, in order to manage the relationship between energy supply and demand [1]. For an optimized operation, smart grids exploit a complete interconnected framework formed by communication networks, data management, and real-time monitoring and control applications [2].

Advances in wind power technology have greatly improved system integration issues. However, there are still some unsolved challenges in expanding its use. Due to the usual variations of the wind speed, wind utilization entails undesirable fluctuations in the generated power that, if not compensated in real time, can lead to frequency imbalance and disturbance in the stability of the electrical system. Although smart grids can minimize this problem through an efficient demand response for load control and dispatch of other generation resources, the use of variable speed aerogenerators and a precise power control system is still necessary.

Among existing aerogenerators, doubly fed induction generators (DFIGs) are the most widely employed in wind power systems [3], due to their interesting main characteristics such as, for instance, the ability to operate at variable speed and the

☆ This paper was originally submitted to the special issue "ICNC-FSKD12".

* Correspondence to: Av. Albert Einstein - 400. CEP: 13083-852. Campinas-SP, Brazil. Tel.: +55 19 3521 3720; fax: +55 19 3521 3866.
E-mail addresses: carlos.capovilla@ufabc.edu.br (C.E. Capovilla), ivan.casella@ufabc.edu.br (I.R.S. Casella), alfeu.sguarezi@ufabc.edu.br (A.J. Sguarezi Filho), azcue@ieee.org, jl.azcue@gmail.com (J.L. Azcue-Puma), rogeriovj@yahoo.com.br (R.V. Jacomini), ruppert@fee.unicamp.br (E. Ruppert).

0898-1221/$ – see front matter
http://dx.doi.org/10.1016/j.camwa.2013.06.030

capacity to control the active and reactive power into four quadrants by means of field orientation [4,5]. The precise power control of the aerogenerators is essential in order to maximize the generated power. The conventional proportional–integral (PI) [6] and proportional–integral–derivative (PID) [7,8] control techniques have been widely used as the core of different power control systems due to their simplicity of implementation. However, the design of these fixed gain control systems is very cumbersome, since they depend on the exact mathematical model of the generator. Also, they are very sensitive to disturbances, parameter variations, and system nonlinearities.

In contrast, the design of intelligent control systems based on computational intelligence (CI) does not require an exact mathematical model of the generator. Among CI techniques, fuzzy logic (FL), and artificial neural networks (ANNs) appear as powerful options for identification and control of nonlinear dynamic systems as power control systems. However, each of these intelligent techniques has its own drawbacks which restrict its use. For instance, FL suffers from some limitations such as the appropriate selection of membership functions (MFs), the adequate selection of fuzzy rules and, furthermore, how to adjust both of them to achieve the best performance. ANNs have also some limitations such as their black-box nature, the selection of the best structure and size, and the considerable training time to solve a specific problem. In order to overcome these problems, it is possible to use a hybrid neuro-fuzzy system [9] that can combine the learning capability of an ANN with the knowledge representation of FL based on rules. One of the most widely used neuro-fuzzy systems is the Adaptive Neural Fuzzy Inference System (ANFIS), proposed by [10]. It can use a hybrid learning procedure to construct an input–output mapping based on both human knowledge as fuzzy rules and approximate MFs from the corresponding input–output data pairs as ANN learning data.

Another very important issue in the deployment of smart grids is the application of a modern telecommunication system to guarantee effective monitoring and control of the grid. Nevertheless, its development and operability require a fairly complex infrastructure and present several non-trivial problems due to the convergence of different areas of knowledge and design aspects.

The use of wireless monitoring and control technologies for wind energy systems has become increasingly interesting from technical and economic perspectives, such as the low cost of development, expansion facilities, the possibility of using the technologies currently applied in mobile telephone systems, flexibility of use, and distributed management. However, it is worth noting that, although there are some works in the scientific literature referencing the use of wireless technology for monitoring wind energy systems in different scenarios [11–14], showing its advantages and potential applicability in the near future, there are no publications that suggest and investigate the use of wireless technology for wind energy control or propose techniques to improve the reliability and security of the transmitted monitoring and/or control information over the wireless channel. There also is no background information about the computational intelligence methods which are used tackle the similar explored topics.

On the other hand, the employment of wireless technologies for transmitting power control signals may cause apprehension due to the possibility of the occurrence of errors in the transmission process that can cause serious problems to the generators and, consequentially, to the energy system. Such behavior is different from what usually happens in telecommunication systems designed for voice and data transmissions, where small errors can be detected, initiating requests for retransmission (generating delays), or even, in some cases, can be ignored without any significant impact to the network.

Wireless digital communication techniques can be used to improve the robustness of the power control system and to minimize the mentioned problems through the application of forward error correction (FEC) [15]. FEC is a coding technique used in all current digital wireless systems and it is essential to ensure the integrity of information, significantly reducing the bit error rate (BER) and the latency of the information by adding controlled redundancy to the transmitted information [16]. In theory, the appropriate use of coding technology can offer the same reliability obtained by using fiber optic cables [17].

There are currently several different schemes of FEC that are used in commercial wireless communication systems [18–22]. Among them, low-density parity check (LDPC) is the one that presents the best performance and shows an excellent compromise between decoding complexity and performance [23,24]. The LDPC coding has recently been added to the IEEE 802.16e Standard, commonly known as Worldwide Interoperability for Microwave Access (WiMAX) for mobile applications [25].

In this context, this paper proposes and analyzes the performance of a wireless-coded adaptive neuro-fuzzy power control system for a variable speed wind DFIG, as presented in Fig. 1. The system is based on a discrete dynamic mathematical model of the generator and it uses the vector control technique to independently control the active and reactive power. The wireless communication system, employed to send the power reference signals to the DFIG controller, uses LDPC coding to reduce the transmission errors and the overall latency of the system. The performance of the system is investigated in a frequency flat fading scenario, to evaluate the real impact of the wireless transmission in the wind energy control system.

As a result, this paper aims to fill a gap in the literature by analyzing the operational performance of a wireless communication system when applied to a wind generation control system and by demonstrating the viability of its use for this type of application, if appropriate modulation and coding techniques are employed. It is noteworthy that the errors generated in the wireless transmission cannot be easily removed without using advanced FEC coding techniques similar to those presented in this work.

The paper is organized as follows. DFIG neuro-fuzzy power control is shown in Section 2; the wireless coding communication is presented in Section 3; main results are considered in Section 4; and Section 5 concludes the work.