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Review

A review on wind turbine control and its associated methods

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A B S T R A C T

Nowadays, the increasing environmental issues especially concerning the global warming have motivated a run for the use of renewable energy sources. Wind energy represents a major player in this context and today it is the most widespread renewable fuel, but still requires many technological improvements. The control of wind turbines (WTs) plays a key role in wind energy applications, ensuring their high efficiency and cost-effectiveness. This has been an intensively researched subject and its developments are crucial to design even better and more efficient wind turbines. However, currently very little papers are addressed to summarize and list wind turbine control concepts. In the present paper, a literature review of wind turbine control is presented dealing with the main wind energy control methods. The main objective of the paper is to form a detailed background to serve as a starting point for new researches on WT control that can be decisive to energetic sustainability. Further, the paper discusses the most recent control developments and their contributions to mitigate environmental issues.

Contents

1. Introduction

Wind is a renewable, clean and endless energy resource, which makes it very suitable to satisfy the increasing energy demand of

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many countries. Thereby, wind energy has experimented a strong growth worldwide, especially in the last two decades, and the total world installed capacity by the wind industry has changed from 1.29 GW in 1995 to 370 GW by the end of 2015 (GWEC, 2016). Due to environmental concerns and the continuous pursuit for energy security, this scenario should even increase in the next years, with more installed capacity and larger wind turbines (WTs). These machines have been evolving from simple designs towards complex multi-MW generation units, installed together in large arrays named “wind farms”. The complexity of modern WTs forces the control systems to be key components of a wind turbine to ensure safe and efficient operation of these sophisticated wind energy conversion systems (Manwell et al., 2010).

This happens because unlike other energy sources, the wind is not controllable. The wind flux is a strongly random process, variable both in time and in space. This variability leads to a difficult conversion of energy, as WTs are subjected to a non-uniform and transient resource, variable mechanical loads and non-linear dynamics. This is the why control systems are indeed very important for WTs. They make possible to cope with the wind variability to produce energy in a reliable and cost-effective manner. The main objectives of the control systems embedded in WTs are maximizing power production, mitigating dynamic and static mechanical loads and guaranteeing a continuous power supply to the grid, according to the utilities requirements. For achieving these goals, the WTs should have operational control systems dedicated to regulate turbine parameters to the desired set-points (Lubosny et al., 2007). The blade pitch angle and the generator torque are the major parameters to be controlled in WTs. Pitch angle control allows to control the wind input torque, in order to enable a smooth power production and to reduce the mechanical loads. On the other hand, the generator torque control allows to vary the WT rotor speed following a Maximum Power Point Tracking (MPPT) strategy, for extracting as much power as possible from the wind flux.

Furthermore, the WTs should also have a control of grid integration to control the power delivered to the grid, to provide a well-conditioned electrical power supply. This is necessary because grid integration of WTs becomes a complex task due to the random nature of the wind, which can cause problems to grid frequency stability (Yingcheng and Nengling, 2012).

Each one of the above cited control systems (pitch control, generator torque control and grid integration control) has its own technology and methods to be realized, which depend on the WT operational regimes and their respective control objectives. Although there are some specific pitch control and MPPT torque control (Abdullah et al., 2012) and grid integration reviews in the literature (Yingcheng and Nengling, 2011), review papers dealing with the main WT control issues simultaneously are very little reported. Addressing methods for MPPT torque control, WT pitch control and grid integration control in a same paper must be accomplished to construct a general background of invaluable use for future research developments. With the aim of bridging this gap, this review paper presents a literature review of WT control dealing simultaneously with the main WT control systems. The objective consists in making easier the development of future researches on WT control in order to contribute to a more sustainable electrical power generation. Further, once the WT control systems have been analyzed, the paper concludes with a discussion regarding the WT control technology, pointing the future trends that should be applied to improve the wind turbine efficiency, reliability, cost-effectiveness and grid integration. These are mandatory issues to strengthen the wind energy as a renewable and clean energy source.

2. Methods

A systematic search of scientific literature was carried out to cover all the aspects and research trends of wind turbine control systems. The main information sources were online scientific databases, even though some classical wind energy books were also consulted to provide a general overview. The online checked scientific databases included the Science Direct, Research Gate and mainly the CAPES Journal Portal, the official scientific search engine of the Brazilian government. The CAPES Journal Portal provides access to more of 37.000 peer-reviewed scientific journals, 66 research bases of thesis and dissertations, 11 research bases of patents and 31 research bases of e-books.

The inserted keywords include “wind turbine control”, “control of wind turbines”, “MPPT methods”, “MPPT strategies”, “pitch control”, “wind turbine pitch control” and “grid integration of wind turbines”. In a such vast universe of research, an enormous number of papers were found. Some general criteria have been adopted for each first search with a specific keyword, in order to filter the preliminary results. They are: i) papers must be published only in English, in peer-reviewed journals or in recognized high-quality and traditional conferences about wind energy; ii) papers must be focused specifically on wind turbines and general papers about control must be discarded; iii) papers must deal with one of the following WT control issues: MPPT strategies, pitch control and grid integration.

The research has resulted a total of 262 selected papers, including many different WT control issues. Due to space constraints, this number must be reduced to environ 100 papers. To select these, all the papers were analyzed and read carefully to choose the ones most relevant. Afterwards, papers were classified in three categories, according to the main control problem approached: i) WT generator torque control and MPPT strategies; ii) WT pitch control; iii) Grid integration control for frequency regulation. Each category is approached in a specific section of this paper.

3. Control objectives and operational regions of WTs

The control objectives of WTs determine the moment of operation of each WT control system and must be clearly established to avoid misunderstanding in analyzing the WT control methods. The definition of control objectives is dependent on the wind turbine operational regions. These are closely related to the wind speed and one can identify three operational regions according to the wind speed (Burton et al., 2011). In the so-called Region 1, below the cut-in wind speed, there is no production of electrical power, as the wind speed is too low and the produced power would not compensate the losses in the turbine operation. In this operational region, the turbine should be stopped or in idle mode. Region 2, between the cut-in and the rated wind speed, has an increasing power production as the wind increases progressively. In Region 2 the WT is in the partial-load regime. In Region 3, wind reaches rated speed and WT enters in full-load regime. Power production must be limited to the WT rated power, for ensuring operation within the safety limits of generator speed and WT mechanical loads. Some authors also identify a Region 2.5, where the WT rotor has achieved rated speed but the torque is still below its rated value (Aho et al., 2013). One can also consider the additional Region 4, after the cut-out wind speed, where the WT must be switched off due to the very high wind regimes.

The power extracted from the wind can be expressed according to Eq. (1) (Rohatgi and Vaughn, 1994):