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Advanced control for wind energy conversion systems with flywheel storage dedicated to improving the quality of energy

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ABSTRACT

In this article presents two techniques of commands DTC (direct torque control) and DPC (direct power control) applied in the system of converting wind energy with storage. The wind generator used is based on a double fed induction generator (DFIG) where the stator is linked directly with the network and the rotor is connected to the network through the power converter. The flywheel energy storage system (FESS) based on a flywheel, an induction machine (IM) and an electronic power converter is associated with the wind generator via the DC bus. The two converters side DFIG and the (FESS) are controlled by the DTC. The three-level converter side electricity grid which ensures constant DC bus voltage is controlled by the DPC, in order to mitigate the wave quality problems. In the literature, this control strategy has been frequently used for the two levels converter. The direct control of these systems has a purpose of eliminating the block of pulse width modulation and loops of regulations internal controlled variables, which gives a faster response. The use of switching table makes the system more efficient from the technical and economic view. A maximum power tracking technique «Maximum Power Point Tracking» (MPPT) and a pitch angle control strategy are presented. The model of the complete system is developed in Matlab/Simulink/to analyze from the simulation results the integration of wind chain to electric networks.

Introduction

Meeting the energy demand is a worldwide daily problem which keeps increasing more and more. The rapid boost in industrial activity in the developed countries and business investment in countries that provide a lower production cost rapidly augment the global demand for energy. This increase is reflected in reality by an oil price increase that represents the most important source of energy. World reserves of oil

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decreases more and more and in the following years there will not be enough oil to cover the demand. The climate of the earth is worsening and the natural water sources are becoming scarce. Nuclear power is not available to everyone for political or financial reasons; its installation is expensive and can be ecologically dangerous. The use of these conventional sources is then limited or is not encouraged for causes related to the environment. For all these reasons the world is heading towards the sources of clean and renewable energy such as wind power. This latter is today the Clean Energy less costly to produce, which explains the strong enthusiasm for this technology [1–3].

Wind turbines whose operation is based on a doubly fed induction generator are widely recognized in the industry as one of the most promising wind turbine configurations [4]. Indeed, the latter allows functioning variable-speed wind turbine which gives the possibility to produce the maximum possible power on a wide range of variation of the wind speed. Furthermore, static converters are used to control the machine which can be designed to pass only a fraction of the total power (which represents the power of sliding) [5].

The need to control wind turbines goes back to their origins of use. The main purpose was the limitation of the power and the rotational speed of the turbines to protect them from strong winds [6]. At present, wind turbines have become larger in size and power, demanding control specifications and more sophisticated regulatory mechanisms. In addition to that, it was expected that not only control systems keep the turbine in its safe operating area, but also improve the efficiency and quality of energy conversion which requires a more precise modelling and more demanding and different control techniques for each range of wind speeds, low, medium or high. Controlling a variable speed wind turbine is divided into two parts: the control mechanism by means of the pitch angle of the blades and the control of the electric machine via the power electronics. Currently, the strategies are designed to extract maximum power from the wind. This power is extracted when the turbine operates at maximum power coefficient. Using the MPPT (Maximum Power Point Tracking) strategy that automatically adjusts the specific rate at its optimum value, so as to obtain the maximum power coefficient [7–9]. However, in the case of significant wind, it is necessary to degrade a part of the kinetic power to avoid damage to the turbine as well as the electrical machine. The speed limitation is obtained with the control of the pitch angle. When the speed of the wind becomes too serious and great, the pitch angle increases so as to reduce the turbine speed and limit the power generated at the rated power [8,10,11]. The turbine control designed then to optimize the power extracted from the wind when the wind speed is less than its face value and to limit the electrical power when the wind speed is greater than the nominal value [12].

The penetration rate of wind power is limited to less than 30%. To overcome this drawback, generation distribution must contribute to system services such as the adjustment of the frequency, voltage, reactive power, the ability to self-start and islanding operation. Due to the highly fluctuating and unpredictable nature of the wind, wind alone can not participate in services systems [13]. It is necessary to add systems of generation or storage of energy to allow having an additional reserve. To ensure the generation/consumption balance, a storage system inertial type is included. There are several reasons for this choice: good momentum, good performance and life duration similar to the wind turbine, etc [14,15].

Nevertheless, with the continuous development in the field of power electronics that allows us to develop several systems in order to improve the power quality and reduce the harmonics generated by the converters of power electronics. Today, in addition to the main function thereof, existing regulations impose an additional condition of good power quality. Several techniques have been employed in the control of these converters [16–18]. In this article, we present two techniques of commands DTC (direct torque control) and DPC (direct power control), applied to the system for converting wind energy with storage. These are very competitive as they attract the attention of various researchers in order to achieve a successful order that meets the modern industrial requirements.

The first figure (Fig. 1) shows the configuration of the selected generation system. In this article, we begin by modelling the wind turbine; its variable speed control will be elaborated. The objective is to maximize the power generated by the turbine when the wind speed is below its nominal value. When the wind speed exceeds its nominal value, the blades will be commissioned in order to limit the electrical power to its nominal value. Then, we discuss the direct control technique of torque and flux of the DFIG, torque and rotor flux are used to control, in an indirect way, the active and reactive powers respectively. After that, the flywheel Energy Storage System will be modelled. The DTC control of FESS is based on the same principle as that applied to the converter side rotor of the DFIG. Subsequently, a new approach of the DPC technical control of converter network side is considered this time at three levels, in order to mitigate the wave quality problems, developed by analogy with the direct torque control (DTC) of electrical machines is presented. We describe the principle of direct control of instantaneous power, the estimation technique of the line voltage and the development of the switching table. Lastly, the model of the complete system is developed in Matlab/Simulink in order to analyze from the simulation results the integration of wind turbines based in the DFIG in the electricity networks. The effectiveness of the suggested strategies of control is assessed by the results of simulations.

Wind turbine model

The aerodynamic torque produced by the wind turbine is given by.

$$T_{aer} = \frac{P_{aero}}{\Omega_t} = \frac{1}{2\Omega_t} C_p(\lambda,\ \beta) \cdot \rho \pi R_t^2 \upsilon^3 \tag{1}$$

Where ρ is the air density, v is the wind speed, and R_t is the turbine radius, Ω_t is the angular velocity of wind turbine. The power coefficient Cp is a function of the speed ratio λ and the pitch angle of the blades β (Fig. 2). In this work, it is given by the expression [19].