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A proposed strategy for power optimization of a wind energy conversion system connected to the grid

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ABSTRACT

Many strategies have been developed in last decade to optimize power extracted from wind energy conversion system where many of them can produce only 30% more than the rated power. With the considered strategy, the generated wind power can reach twice its nominal value using a fast and reliable fully rugged electrical control. Indeed, by employing a suitable control technique where the produced power in super-synchronous mode is derived from both the stator and the rotor. Also, the rotor provided power in this case grows up 100% comparing to stator rated power. However, this solution permits to maintain the wind energy conversion system operation in its stable area.

The considered system consists of a double fed induction generator whose stator is connected directly to the grid and its rotor is supplied by matrix converter. In this paper, the sliding mode approach to achieve active and reactive power control is used. This latter is combined with de Perturbation and Observation Maximum Power Point Tracking used in the second operation zone. The obtained simulations results are assessed and carried out using Matlab/Simulink package and show the performance and the effectiveness of the proposed control.

1. Introduction

Due to its advantages, wind energy attracts many researchers in the last decade. Some authors focused their research on problems relating to the storage of this energy like John and David who led a study on probabilistic energy storage and its use with intermittent renewable energy [1]. Xiaosong et al. made comparative study of three electrochemical energy buffers applied to a hybrid bus Powertrain with optimal sizing and energy management [2]. Others are more interested in improving the quality of energy produced and injected into the grid and working on models and various control techniques. In [3], the authors propose a model to control a wind turbine associated with a flywheel energy storage system to improve the quality of power injected into the grid. In [4], a grid power flux control of a variable speed wind generator which consists of a doubly fed induction generator is investigated. A new control strategy for small wind farm is proposed in [5] to improve supplying reactive power and transient stability. To avoid strong transients in the turbine components, a cascaded nonlinear controller is designed in [6] for a variable speed wind turbine equipped with a doubly fed induction generator. In [7], authors proposed a control method for a doubly fed induction generator used in wind energy conversion systems. Three different controllers are presented: proportional-integral, polynomial RST and linear quadratic Gaussian. As an alternative to conventional methods, a nonlinear predictive control approach is developed for a doubly fed induction generator in [8]. In [9], authors presented the design and the implementation of a model reference adaptive control. The active and reactive power regulation which is achieved below synchronous speed of a grid connected wind turbine based on a doubly fed induction generator is investigated. To reduce the total harmonic distortion and enhance power quality during disturbances, an unconventional power electronic interface for a wind energy conversion system is presented in [10]. Other researchers have exploited the advantages of matrix converters which are better adapted to the AC/AC conversion over the classic converter topologies as back to back converters. Indeed, in [11] a grid connected wind power generation scheme using a doubly fed induction generator with a direct AC/AC matrix converter is presented. To reduce large active and reactive power ripples which is one of the main drawbacks on conventional method, a new strategy is developed in [12] for a matrix converter-fed doubly fed induction generator. In [13], authors investigated a three-level sparse matrix converter associated to a grid connected variable speed wind generation scheme using a doubly fed induction generators.

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Nomenclature

v_{wind}	wind velocity
ρ	air density
R	turbine radius
C_p	power coefficient
λ	tip speed ratio
λ_{opt}	optimal tip speed ratio
β	blade pitch angle
T_t	turbine torque
f	coefficient of viscous friction
Ω_{mec}	mechanical speed
Ω_{mec_opt}	optimal mechanical speed
G	gear ratio
P_{wind}	wind power
P_{mec}	mechanical power
P_{mec_opt}	optimal mechanical power
P_s	stator active power
P_r	rotor active power
P_g, P_{g_ref}	grid active power and it's reference
v_a, v_b, v_c	input voltage of the MC
Q_s, Q_{s_ref}	stator reactive power and it's reference
Q_r	rotor reactive power
Q_{rg}	reactive power from the converter grid side
T_{em}	electromagnetic torque of the DFIG
σ	the leakage coefficient
R_s, R_r	per phase stator and rotor resistances
L_s, L_r	total cyclic stator and rotor inductances
L_m	magnetizing inductance
$\varphi_{sd}, \varphi_{sq}, \varphi_{rd}, \varphi_{rq}$	two-phase stator and rotor fluxes
$v_{sd}, v_{sq}, v_{rd}, v_{rq}$	two-phase stator and rotor voltages
$i_{sd}, i_{sq}, i_{rd}, i_{rq}$	two-phase stator and rotor currents
P	number of pole pairs
η	generator efficiency
s	generator slip
ω_s	stator angular speed
ω_r	rotor angular speed
ω	angular speed
$S_{ij}(t)$	switch function
v_A, v_B, v_C	output voltage of the MC
i_A, i_B, i_C	output current of the MC
Ω_N	nominal speed of DFIG
WECS	wind energy conversion system
MC	matrix converter
DFIG	doubly fed induction generator
SMC	sliding mode control

Other researchers are interested on the study of wind generators themselves to improve their performances. Indeed, several studies have used different control strategies in order to optimize the extracted power from variable speed wind turbine. In [14], an autonomous induction generator driven with a wide speed range turbines controlled by the strategy of saturation effect compensation is presented but the maximum speed using this strategy does not exceed 13% of the rated speed.

Unconventional converter is proposed in [15]. To improve the used conversion energy system, the proposed converter has been connected to the rotor of the doubly fed generator with a fraction equal to 30% of the total power. This explains that, the generator speed does not exceed 30% in excess of the synchronism speed. A high dynamic control of a generator with the speed range up to 20% is developed in [16]. A nonlinear robust control system technique for converting wind energy is performed in [17]. However, once again, the speed does not exceed 30% of its nominal value. In all above cited research works, the rated power and speed have been dealt with improving the generated power quality, with out exceeding 30% of rotor rated power. Yong et al. conducted a very interesting work where they have operated a double stator induction machine to reach the speed up to twice the nominal value [18]. But the maximum power extracted using their system do not have been doubled since one of the generator stators is controlled by static excitation. A solution to double a rated power at a double speed, is proposed in [19]. However, the system is entirely grid interfaced, ie requiring two power converters. In this context, the present deals and focuses on improving the performances of a WECS based on DFIG, using one power converter, expanding the speed variation range and arriving to extract a power that can reach the twice the rated power. Obviously, this cannot be done without taking into account the electrical and mechanical constraints related to the wind turbine operation in the range of high speeds. For this, we proceed as follows: When the turbine torque is less than its nominal value the MPPT algorithm is applied. Otherwise, the MPPT strategy is stopped and limits the turbine torque at its nominal value. Several MPPT algorithms are proposed in the literature. The most used is that named Perturbation and Observation (P&O). It is to note that it was always used in the Zone-I. In our case, an extension to the Zone-II is performed to taking into account the above-cited electrical constraints. Consequently, the stator power is also fixed, leaving the turbine speed increase above its synchronous value and the rotor becomes a generator of electric power that increases and reaches its nominal value when the turbine speed is doubled. Thus, the power generated by the rotor is added to that of the stator that are injected to the grid. In terms of control techniques, the sliding mode control, which is a robust and reliable approach is suitable and gives an added value to WECS based on DFIG. In [20] one found the impact on the active and reactive powers values is important for PI controller where as it is almost non-existent for SMC controller. In [21] sliding mode control strategy is used for tracking power photovoltaic system. In [22], robustness is tested with the respect the uncertainties parameters. Thus, the SMC is chosen as a control technique for the studied system. The global system, represented in Fig. 1, is modeled and simulated under Matlab/Simulink and the obtained simulations results are presented to prove the validity of the proposed strategy.

2. Proposed system

The proposed system consists of (*WECS*) based on a DFIG of 1.5 MW supplied by a matrix converter and connected to the grid (Fig. 1). An optimization program, based on the Perturbation and Observation (*P&O*) method is used to determinate the optimal values of power and speed which will be used in the control of active and reactive power. This control is achieved using sliding mode controller (*SMC*). The matrix converter is dimensioned at 100% of rated power generator. The wind turbine is designed to operate in over rated speed.

3. Modeling of the global system

3.1. Wind generator modeling

3.1.1. Modeling of the wind turbine

The power available and recoverable from the turbine is expressed by the following relationship [23]: