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A stand-alone wind power supply with a Li-ion battery energy storage system

Tedjani Mesbahi [a,*], Ahmed Ouari [a], Tarak Ghennam [b], El Madjid Berkouk [c], Nassim Rizoug [d], Nadhir Mesbahi [a], Moudrik Meradji [b]

[a] Department of Electrical Engineering, Faculty of Sciences Engineering, Badji Mokhtar-Annaba University, P.O. Box 12, 23000 Annaba, Algeria
[b] Laboratoire d'Electronique de Puissance (LEP), UER: Electrotechnique, Ecole Militaire Polytechnique d'Alger, BP 17, Bordj EL Bahri, Alger, Algeria
[c] Laboratoire de Commande des Processus (LCP), Ecole Nationale Polytechnique d'Alger, BP 182, 10 Avenue Hassen Badi, 16200 el Harrach, Algeria
[d] Ecole Supérieure des Techniques Aéronautiques et de Construction Automobile, France

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A B S T R A C T

The improved structure of stand-alone wind power system which is presented in this paper based on a doubly fed induction generator (DFIG) and permanent magnet synchronous machine (PMSM). A Li-ion battery energy storage system is used to compensate the inherent power fluctuations (excess or shortage) and to regulate the overall system operation based on a power management strategy. The modeling and the control of a DFIG for stand-alone power applications are detailed. However, the magnitude and frequency of the DFIG stator output voltage are controlled under variable mechanical speed. This task is ensured via the control of *d* and *q* components of the rotor flux by means of a back-to-back pulse width modulation (PWM) converter connected to the rotor side of the DFIG. The PMSM is coupled mechanically to the wind turbine and supplies a required power to the PWM converter in order to regulate the dc bus voltage to the desired value.

In order to validate the proposed stand-alone wind power supply structure both a theoretical system analysis and a complete simulation of the overall wind energy conversion system (WECS) with Li-ion battery energy storage system is carried out to prove the performances of the control strategy.

Contents

* Corresponding author. Tel./fax: +21 338875398.
E-mail address: tedjani.mesbahi@estaca.fr (T. Mesbahi).

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1. Introduction

Wind power and photovoltaic driven stand-alone systems have turned into one of the most promising ways to handle the electrification requirements of numerous isolated consumers worldwide [1]. These off-grid wind turbines or photovoltaic power systems help in reducing the stress on the grid, diminish the pollution and save on fuel cost by reducing or even eliminating the need for diesel generators, which consume a lot of polluting fuel [2,3]. Therefore, the implementation of stand-alone power systems can handle the rural electrification imbroglio effectively by providing environmentally benign, sustainable and reliable energy supply [4,5].

In recent years, the isolated grid and embedded applications (electric aircraft) used stand-alone wind power supply based on control of variable speed constant frequency (VSCF) generators has become a very important research topic [6–8]. However, many studies and evaluations about wind energy power potential were conducted in many European countries and America to develop wind energy power projects [9].

In this way, some stand-alone wind generation systems, where squirrel cage induction machine is used, are capable to regulate the output voltage magnitude but only at a variable frequency [4]. Others systems are able to achieve voltage magnitude and frequency regulation under variable speed thanks to the use of a PWM converter between the PMSM generator and the load [10]. Preceding from the last power wind architecture, Serra et al. [11] proposed a configuration consists of a rectifier followed by a dc/dc converter and a voltage source working as an inverter with an output filter. This wind power system is controlled in order to generate an output voltage with constant amplitude and frequency, irrespective of the supplied load.

Wang et al. [12] used in his study a hybrid wind-microturbine generation (MTG) distributed generation system that incorporates power electronic interfacing circuits for stand-alone operation.

Recently, the DFIG has been widely applied to wind energy conversion systems. The most important benefit of the DFIG is the small rate of power converter compared to the nominal power of machine (around 30%), so it can be used in high power applications in both grid and stand-alone mode [13].

In this context, the DFIGs are attracted attention as sources of constant frequency generators from variable speed movers [14,15]. In the rotor circuit, the speed range can be extended above synchronous speed and power can be generated both from the stator and the rotor. An advantage of this type of DFIG wind power is that can be operated under variable wind speed [15].

This paper presents an improved structure of stand-alone wind power system based on DFIG and PMSM. Nevertheless, the control strategy of our system developed for the purpose of regulating the rms value of the DFIG stator output voltage to 220 V and a nominal frequency at 50 Hz. The rotor of the DFIG is fed by both PMSM and Li-ion battery energy storage system via a PWM converter [16,17]. The control strategy of the DFIG uses a vector control scheme based on a d,q synchronous reference frame. The stator-flux vector is aligned with d-axis of the synchronous frame allowing by decoupled active and reactive powers control [15]. Two independent control loops are used; the first one is devoted to the stator voltage control while the second is dedicated to the rotor flux control. In a stand-alone wind power system the energy management strategy dispatches the power between the principal components of our system [7,18]. Many studies have been done on management strategies of wind energy conversion system [7]. Where, the authors propose a various management methods with different algorithms depend to the operating mode. For our case, a simple energy management strategy used to smooth wind power fluctuations by the Li-ion battery energy storage system.

The rest of this paper is organized as follows. The WECS system is briefly described in Section 2. The WECS model is discussed in Section 3. Section 4 presents the control of the WECS in isolated mode. Simulation results are presented in Section 5 to evaluate the proposed configuration and control. Finally, the conclusions are given in Section 6.

2. WECS description

Fig. 1 shows the simplified diagram of the power system based wind power generation in isolated mode. It consists of a wind turbine, a gearbox, a DFIG, a back-to-back PWM converter and a PMSM. Basically, the stator of the DFIG is directly connected to an isolated load where as its rotor is interfaced by a variable frequency power converter to cover a wide operation range from low to high power and assures the regulating of the stator voltage magnitude and constant frequency by controlling the rotor flux components [19]. The second PWM converter regulates the dc bus voltage by using the power generated from the PMSM [20].

3. WECS model

3.1. Modeling of the wind turbine and gearbox

The aerodynamic power P_{wind}, which is converted by a wind turbine, is related to the power coefficient C_p by the following equation [18,21,22]:

$$P_{wind} = \frac{1}{2} C_p(\lambda,\beta)\rho\,\pi\,R^2 V^3 \tag{1}$$

The wind turbine torque presents the ratio of the output power to the turbine speed Ω_t:

$$T_{aer} = \frac{P_{wind}}{\Omega_t} \tag{2}$$

The turbine is generally coupled to the generator through a gearbox whose gear ratio G is chosen somehow to set the generator shaft speed within a desired speed range. By neglecting the transmission losses, the torque T_g and shaft speed Ω_{mecref} to the generator side of the gearbox, are given by the following equation:

$$T_g = \frac{T_{aer}}{G} \text{ and } \Omega_t = \frac{\Omega_{mec}}{G} \tag{3}$$

A wind turbine can convert just certain percentage of the captured wind power. This percentage is represented by a coefficient $C_p(\lambda)$ that depends on the wind speed, turbine speed and