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Experimental study of variable speed wind generator contribution to primary frequency control

M. El Mokadem [a], V. Courtecuisse [a], C. Saudemont [a], B. Robyns [a,*], J. Deuse [b]

[a] National Center of Technological Research (CNRT FUTURELEC), Laboratoire d'Electrotechnique et d'Electronique de Puissance (L2EP), Ecole des Hautes Etudes d'Ingénieur, 13 rue Toul, 59046 Lille Cedex, France
[b] Suez, Tractebel, Avenue Ariane 7, B-1200 Brussels, Belgium

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ABSTRACT

The work presented in this paper analyses, with the help of experiments on a 2.2 kW test bench, the possibility to participate in the primary frequency control with a variable speed wind generator. A power reserve is obtained with the help of the generator torque control by following a power reference value lower than the maximum power which must be extracted from the wind. This approach allows also using a part of the kinetic energy in the blades inertia to contribute to this reserve.
The dynamic tests carried out on the test bench, by using medium and high variable wind speeds, confirm the capacity of the wind turbine generator (WTG) to participate in the primary frequency control.

1. Introduction

The electricity market liberalization and the development of the decentralised, renewable generation lead to many new scientific and technical questions. The major concern experienced with decentralised energy resources, and particularly renewable energy ones, is their limited abilities for contributing to power system management. Particularly, large amount of wind energy resources in the energy mix will necessarily cause problems for the overall system "stability". When considering the wind power impact on grid frequency, it is important to make a clear distinction between

- the wind power impact on the grid;
- and the required behaviour of wind generators for dealing with different network events, like the sudden loss of generating units or the fluctuation of significant loads in the system.

The unpredictable and highly fluctuating wind generation can have consequences in terms of frequency "stability"; on the one hand, the sudden change of generated power can lead to unacceptable frequency variations. On the other hand, difficulties in forecasting the energy production make network management more challenging [1].

Refs. [2,3] show the importance of system inertia. The system inertia plays an important role as it determines the sensitivity of system frequency under power unbalancing; the lower the system inertia, the higher the rate of change of frequency when load variations or generation variations appear. Classical wind turbines are characterized by lower inertia than classical power plants. Further, some variable speed turbine technologies use back-to-back power electronic converters for the grid connexion. The intermediate DC voltage bus creates an electrical decoupling between the machine and the grid. Such decoupling leads to an even lower participation of wind turbines to the system stored kinetic energy. This can be compensated by suitable implementation of the machine control. In the case of variable speed wind generator, Refs. [4,5] propose using the kinetic energy storage system (blade and machine inertia) to participate in primary frequency control. But releasing or storing kinetic energy can only be considered as a part of primary control. Indeed, the wind persistence being limited, this power reserve cannot be guaranteed further to short-term.

Ref. [5] proposes also to maintain a power reserve with the help of the pitch control when the wind generator works at a power close to the rated power.

In this work, the power reserve is obtained with the help of the generator torque control by decreasing the turbine power efficiency. This approach allows also to use a part of the kinetic energy in the blade inertia to contribute to this reserve. The pitch control allows to limit the turbine speed.

The possibility to participate in the primary frequency control is analysed with the help of experiments on a test bench which

* Corresponding author. Ecole des Hautes Etudes d'Ingénieur (HEI)-13, rue de Toul, F-59046 Lille Cedex, France. Tel.: +33 (03) 28384858; fax: +33 (03) 28384804.
E-mail addresses: mostafa.el-mokadem@hei.fr (M. El Mokadem), benoit.robyns@hei.fr (B. Robyns).

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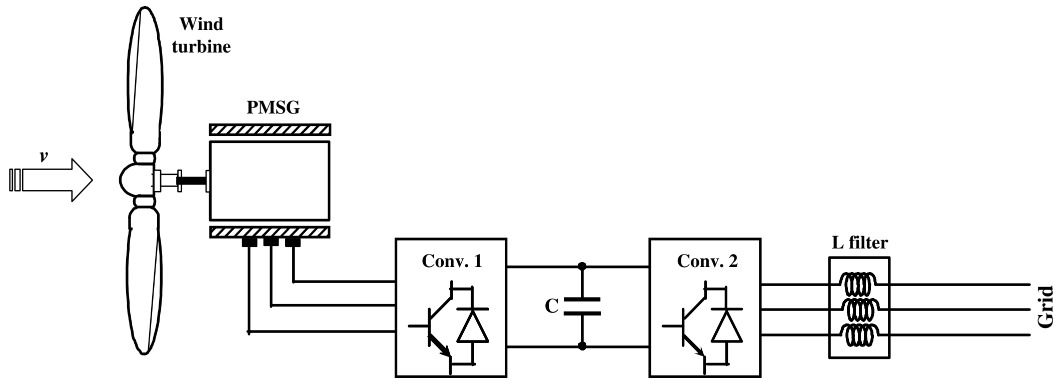

Fig. 1. Variable speed wind generator considered in this paper.

emulate a variable speed wind generator based on a permanent magnet synchronous generator.

In Section 2, wind turbine model, maximum delivered power and primary frequency control strategies will be presented. The implementation of this control strategy in the test bench will be described in Section 3. In Section 4, experimental results, obtained by considering different wind speeds, confirm the possibility to participate in primary frequency control with variable speed wind generators under certain wind conditions.

2. Wind turbine generator (WTG)

A type of electrical machine used more frequently in wind turbine applications is the permanent magnet generator. It does not need any excitation system and then is well adapted to contribute to ancillary services like voltage and frequency control and to work in islanding mode [6]. It is usually used in direct drive. The main difference from standard machines is that they are built with a sufficient number of poles that the generator rotor can turn at the same speed as the wind turbine rotor. This eliminates the gearbox. To operate at different wind speeds or to extract the maximum available wind power, the direct drive generators in wind turbines are frequently used in conjunction with power electronic converters [1,7]. Fig. 1 shows the scheme of the variable speed wind generator considered in this paper.

2.1. Wind turbine modelling

The wind turbine mechanical power is given by

$$P_t = \frac{1}{2}\left(\rho S C_p v^3\right) \tag{1}$$

with ρ the air density (kg m^{-3}), S the rotor surface area (m^2), v the wind speed (m s^{-1}) and C_p, the power coefficient.

Fig. 2 shows an example of power coefficient C_p for a variable pitch wind turbine, as a function of the speed ratio λ and pitch angle β [1,7,8]. The speed ratio λ, is given by

$$\lambda = \frac{R_t \Omega_t}{v} \tag{2}$$

with R_t the turbine radius (m) and Ω_t the mechanical turbine speed (rad s^{-1}).

The turbine torque is obtained by dividing Eq. (1) by the shaft rotation speed Ω_t

$$T_t = \frac{P_t}{\Omega_t} = \frac{\rho S C_p v^3}{2\Omega_t} \tag{3}$$

The introduction of the speed ratio λ in Eq. (3) leads to the expression (4)

$$T_t = \frac{\rho S C_p v^2 R_t}{2\lambda} \tag{4}$$

or

$$T_t = \frac{1}{2}\left(\rho \pi R_t^3 C_m v^2\right) \tag{5}$$

with

$$C_m = \frac{C_p}{\lambda} \tag{6}$$

2.2. Maximum delivered power (MDP)

The main control objective of variable speed wind turbine generator is power efficiency maximization. To achieve this goal the turbine tip-speed-ratio should be maintained at its optimum value, λ_{opt}, for different wind speed values. Nevertheless, control is not always aimed at capturing as much energy as possible. In fact, above rated wind speed, the captured power needs to be limited or decreased by using the pitch control [9].

To extract the maximum available wind power, the permanent magnet synchronous generator torque is imposed to follow the wind turbine torque calculated versus the available wind speed.

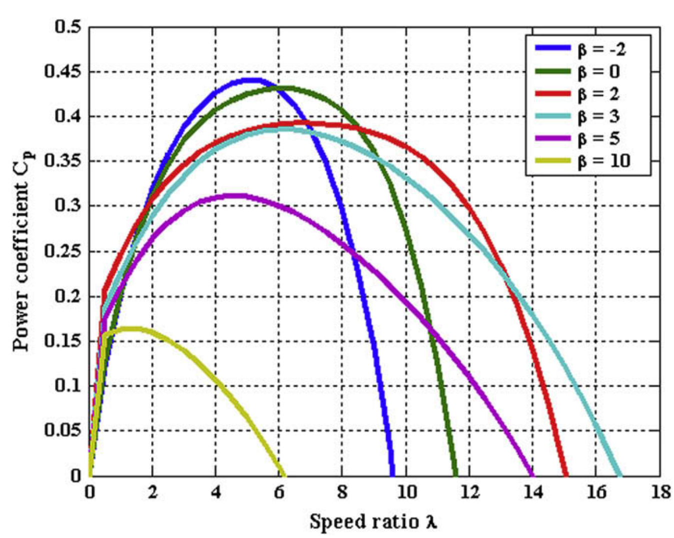

Fig. 2. Static power coefficient characteristic versus speed ratio and pitch angle.