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Study of a double fed induction generator using matrix converter: Case of wind energy conversion system

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ABSTRACT

Due to the growing of the power electronics, especial attention has been given to the use of new generation of power converters, AC/AC matrix converter to which provide a direct power converter AC/AC, bi-directional power flow, almost sinusoidal input and output waveform. In this paper, we present the performance study of a variable-speed wind turbine based on doubly fed induction generator fed by matrix converter using the maximum power point tracking method to extract the maximum power available. The whole system is presented in d-q-synchronous reference frame. The control scheme is tested and the performances are evaluated by simulation results. The simulation results obtained under MatLab/Simulink show the effectiveness and validity of the considered control.

Introduction

Starting from the principle of Lavoisier: Nothing is lost, nothing is created, everything is transformed. Energy is the motor of natural phenomena, it can be transformed from one form to another. Wind energy is one of the cleanest sources of energy because while producing electricity it does not generate any gas greenhouse effect, does not degrade air quality and does not pollute soils or water. Furthermore, it does not produce toxic or radioactive waste [1–5]. Nowadays, Owing to the increasing pollution of environment and atmosphere, huge efforts have been made in promoting the wind energy conversion systems WECS to reduce costs and increase reliability and robustness [6]. Indeed, it exists several WECS which allow transforming the wind kinetic energy into electrical energy. In this work, the WECS is constituted, principally, of a turbine, a gearbox and a doubly fed induction generator (DFIG). The DFIG is connected directly to the grid via its stator but also via its rotor by means of matrix converter (MC) to allow an exchange of energy between the network and the DFIG at the synchronism speed. Wind turbine is a mechanical device, it ensures the conversion of the kinetic energy into mechanical energy, there after it will be converted to electrical energy by coupling a generator to the wind turbine. Nowadays, in the field of renewable energies, several types of electric machines are used as generators in wind energy conversion systems [6–8]. Therefore, the study of double fed induction generator (DFIG) has regained importance because it has become the most popular generators for wind energy

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applications. The converter consists of nine bi-directional switches, arranged as three sets of three so that any of the three input phases can be connected to any of the three output lines. There is now competition between the matrix converter and the voltage source inverter with a regenerative input rectifier [9]. The MC is widely used in large wind farms, and this for its many advantages: direct power converter AC/AC, bi-directional power flow, quasi sinusoidal input and output waveform, and allows to control: the rotor currents magnitude, frequency and input power factor [10–12]. Moreover, the use of matrix converter instead of two converters allow the reduce of maintenance, cost and number of components used in conventional systems [13]. The wind turbine can be operated at the maximum power operating point (MPPT) for various wind speeds by adjusting the shaft speed optimally to achieve maximum efficiency at all wind velocities [14–16]. Pitch angle regulation is required in conditions above the rated wind speed when the rotational speed is not kept constant. Small changes in pitch angle can have a dramatic effect on the power output [17].

The aim of this work is to show the importance of wind energy conversion system (WECS) driven by matrix converter.

This paper is organized as follows, in Section Wind system modeling, the modeling of the turbine and gearbox is presented. In Section Control structure, firstly, the mathematical model of doubly fed induction generator is given, then, the model of three phases converter matrix and its control strategy are considered. The whole of the chain studied and completed by the necessary details are established in Section Simulation results. In Section Conclusion, computer simulation results obtained under MatLab/Simulink are shown and discussed. Finally, the reported work is concluded.

Wind system modeling

The wind energy conversion system considered in this work includes the wind turbine, gearbox, double fed induction generator, matrix converter and the electrical network. Fig. 1 shows the equivalent diagram of wind energy conversion systems.

Wind turbine modeling

The mechanical power produced by the wind is given by Refs. [13,18]:

$$P_{tur} = C_p(\lambda, \beta) \cdot \frac{\rho \cdot S \upsilon^2}{2} \tag{1}$$

The power coefficient of wind turbine $C_p(\lambda, \beta)$can be defined as a function of the blade pitch angle (β) and the tip-speed ratio (λ) which is given by Refs. [13,19–21]:

$$\lambda = \frac{R \cdot \Omega_{tur}}{V} \tag{2}$$

$C_p$is different from a turbine to another, and is usually provided by the manufacturer and can be used to define a mathematical approximation. Generally, the used expression of the power coefficient can be approximated by the following Eqs. (22) and (23):

$$C_p(\lambda, \beta) = 0.22\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{\frac{-12.5}{\lambda_i}} \tag{3}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1 + \beta^3} \tag{4}$$

So, the aerodynamic torque is expressed by Refs. [13,22]:

$$T_{tur} = \frac{P_{tur}}{\Omega_{tur}} = C_p(\lambda, \beta) \cdot \frac{\rho \cdot S \cdot V^3}{2} \cdot \frac{1}{\Omega_{tur}} \tag{5}$$

Modeling of the mechanical part

Fig. 2 show the mechanical part of the wind turbine. The gearbox is installed between the turbine and the generator to adapt the turbine speed to that of the generator. Thus, we define the mathematical expressions of the chain as follows [24]:

$$\Omega_{mec} = G \cdot \Omega_{tur} \tag{6}$$

Furthermore, In the case where: friction, elasticity and energy losses in the gearbox are neglected.

$$G = \frac{T_{tur}}{T_{mec}} \tag{7}$$

The mechanical equations of the system can be characterized by:

$$J\frac{d\Omega_{mec}}{dt} = T_{mec} - T_{em} - f\Omega_{mec} \tag{8}$$

with: $J = \frac{J_{tur}}{G^2} + J_{gen}$

Fig. 3 show the block diagram of the wind turbine shaft model associated with the turbine model.

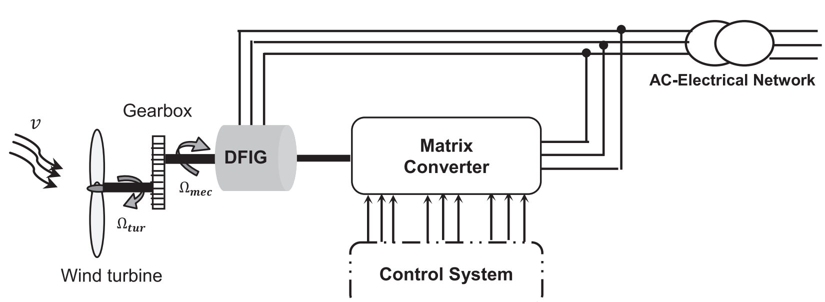

Fig. 1 – Block diagram of wind energy conversion system.