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Improving power quality of wind energy conversion system with unconventional power electronic interface

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ABSTRACT

The increasing interest to utilize wind energy as a power source prompted more researches to be dedicated to the unconventional integration of this power source into the current grid. In this paper, one avenue to achieve this efficient utilization, through the use of integrated wind energy conversion system (WECS) using doubly fed induction generator (DFIG) is presented. Wind grid integration brings the problems of voltage fluctuation and harmonic distortion. This paper presents an Unconventional Power Electronic Interface (UPEI) to reduce the total harmonic distortion (THD) and enhance power quality during disturbances. The models used in the paper includes a pitch-angled controlled wind turbine model, a DFIG model, power system model and an UPEI having controlled converters. A phase to phase fault is simulated on 132 kV bus and the measured results obtained from grid connection of the wind generation system are presented. The results have demonstrated the ability of UPEI to regulate pitch angle, VAR and to reduce THD. The proposed system increases the effectiveness of the utilization of wind energy.

1. Introduction

The increasing demand of energy from the growing modern society has created a concern in the last few decades. This is made worse by the fact that most of the current energy sources are exhaustible and depleting rapidly. Moreover, the combustion process of most of the current energy sources such as coal and fuel produces a high level or air pollution that causes global warming, which is a currently emerging problem. These issues have prompted the rapid development of many renewable energy sources over recent years, particularly the clean and pollution free wind energy that has an eligible rate of depletion. Thus, many efforts are dedicated to efficiently integrate wind energy into the grid network [1,2]. However, electric utility grid systems cannot readily accept connection of new generation plant without power electronic interface. Recent developments have made the trade-off benefits exceed the cost premium of machine in the power ranges up to several 100 kW. Considering these trends, one of the best topologies for wind power conversion system is the full size AC–DC–AC converter [3,4].

Power quality has also been a growing concern in recent years with many researches done in this area [5,6]. Harmonic emissions are recognized as a power quality problem for modern variable-speed wind turbines (WTs). For this reason, relevant standards require the measurement of harmonics [7–10] and their inclusion in the power quality certificates of WTs, and grid interconnection assessment procedures always comprise provisions for their control [11,12]. In this paper, the WECS with UPEI capable of reducing THD noticeably during disturbances [13] is proposed. It has a pitch-angled controlled wind turbine model, a DFIG model, a power system model and UPEI having controlled converters. Simulations have been conducted with Matlab/Simulink software to validate the model and the control schemes. This wind energy conversion system has many advantages, such as low total harmonic distortion, long distance between generator and converter possible, able to stand wide transients of grid voltage and current, regulation of generator speed to 1 p.u., regulation of reactive power to zero MVAR, regulation of pitch angle to zero degree and thus increase power quality. This paper is organized as follows. Section 2 presents modeling of wind turbine with DFIG. Power electronic interface model is present in Section 3. Results and discussion are presented in Section 4. Finally important conclusions are summarized in Section 5.

2. Modeling of wind turbine with DFIG

Half of the world's leading wind turbine manufacturers use the DFIG systems. This is due to the fact that the power electronic

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converter only has to handle a fraction (20–30%) of the total power, i.e., the slip power. This means that if the speed is in the range ±30% around the synchronous speed, the converter has a rating of 30% of the rated turbine power, reducing the losses in the power electronic converter, compared to a system where the converter has to handle the total power. In addition, the cost of the converter becomes lower. The WECS considered for analysis consist of a DFIG driven by a wind turbine, rotor side converter, DC to DC intermediate circuit and grid side converter. Fig. 1 shows a schematic diagram of WECS having DFIG and UPEI that will be discussed in this paper. The mechanical power available from a wind turbine

$$P_w = 0.5\rho\pi R^2 V_w^3 C_p(\lambda, \beta) \tag{1}$$

where P_w is the extracted power from the wind, ρ is the air density, R is the blade radius, and V_w is the wind speed. C_p is called the 'power coefficient', and is given as a nonlinear function of the parameters tip speed ratio λ and blade pitch angle β. Here the following function will be used [14]

$$C_p = \frac{1}{2} * (\lambda - 0.022 * \beta^2 - 5.6) * e^{-0.17\lambda} \tag{2}$$

$$\lambda = \frac{V_w}{\omega_B} \tag{3}$$

where ω_B is the rotational speed of turbine. Usually C_p is approximated as [15]

$$C_p = \alpha\lambda + \beta\lambda^2 + \gamma\lambda^3 \tag{4}$$

where α, β and γ are constructive parameters for a given turbine. The torque developed by the windmill is

$$T_t = 0.5\rho\left(\frac{C_p}{\lambda}\right) V_w^3 \pi R^2 \tag{5}$$

The equation of rotor motion is given as

$$\frac{d\omega_r}{dt} = \frac{2P_a}{J\omega_r} \tag{6}$$

where J is the moment of inertia due to the rotating mass and P_a is the rotor acceleration mechanical power. The angular velocity of the rotor is considered in the region $0.7\omega \leqslant \omega_r \leqslant 1.3\omega$ for the case study presented in this paper. The DFIG equations can be written as [16]

$$\frac{d\lambda_{ds}}{dt} = u_{ds} - R_s i_{ds} + \omega_r \lambda_{qs} \tag{7}$$

$$\frac{d\lambda_{qs}}{dt} = u_{qs} - R_s i_{qs} - \omega_r \lambda_{ds} \tag{8}$$

$$\frac{d\lambda_{dr}}{dt} = u_{dr} - R_r i_{dr} + s\,\omega_r \lambda_{qr} \tag{9}$$

$$\frac{d\lambda_{qr}}{dt} = u_{qr} - R_r i_{qr} - s\,\omega_r \lambda_{dr} \tag{10}$$

The stator electric values are indicated by the subscript s and the rotor electric values are indicated by the subscript r. u is a voltage, R is a resistance, i is a current, λ is a flux linkage. ω is the stator electrical frequency and s is rotor slip. The flux linkages are given by [16]

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr} \tag{11}$$

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr} \tag{12}$$

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds} \tag{13}$$

$$\lambda_{qr} = L - s\, i_{qr} + L_m i_{qs} \tag{14}$$

L_s, L_r are the stator and the rotor leakage inductance respectively and L_m is the mutual inductance between the stator and the rotor.

Fig. 2 shows turbine power characteristics for zero degree pitch angle. The power is controlled in order to follow a pre-defined power–speed characteristic, named tracking characteristic. This characteristic is illustrated in the Fig. 2 by the dotted ABCD curve superimposed to the mechanical power characteristics of the turbine obtained at different wind speeds. The dashed line in Fig. 2 indicates maximum power at base wind speed (11 m/s) and pitch angle zero degree.

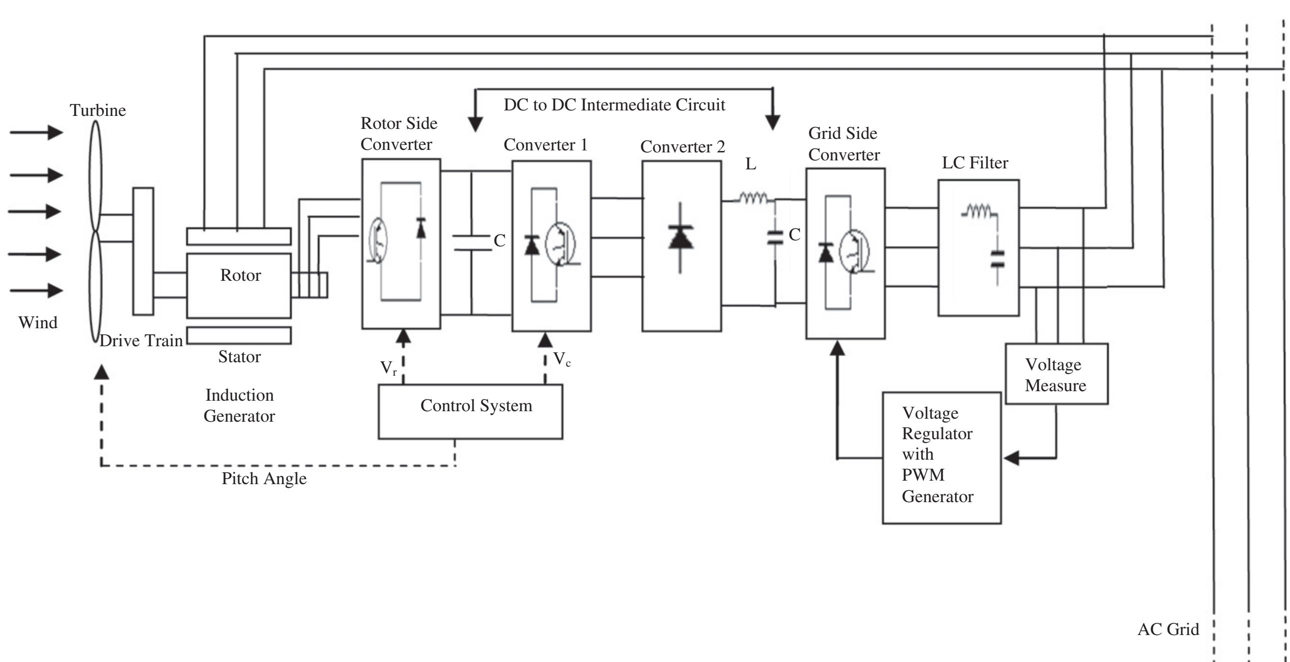

Fig. 1. Proposed wind energy conversion system with DFIG and controlled UPEI.