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A new approach for low voltage ride through capability in DFIG based wind farm

M. Kenan Döşoğlu *

Duzce University, Faculty of Technology, Electrical Electronics Engineering Department, 81620 Konuralp, Duzce, Turkey

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ABSTRACT

Protection against voltage dips is very important for transient stability in a Doubly Fed Induction Generator (DFIG). Conventional crowbar circuits have been used for protection of DFIGs; however, they may be insufficient in some transient situations. Therefore, the Low Voltage Ride Through (LVRT) capability was enhanced by a Demagnetization Current Controller (DCC) for the purpose of transient analysis. In addition, both stator and rotor circuit electromotive forces were modeled in a DFIG. The performances of the DFIG models with and without the DCC were compared. Modeling was carried out in a MATLAB/SIMULINK environment. A comparison of system behaviors was made between three-phase faults with and without a stator–rotor dynamic. Parameters for the DFIG including output voltage, speed, electrical torque variations and *d–q* axis rotor–stator current variations in addition to a 34.5 kV bus voltage were examined. It was found that in the DFIG model the system became stable in a short time when using the DCC.

Introduction

In recent years, the Doubly Fed Induction Generator (DFIG) has been widely used for wind turbines operating above one MW. The use of DFIGs on wind farms provides many advantages including variable speed operation, active–reactive power, and a voltage and current controller. Modern wind farms have the different operation point and a grid connection by power converters. Modern wind farms have a more widespread in the market national or international. However, wind turbines based on the DFIG are very sensitive in a state of transient instability such as during grid disturbances and voltage dips. Drops in the grid voltage cause excessive voltage and current in the rotor circuit [1–3]. Low Voltage Ride Through (LVRT) and various control methods are used to remove this problem in DFIG-based wind farms. A LVRT strategy has been proposed Ref. [4] to enhance transient stability in grid disturbances for a DFIG. In this strategy, the operation mode was developed as a reactive power base to protect against a voltage dip in the DFIG. Another control strategy using rotor- and grid-side converters against over-currents was suggested by Ref. [5], whereby an active–reactive power control acts to fulfil the grid code requirement during voltage dips [6]. Furthermore, this new control strategy enhances the ability of the reactive power support for the transient stability of a DFIG-based wind farm. With this control strategy, wind energy and DC-link voltage and rotor current controls are used more effectively [7]. Ref. [8] discussed a new direct power control strategy implemented for DFIG-based wind farms as well as a vector modulation technique used during voltage dips. The rotor current control in the DFIG is applied in a generalized way that can be used for analysis during symmetrical voltage faults. The direct aim is to employ space vector methods for symmetrical voltage dips in the power system [9,10]. Ref. [11] presented a hybrid current control scheme implemented in the rotor- and grid-side converters of the DFIG for enhancing the LVRT capacities of DFIG-based wind farms. This control strategy is used for steady and transient state operation of the DFIG. For LVRT capability in the DFIG, both steady and transient states are enhanced by this new approach, which uses a new reference control in the grid-side converter circuit to provide protection against voltage dips [12]. In the control strategy described by Ref. [13], optimum power control is provided during various fault analyses applied to the constant voltage regulation in the DFIG, regardless of fluctuation or disruption of wind. The LVRT capability for voltage dips in a DFIG provides a control point of common coupling. In addition, the point of common coupling enhances the current control scheme against the transient state in the rotor-side converter. This control has been used with different operation modes [14–16]. Another control technique in the DFIG uses a series voltage source for the regulation of the transient instability state in the rotor-side

* Tel.: +90 380 5421133; fax: +90 380 5421134.
E-mail address: kenandosoglu@duzce.edu.tr

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converter circuit, and a comparison was made by combining the series voltage source control with a conventional crowbar unit in the DFIG [17]. In a DFIG-based wind farm, the LVRT capability was enhanced with a linear quadratic feedback centralized control unit in the rotor- and grid-side converters. This centralized control was effective for various fault types in the DFIG [18]. The proposed LVRT control strategy provides new flux tracking for a short circuit state in the DFIG. In the proposed control strategy, in addition to rotor electromotive force modeling during faults, the stator flux linkage is provided by a rotor-side converter control [19,20]. In Refs. [21,22], the behavior of the DFIG including the generator machine magnetizing current control, was analyzed during voltage dips using models in the dominant frequency. The aim was to enhance the system response during balanced and unbalanced voltage dips in the DFIG. Power Oscillation Damping (POD) is important for regulates voltage sags-swells in besides the over-currents in the DFIG based wind farm in grid faults, and therefore, significantly enhances the LVRT capability of the DFIG based wind farm [23–25].

In this study, dynamic modeling with a base voltage source was developed for the LVRT capability of both stator and rotor circuits in a DFIG. Additionally, for transient stability conditions, the LVRT was enhanced by a DCC. A comparison was drawn between the systems developed through stator- and rotor-based electromotive forces with and without the DCC during various faults.

Modeling of wind farm

The DFIG of a wind turbine is basically a wound rotor induction machine with the stator windings directly connected to the three-phase grid and with the rotor windings connected to a back-to-back converter, consisting of a grid-side converter and a rotor-side converter connected to a common DC bus. The behavior of the DFIG is governed by these converters and their controllers in both steady-state and transient conditions. The converters control the rotor voltage in magnitude and phase angle and therefore, they are used for active and reactive power control [26,27]. The equivalent circuit of the induction generator, seen from the stator and rotor side, can be seen in Fig. 1.

The rotor model expresses the mechanical power extracted from the wind as a function of the wind speed, the blade tip speed ratio and the blade pitch angle, as defined in:

$$P_w = \frac{1}{2}\rho A u^3 C_p(\lambda, \theta) \tag{1}$$

where P_w is the mechanical power extracted by the wind turbine rotor, ρ is the air density, A is the area of the rotor disk, u is the wind speed and C_p is the power coefficient. The power coefficient terms the rotor aerodynamics as a function of both tip speed ratio λ and the pitch angle of the rotor blades θ. The tip speed ratio is described as the ratio between the blade tip speed and the wind speed, explained as:

$$\lambda = \frac{w_r R}{u} \tag{2}$$

where w_r is the rotor speed and R is the radius of the wind turbine rotor. The power extracted from the wind is maximized when the rotor speed is such that the power coefficient is at maximum, which occurs for a determined tip speed ratio. The control system of the DFIG wind turbine assures that the variable speed operation maximizes the output power for a wide range of wind speeds, according to the optimum power extraction curve, given as:

$$P_{op} = K_{op} w_r^2 \tag{3}$$

As the wind turbine limits the output power to the rated power of the generator for high winds, the power–speed curve is the rated power. This power–speed curve gives a dynamic reference for the control system of the DFIG wind turbine [28]. The drive train of the DFIG wind turbine has been defined in two mass models:

$$T_w - T_m = 2H\frac{dw_r}{dt} \tag{4}$$

$$T_m = D_m(w_r - w) + K_m\int(w_r - w)dt \tag{5}$$

where T_w is the mechanical torque from the wind turbine rotor shaft, T_m is the mechanical torque from the generator shaft, H is the rotor inertia, and K_m and D_m are the stiffness and damping of the mechanical coupling [29].

The purpose of the rotor-side converter controller is to control the DFIG output active power for tracking the input of the wind farm torque, and to maintain the terminal voltage to control setting. The active power and voltage are controlled independently by v_{qr} and v_{dr}, respectively. The control equations are given as:

$$\frac{dx_1}{dt} = P_{ref} + P_s \tag{6}$$

$$I_{qr\_ref} = K_{p1}(P_{ref} + P_s) + K_{i1}x_1 \tag{7}$$

$$\frac{dx_2}{dt} = I_{qr\_ref} - I_{qr} = K_{p1}(P_{ref} + P_s) + K_{i1}x_1 - I_{qr} \tag{8}$$

$$\frac{dx_3}{dt} = v_{s\_ref} - v_s \tag{9}$$

$$I_{dr\_ref} = K_{p3}(v_{s\_ref} - v_s) + K_{i3}x_3 \tag{10}$$

$$\frac{dx_4}{dt} = I_{dr\_ref} - I_{dr} = K_{p3}(v_{s\_ref} - v_s) + K_{i3}x_3 - I_{dr} \tag{11}$$

$$v_{qr} = K_{p2}(K_{p1}\Delta P + K_{i1}x_1 - I_{qr}) + K_{i2}x_2 + sw_sL_mI_{ds} + sw_sL_{rr}I_{qr} \tag{12}$$

$$v_{dr} = K_{p2}(K_{p3}\Delta v + K_{i3}x_3 - I_{dr}) + K_{i2}x_4 - sw_sL_mI_{qs} - sw_sL_{rr}I_{dr} \tag{13}$$

where K_{p1} and K_{i1} are the proportional and integrating gains of the power regulator, respectively; K_{p2} and K_{i2} are the proportional and integrating gains of the rotor-side converter current regulator, respectively; K_{p3} and K_{i3} are the proportional and integrating gains of the grid voltage regulator, respectively; I_{dr_ref} and I_{qr_ref} are the current control references for the d and q axis components of the generator side converter, respectively; v_{s_ref} is the specified terminal voltage reference; and P_{ref} is the active power control reference.

The grid-side converter controller aims to maintain the DC link voltage and control the terminal reactive power. The voltage of the DC link is controlled by *idg* while the reactive power is controlled by *iqg*. The following equations are based on introduction of the intermediate variables $\times 5$, $\times 6$ and $\times 7$:

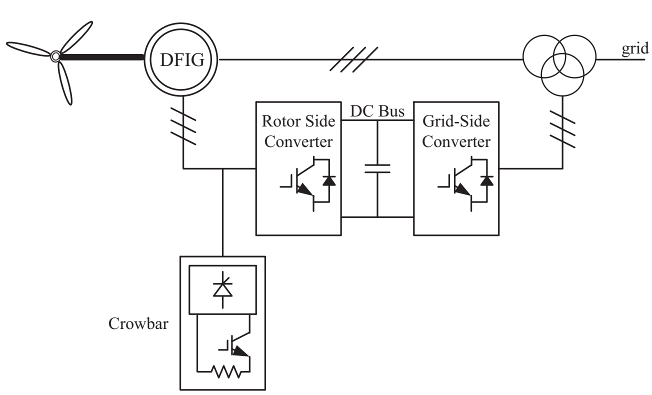

Fig. 1. DFIG circuit modeling.