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A new method based on state-estimation technique to enhance low-voltage ride-through capability of doubly-fed induction generator wind turbines

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ABSTRACT

Among different forms of wind energy technologies, doubly fed induction generator (DFIG) has been one of the most growing one during recent years. According to the updated grid codes, wind energy resources are needed to stay connected to the network during and after faults. To improve zero or low-voltage ride-through (LVRT) capability of DFIG, a control approach is proposed in the paper. The input signals of the proposed control approach are obtained by using state estimation technique. Since the dynamic behavior of the rotating speed of the stator flux can be considered in this method, it can minimize transient rotor current during and after clearing fault. Furthermore, the employment of state estimation method can minimize the effect of probable noise level in metering devices which is another advantage of this method. Simulation studies are done in a numerical case study to confirm the advantages of this method.

1. Introduction

Due to an increased fossil fuels cost, limited reserve resources, and adverse environmental impacts imposed by fossil fuels, renewable energy resources have recently been attracting much consideration. Furthermore, technological developments, cost reduction, and governmental motivations have made some renewable resources more competitive in the market. Between different kinds of renewable resources, wind energy is one of the most growing forms of renewable resources utilized for power generation [1].

Based on the updated grid codes, these wind energy resources are needed to keep connected to the grid during and after faults. The performance is commonly recognized as zero or low-voltage ride-through (LVRT) capability [1].

Due to their efficiency, low investment cost and reliability, the number of doubly fed induction generators (DFIGs) has grown as one of the most important technologies for wind energy systems [1]. DFIG is so sensitive to network disturbances since the DFIG stator is directly connected to the network. Therefore, zero or low voltage ride through capability for DFIG requires further examination.

When a short-circuit fault occurs near a wind energy system, a voltage dip is caused. The voltage dip produces a great transient rotor current, which may cause overvoltage on the DC-link capacitor and damage the rotor converter, leading to disconnection of the wind energy system from the grid [2].

To alleviate this problem different solutions have been suggested. Refs. [3–8] propose installing the crowbar. This solution changes the DFIG to a squirrel cage induction generator absorbing reactive power from the grid. Therefore, the problem of reactive power absorption during the time of short circuit fault is elevated.

Additional series grid-side converter [9], energy storage system (ESS) [10,11], series grid-side impedance [12], VAR compensator equipment [13] and fault current limiter [14,15] are also proposed, which may be technically practical, but are costly.

During the fault, it is preferred to remain DFIG connected to the grid and it is desired to control active and reactive power of the DFIG. Based on them, [16] and [17] present some control approaches. In these schemes, the injection of additional feed-forward transient compensation terms into the outputs of a conventional rotor-side converter (RSC) current controller decreases the rotor transient current. Therefore, the occurrence of crowbar interruptions is minimized. However, these control schemes may not work properly when the measured value contains some noise. Furthermore, both of the scholars have failed to consider the stator resistance in their scheme. Moreover, the method presented in [16] does not consider the dynamic behavior of rotating speed of the

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stator flux, so it cannot minimize the rotor transient current during and after clearing fault properly. The rotating speed of the stator flux is considered 1 and 0 in steady-state stator voltage and a deep stator voltage sag condition, respectively. Furthermore, it does not consider the dynamic value of the stator flux rotating speed after clearing the fault [16].

In this paper, a feed-forward transient current control approach based on state estimation technique is proposed to remove the mentioned deficiency in [16] and [17]. The dynamic behavior of the rotating speed of the stator flux can be considered in this method. Therefore, it can minimize the transient rotor current during and after removing the fault properly. Furthermore, the employment of state estimation method can minimize the effect of probable noise level in metering devices which is another advantage of the proposed method. The stator resistance is not neglected in the proposed scheme. Comparison is performed in a numerical case study, which demonstrates the advantages of the proposed model against the method proposed in [16].

In the state estimation method, state-space equations and some measurements obtained by meters are used to estimate the state variables [18]. State estimation is used in the power system in terms of static sate estimation and dynamic state estimation. Recently, due to improvements in monitoring and signaling techniques, estimation of state variables has become feasible and attracted further attention. Dynamic state estimation has previously been employed to estimate the dynamic state variables of permanent synchronous generator [19], DFIG [20] and synchronous machine [21,22].

This paper is prepared as follows: in Section 2, an 11th-order DFIG model is obtained. The control scheme based on state estimation technique is proposed in Section 3. In Section 4, Numerical examples are studied to determine the efficacy of the proposed control scheme.

2. Dynamic model of DFIG

In this section, the DFIG model for developing feed-forward transient current control scheme based on state estimation technique is presented. A DFIG joined to the infinite bus is presented in Fig. 1.

To obtain the DFIG model, the following stator voltage and flux linkage equations related to stator voltage are used [1]

$$v_{sd} = R_s i_{sd} - \omega \psi_{sq} + \frac{1}{\omega_b}\frac{d\psi_{sd}}{dt} \tag{1}$$

$$v_{sq} = R_s i_{sq} + \omega \psi_{sd} + \frac{1}{\omega_b}\frac{d\psi_{sq}}{dt} \tag{2}$$

$$v_{rd} = R_r i_{rd} - (\omega - \omega_r)\psi_{rq} + \frac{1}{\omega_b}\frac{d\psi_{rd}}{dt} \tag{3}$$

$$v_{rq} = R_r i_{rq} + (\omega - \omega_r)\psi_{rd} + \frac{1}{\omega_b}\frac{d\psi_{rq}}{dt} \tag{4}$$

$$\psi_{sd} = L_s i_{sd} + L_m i_{rd} \tag{5}$$

$$\psi_{sq} = L_s i_{sq} + L_m i_{rq} \tag{6}$$

$$\psi_{rd} = L_m i_{sd} + L_r i_{rd} \tag{7}$$

$$\psi_{rq} = L_m i_{sq} + L_r i_{rq} \tag{8}$$

where subscript d, q, r and s represent the quantities in d axis, q axis, rotor and stator, respectively. R, L, i, Ψ and v indicate resistor, inductor, current, flux and voltage respectively. L_m denotes the mutual inductance. ω_b and ω_r are the base and rotor angular speed, respectively. ω is the speed of d–q reference frame or the stator flux rotational speed.

A traditional vector control scheme used to control the active and reactive power for both the RSC and the grid-side converter (GSC) of DFIG are shown in Figs. 2 and 3 [16].

However, as mentioned in [16], in the traditional control approach, the compensation term is designed according to the steady-state operation. So, it may not do proper compensation in fault circumstance. Therefore, [16] uses DFIG transient model and presents the feed-forward transient current control (FFTCC) approach to correct the alignment of the RSC voltage with the transient-induced voltage and minimizes the transient current in the rotor in stator voltage dips. This control scheme is shown in Fig. 4.

As mentioned, in this control scheme the rotating speed of the stator flux is considered 1 in steady-state stator voltage and 0 in a deep stator voltage sag condition. The control scheme ignores dynamic behavior of the stator flux rotational speed. So, it can cause instability in some short circuit fault situations. In the rest of this section, the equation presenting rotating speed of the stator flux is presented. Then, in the Section 3 this is applied in the proposed control scheme.

The d-q current of the RSC could be obtained using (1)–(8).

$$\frac{L'_r}{\omega_b}\frac{di_{rd}}{dt} = -R'_r i_{rd} + (\omega - \omega_r)L'_r i_{rq} - \frac{L_m}{L_s}v_{sd} - \frac{L_m}{L_s}\omega_r\psi_{sq} + \frac{L_m}{L_s} \times \frac{R_s}{L_s}\psi_{sd} + v_{rd} \tag{9}$$

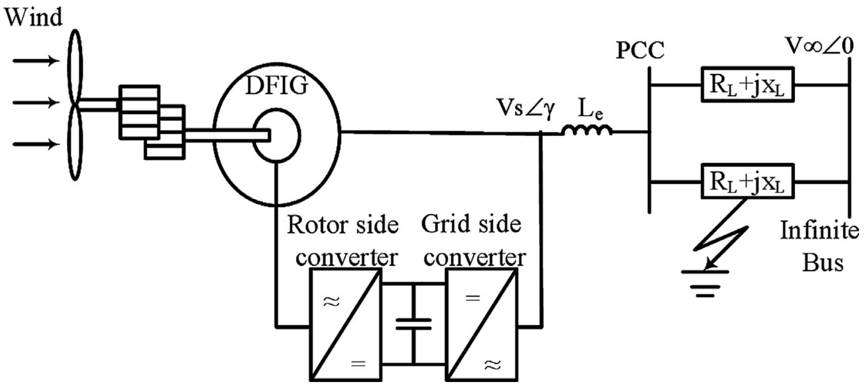

Fig. 1. General structure of DFIG connected to the infinite bus.