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Reactive power control of grid-connected wind farm based on adaptive dynamic programming

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A R T I C L E I N F O

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A B S T R A C T

Optimal control of large-scale wind farm has become a critical issue for the development of renewable energy systems and their integration into the power grid to provide reliable, secure, and efficient electricity. Among many enabling technologies, the latest research results from both the power and energy community and computational intelligence (CI) community have demonstrated that CI research could provide key technical innovations into this challenging problem. In this paper, a neural network based controller is presented for the reactive power control of wind farm with doubly fed induction generators (DFIG). Specifically, we investigate the on-line learning and control approach based on adaptive dynamic programming (ADP) for wind farm control and integration with the grid. This controller can effectively dampen the oscillation of the wind farm system after the ground fault of the grid. Compared to previous control strategies, this controller is on-line and "model free", and therefore, can reduce the control complexity. Simulation studies are carried out in Matlab/Simulink and the results demonstrated the effectiveness of the ADP controller.

1. Introduction

The development of renewable energy for sustainable, efficient, and clean electric power systems has become a critical research topic world wide [1–4]. Among various renewable energy sources, wind power is the most rapidly growing one in the world. While the wind is random and intermittent, the major hurdle in developing such energy has been the lack of efficient control. In this paper, we focus on the adaptive dynamic programming (ADP) based reactive power control of the wind farm under grid fault.

In general, there are mainly three kinds of wind power generators: squirrel-cage induction generator, permanent magnet synchronous generator and doubly fed induction generator (DFIG). DFIG is widely used in the wind power system for its advantages over other two types [5]. The characteristics of DFIG are high efficiency, flexible control and low investment. The stator of DFIG is directly connected to the power grid while the rotor is connected to the power grid through a back-to-back converter, which only takes about 20–30% of the DFIG rated capacity for the reason that the converter only supplies the exciting current of the DFIG. The back-to-back converter consists of three parts: rotor side converter (RSC), grid side converter (GSC) and DC Link capacitor. From the previous research, the controller of the converter has significant effect on the stability of grid-connected DFIG [6,7].

In the previous research, the stability analysis and optimal control of wind farm with DFIG have been studied in the community [8–16]. The key challenge for wind farm optimization is to build an accurate wind farm model and the involvement of a large number of parameters need to be optimized to ensure a good interaction of the wind farm with the power grid at the common coupling point (CCP). For instance, in [8], the authors proposed to use particle swarm optimization (PSO) to optimize the control parameters in a DFIG simultaneously. This method can improve the performance of the DFIG in the power grid, however, when the number of the DFIG in a wind farm increases, the number of the control parameters will increase significantly (i.e., curse of dimensionality issue). Fuzzy logic control has been successfully applied to control DFIG in different aspects. In [11], fuzzy logic control was implemented on primary frequency and active power control of the wind farm. In [12], Neuro-Fuzzy vector control was used and realized on a laboratory DFIG. Other advanced coordinated control approaches such as ADP based methods have shown promising results for such a challenging problem [17–20].

In [19], the authors proposed a heuristic dynamic programming (HDP) based coordinated reactive power control of a large wind farm and a STATCOM. This HDP controller can improve the

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performance of the DFIG in the power grid when there is a grid fault. However, this HDP controller needs to be sufficiently pre-trained based on the information from the power system before connected to the grid. Motivated by our previous research on ADP [29,30,21], in this paper, we use the on-line ADP architecture as proposed in [22] for wind farm reactive power control. This ADP control method is "model free," that is to say without the requirement of a detail physical model as well as a complex model network to predict the system status [22]. This enables the ADP approach to learn "on-the-fly" while interacting with the power grid. This approach has been successfully demonstrated with many applications including stabilization and tracking control of an Apache helicopter [23,24], damping oscillation control in a classic "four machine two area" system, a large power system in China [25], among others [26–28]. In this paper, we aim to investigate the reactive power control of a wind farm connected to the power grid under fault condition.

The rest of the paper is organized as follows. Section 2 briefly introduces the DFIG wind system, RSC and GSC controller model. Detailed ADP control approach has been presented in Section 3. The power system scenario that we study in this work and simulation results are presented in Section 4. Finally, a conclusion is given in Section 5.

2. DFIG wind turbine system model

The wind turbine model studied in this paper is illustrated in Fig. 1. In this system, the wind turbine is connected to the DFIG through a drive train system, which consists of a low and a high speed shaft with a gearbox in between. The wind turbine (WT) with DFIG system is an induction type generator in which the stator windings are directly connected to the three-phase grid and the rotor windings are fed through three-phase back-to-back insulated-gate bipolar transistor (IGBT) based pulse width modulation (PWM) converters. The back-to-back PWM converter includes three parts: a rotor side converter (RSC), a grid side converter (GSC) and a DC Link capacitor placed between the two converters. Their controller also includes three parts: rotor side converter controller, grid side converter controller and wind turbine controller. The function of these controllers are to produce smooth electrical power with constant voltage and frequency to the power grid whenever the wind system is working at sub-synchronous speed or super-synchronous speed, depending on the velocity of the wind. Vector control strategy is employed for both the RSC controller and the GSC controller to achieve decoupled control of active and reactive power.

2.1. Model of drive train

The drive train system [8] includes the turbine, a low and a high speed shaft, and a gearbox. This system can be represented by a two-mass model as follows:

$$2H_t \frac{d\omega}{dt} = T_m - T_{sh} \tag{1}$$

$$\frac{d\theta_{tw}}{dt} = \omega_t - \omega_r = \omega_t - (1 - s_r)\omega_s \tag{2}$$

$$2H_g \frac{ds_r}{dt} = -T_{em} - T_{sh} \tag{3}$$

$$T_{sh} = K_{sh}\theta_{tw} + D_{sh}\frac{d\theta_{tw}}{dt} \tag{4}$$

where

H_t the inertia constants of the turbine
H_g the inertia constants of the generator
ω_t the WT angle speed
ω_r the generator rotor angle speed
$\theta_{t\omega}$ the shaft twist angle
K_{sh} the shaft stiffness coefficient
D_{sh} the damping coefficient
T_{sh} the shaft torque
T_m the wind torque
T_{em} the electromagnetic torque

The maximum power coefficient may be achieved by controlling the WT speed in order to track the maximum power from wind. The tracking strategy for the DFIG is achieved by driving the generator speed along the optimum power speed characteristic curve, which corresponds to the maximum energy capture from the wind.

2.2. Model of DC Link capacitor

From Fig. 1, the active power flow through the back-to-back PWM converter is balanced by the DC Link capacitor [8]. The power balance equation can be represented as follows:

$$P_r = P_g + P_{DC} \tag{5}$$

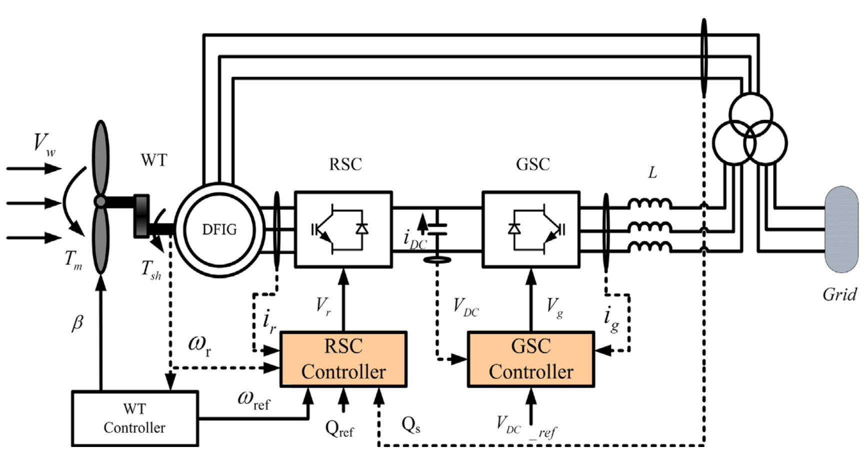

Fig. 1. Schematic diagram of DFIG wind turbine system [13,14].