Reactive Power Control Strategy of DFIG Wind Farms for Regulating Voltage of Power Grid

Jingjing Zhai
School of Electric Power Engineering
Nanjing Institute of Technology
Nanjing, China
zhaijj@njit.edu.cn

Haoming Liu
College of Energy and Electrical Engineering
Hohai University
Nanjing, China
liuhaom@hhu.edu.cn

Abstract—**If a wind farm is weakly connected to a power grid, then the voltage of the connection point fluctuates frequently due to the changeable wind speed. The active and reactive power of a doubly-fed induction generator (DFIG) can be decoupling controlled and the grid-side converter (GSC) of a DFIG can also generate some reactive power by adjusting the power factor, thus a DFIG can be considered as a reactive power resource to stabilize the voltage of the connection bus. Based on the power relationship of a DFIG, the up and down reactive power limitations of DFIG stator and GSC are analyzed. Then a reactive power control strategy of a DFIG wind farm is proposed, in which, a certain number of DFIGs are selected to support reactive power to the power grid when the voltage of the connection point drops. The control strategy aims at bringing the reactive power capability of DFIG into play and cutting down the investments in the reactive power compensation devices which are used less. The simulation model of a grid-connected DFIG wind farm is developed on the PSCAD/EMTDC platform, and the simulation results demonstrate the effectiveness of the control strategy proposed.**

Index Terms--**Doubly-fed induction generator (DFIG); reactive power control; voltage control; power limitation.**

I. Introduction

Nowadays more and more wind farms are connected into the power grid. Long-distance transmission lines are usually required for the connection because most wind farms are located at the remote areas or off shores. The output active power of wind farms is variable and intermittent due to the changeable wind speed, which threats the voltage stability of local power grids. More reactive power is demanded to maintain the voltage when it drops. Since a wind farm is composed of many wind turbines, the operation and control modes of the wind turbines have a great impact on the voltage stability of local power grids. The doubly-fed induction generator (DFIG) is widely used in wind farms because it has many advantages, one of which is the decoupled control of active and reactive power [1]. Besides, both the stator and the grid-side converter (GSC) of a DFIG can inject reactive power into the grid to help to maintain the fluctuant voltage [2][3]. As mentioned, the voltage of a weakly-connected power grid to wind farms is usually unstable, thus taking the reactive power from DFIGs into account will make the compensation more flexible.

There are mainly two reactive power control modes for a DFIG wind turbine, one is power factor control mode and the other is voltage control mode [4]. Many papers have focused on the reactive power characteristics of DFIG wind turbine. The research contents cover the dynamic reactive power limits of doubly-fed wind turbine, the use of reactive power regulation capability to improve the local voltage stability, and the reactive power support for the grid [5]. The voltage stability of power system is mainly dependent on the balance of reactive power, as a result, the doubly-fed wind farm should be equipped with corresponding voltage control schemes according to the reactive power compensation situation [6]-[7]. Based on zoning plans, reference [8] proposed the automatic voltage control strategy of wind farm, which combined the DFIG voltage control with other voltage regulation measures such as switching capacitors. According to the optimal secondary voltage control theory, reference [9] suggested that the reactive power regulation capability would be better played when the key node voltage was controlled. These papers take all the wind turbines in the wind farm into account when allocating the reactive power, which may not only increases the power loss of wind turbines but also makes the dispatch and control of the total wind farm more difficult.

This paper proposes a more flexible reactive power control strategy. The up and down limitations on the reactive power of a DFIG are deduced based on the power relationship. When the voltage of the connection bus drops due to some load disturbances in the power grid, a certain number of DFIG wind turbines are selected according to the up and down limitations to inject the demanded reactive power into the grid, helping to recover the voltage. Not all the wind turbines are involved in this control strategy, the number is dependent on the reactive power needed by the power grid and is determined dynamically. Finally, the proposed strategy is verified by simulations on the PSCAD/EMTDC platform.

978-1-4799-6415-4/14/$31.00 ©2014 IEEE

II. Reactive Power Characteristic of a DFIG Wind Turbine

A. Power Relationship of a DFIG Wind Turbine

The topology of a DFIG is shown in Fig. 1. The stator of a DFIG is connected to the power grid directly, while the rotor is connected to the grid through two back-to-back pulse width modulation (PWM) converters, i.e. rotor-side converter and grid-side converter. The grid-side converter usually works at the unity power factor of 1 and is in charge of maintaining a constant DC-link voltage for the rotor-side converter. The decoupling control of active and reactive power of the DFIG is achieved by adjusting the rotor's current and voltage through the rotor-side converter.

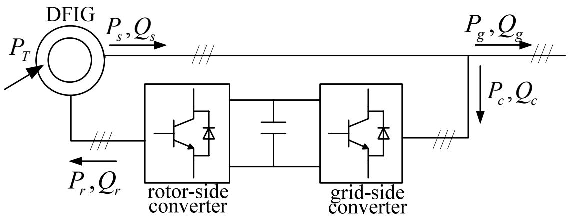

Figure 1. Topology of a DFIG

In Fig. 1, P_T is the input mechanical power from the wind turbine, P_s and Q_s are the output active and reactive power generated by the DFIG, P_c and Q_c are the active and reactive power to the grid-side converter from the DFIG, P_g and Q_g are the active and reactive power to the grid from the DFIG, P_r and Q_r are the active and reactive power to the rotor winding from the rotor-side converter. Assuming that the input mechanical power is completely converted into the electro-magnetic power, the power relationship of DFIG can be presented as:

$$P_T = P_s - P_r \tag{1}$$

The difference between the stator speed and the synchronous speed results in the slip power of the rotor, which is named as the rotor power P_r. Therefore the power relationship can also be expressed as:

$$\begin{cases} P_s = P_T/(1-s) \\ P_r = sP_T/(1-s) \end{cases} \tag{2}$$

B. Reactive Power Limitations of the Grid-side Converter

The rotor-side and grid-side converters only transfer active power, while the reactive power Q_c and Q_r are decoupled. If the power loss is neglected, there is $P_c = P_r$. Since the grid-side converter usually works at the unity power factor of 1, there is $Q_c = 0$. However, Q_r is divided into two parts, one part flows into the rotor, and the other part is transferred to the stator by a certain percentage (slip ratio). Therefore, the capacity of the rotor-side converter is larger than that of the grid-side converter. As a result, when analyzing the reactive power limitations of the grid-side converter, only the capacity of itself is considered.

For a low wind speed, the grid-side converter does not make full use of its capacity. When the grid requires extra reactive power, the grid-side converter can be adjusted into a non-unity power factor to meet the requirement. Assuming the maximum capacity of the grid-side converter is $S_{c\max}$, there is $P_c^2 + Q_c^2 \le S_{c\max}^2$. The reactive power that the grid-side converter can generate or absorb is presented as:

$$-\sqrt{S_{c\max}^2 - P_c^2} \le Q_c \le \sqrt{S_{c\max}^2 - P_c^2} \tag{3}$$

Combining (2) and (3), the reactive power limitations of the grid-side converter can be illustrated as:

$$\begin{cases} Q_{c\max} = \sqrt{S_{c\max}^2 - (sP_s)^2} \\ Q_{c\min} = -\sqrt{S_{c\max}^2 - (sP_s)^2} \end{cases} \tag{4}$$

C. Reactive Power Limitations of the DFIG Stator

Based on the orientation of the grid voltage vector, the rotor current can be expressed as [10]:

$$\begin{cases} i_{rd} = \dfrac{L_s}{L_m} i_{sd} \\ i_{rq} = \dfrac{L_s}{L_m} i_{sq} - \dfrac{u_s}{L_m w} \end{cases} \tag{5}$$

where i_{rd} and i_{rq} are the *d*- and *q*-axis components of the rotor current, i_{sd} and i_{sq} are the *d*- and *q*-axis components of the stator current, L_s is the stator inductance, L_m is the mutual inductance of stator and rotor, u_s is the stator voltage, and ω is the synchronous angular velocity.

It is well known that $i_{rd}^2 + i_{rq}^2 = i_r^2$, so there is

$$\left(\frac{L_s}{L_m} i_{sd}\right)^2 + \left(\frac{L_s}{L_m} i_{sq} - \frac{u_s}{L_m w}\right)^2 = i_r^2 \le I_{r\max}^2 \tag{6}$$

where $I_{r\max}$ is the maximum current of the rotor-side converter.

Similarly, the stator current can be written as:

$$i_{sd}^2 + i_{sq}^2 = i_s^2 \le I_{s\max}^2 \tag{7}$$

where $I_{s\max}$ is the maximum current of the stator.

The active and reactive power of DFIG stator can be presented as [10]:

$$\begin{cases} P_s = \dfrac{3}{2} u_s i_{sd} \\ Q_s = \dfrac{3}{2} u_s i_{sq} \end{cases} \tag{8}$$