Dynamic Optimal Reactive Power Compensation Control Strategy in Wind Farms of DFIG

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***Abstract*—More concerns are given to the reasonable reactive power compensation with the rapid development of wind farms. This study aims to propose an optimal compensation control strategy for Doubly Fed Induction Generator (DFIG)-based wind farms, where the power output varies along with the different wind speed. Firstly, simulation models of wind speed and DFIG are constructed in MATLAB to find the relationship between wind speed and power. Then the Improved Analytic Hierarchy Process (IAHP) is applied to obtain the weights of each factor and a function is presented to calculate the final evaluation value, when considering constrained factors like economy and effectiveness. The optimal compensation strategy is obtained to select appropriate device with minimum function value at the particular wind speed. Calculated results have shown that the proposed strategy can better meet the demand of dynamic reactive power in wind farms, which has a great significance of guiding engineering practice.**

***Index Terms*--DFIG, IAHP, Optimization, Reactive power compensation, Wind farm**

I. INTRODUCTION

In recent years, more and more attentions have been paid to the development and reasonable utilization of renewable sources, among which the wind power is prominent [1-2]. Consequently, the development of wind power has becoming an important measure to improve the structure of power system. With the installed capacity of wind farm increased constantly, the wind farms connected directly to the power are greatly increased too. However, since the wind power is an intermittent energy source, it's power output has a large randomness. Moreover, it will consume some reactive power when the wind farm connects to the power grid [3-4]. In this case, if not handled properly, it will affect the entire grid power quality. Therefore, it has great practical significance to study the wind power reactive power compensation.

Doubly Fed Induction Generator (DFIG) is a kind of variable speed constant frequency wind generator which can output reactive power when not working in the constant power factor mode and be used as a reactive power supply for wind farm [5]. Until now, most of the papers on reactive compensation concern about the performance statically, or focus on how to take advantage of each compensator in wind farms individually [6-7]. But the research on the choice of optimal device is rare. As the wind speed is random, however, we need to consider the whole procedure dynamically according to the real time data. And the economical and practical equipment should play a more significant role.

In this paper, a comprehensive control strategy is presented about optimal reactive compensation when considering the economy and effectiveness. First, a model is built to simulate the real DFIG-based wind farms under the environment of MATLAB/Simulink, which contains several kinds of wind speed model, DFIG model and compensator model. Then the relationships between wind speed and power are shown by the simulation results. An evaluating function is defined to calculate the value of each measure under these constraint conditions with weights obtained by IAHP. Finally, the optimal procedure with the minimum value would be switched into use.

II. MAIN MATHEMATICAL MODEL IN WIND FARM

A. Wind Speed Model

Four components are usually applied to simulate random variation of wind speed, which are basic wind, gust wind, ramp wind and random wind. The details are as follows.

1) Basic Wind

Basic wind can be estimated according to the Weibull distribution parameter, which is defined by (1).

$$\bar{V} = A\tau(1+\frac{1}{K}) \tag{1}$$

where, $\bar{V}$ is basic wind speed, A and K are scale parameter and shape parameter of Weibull distribution, $\tau(1+1/K)$ is Gamma function.

2) Gusty Wind

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Gusty wind is used to describe the suddenly change characteristics, which is given in (2) and (3).

$$V_{WG} = \begin{cases} 0(t < T_{1G}) \\ V_s(T_{1G} < t < T_{1G} + T_G) \\ 0(t > T_{1G} + T_G) \end{cases} \tag{2}$$

$$V_s = (\max T_G / 2)\{1 - cos[2\pi(t / T_G) - (T_{1G} / T_G)]\} \tag{3}$$

where， V_{WG} , T_{1G} , T_G are the gusty wind speed, starting time, and cycle time, separately.

3) Ramp Wind

Gradient feature of wind speed can be simulated by the ramp wind component, which is expressed by (4).

$$V_{WR} = \begin{cases} 0(t < T_{SR}) \\ A_R \dfrac{(t - T_{SR})}{(T_{ER} - T_{SR})}(T_{SR} < t < T_{ER}) \\ A_R(t > T_{ER}) \end{cases} \tag{4}$$

where, V_{WR} , T_{SR} , T_{ER} , A_R are the ramp wind speed, starting time, ending time and maximum wind speed, separately.

4) Ramdom Wind

In order to reflect the stochastic characteristics of wind speed, random noise wind component can be applied, which is presented in (5).

$$V_{WN} = 2\sum_{i=1}^{N}[S_V(\omega_i)\Delta\omega]^{0.5}\cos(\omega_i + \phi_i) \tag{5}$$

where, ϕ_i is the random variable between $0 \sim 2\pi$, K_n is the ground roughness coefficient, F is the disturbance range, μ is the average wind speed of relative altitude, N is the sampling points of frequency spectrum, ω_i is the frequency of each frequency period, and $S_V(\omega_i)$ is the amplitude of component. The expressions of ω_i and $S_V(\omega_i)$ are shown in (6) and (7).

$$\omega_i = (i - \frac{1}{2})\Delta\omega \tag{6}$$

$$S_V(\omega_i) = \frac{2K_N F^2 |\omega_i|}{\pi^2[1 + (F\omega_i / \mu\pi)^2]^{4/3}} \tag{7}$$

Combining the four wind speed components, we can simulate the actual effect on wind turbine of the wind speed as is illustrated in (8).

$$V_W = \bar{V} + V_{WG} + V_{WR} + V_{WN} \tag{8}$$

B. DFIG Model

Convert the equation in three-phase static coordinate system using coordinate transform, the mathematical model in two-phase synchronous rotating coordinate system can be obtained.

1) Voltage Equation

The voltage equation is given by (9).

$$\begin{cases} u_{d2} = R_2 i_{d2} + p\psi_{d2} - \omega_s\psi_{q2} \\ u_{q2} = R_2 i_{q2} + p\psi_{q2} - \omega_s\psi_{d2} \\ u_{d1} = -R_1 i_{d1} + p\psi_{d1} + \omega_1\psi_{q1} \\ u_{q1} = -R_1 i_{q1} + p\psi_{q1} + \omega_1\psi_{d2} \end{cases} \tag{9}$$

where, $u_{d1}, u_{q1}, u_{d2}, u_{q2}$ are voltage components of dq axis, i_{d1} , i_{q1} , i_{d2} , i_{q2} are rotor current components of dq axis, $\psi_{d1}, \psi_{q1}, \psi_{d2}, \psi_{q2}$ are rotor flux-linkage components of dq axis.

2) Flux-linkage Equation

The rotor flux-linkage equation is presented in (10).

$$\begin{cases} \psi_{d1} = L_1 i_{d1} - L_m i_{d2} \\ \psi_{q1} = L_1 i_{q1} - L_m i_{q2} \\ \psi_{d2} = L_2 i_{d2} - L_m i_{d1} \\ \psi_{q2} = L_2 i_{q2} - L_m i_{q1} \end{cases} \tag{10}$$

where, L_1 , L_2 and L_m are the stator winding self-inductance, rotor winding self-inductance and winding mutual-inductance, separately.

3) Torque Equation

The torque equation is illustrated in (11).

$$T_e = p_n(\psi_{q1} i_{d1} - \psi_{d1} i_{q1}) = p_n L_m (i_{d1} i_{q2} - i_{q1} i_{d2}) \tag{11}$$

where, p_n is the number of rotor pole-pairs.

4) Motion Equation

The motion equation is given in (12).

$$T_L - T_e = \frac{J_g}{p_n}\frac{d\omega_m}{dt} + \frac{D_g}{p_n}\omega_r + \frac{K_g}{p_n}\theta_r \tag{12}$$

where, J_g is rotating inertia of generator, D_g is damping coefficient proportional to rotation rate, K_g is flexible torque coefficient.

The DFIG matrix of voltage and flux-linkage equations can be obtained by (9)-(12) in rotating coordinate system which is deduced as (13).