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Torque Control Methods for Wind Turbines and Their Responses

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Abstract: Torque control methods of wind turbine are mainly classified into two methods: torque-mode and speed-mode methods. The traditional torque-mode method, in which generator torque proportional to square of generator speed is determined, has been chosen in many wind turbines but its response is slower as they are larger in multi-MW size. Torque control methods based on both speed-mode and torque-mode can be used to make response of wind turbine faster. In this paper, torque control methods based on the traditional torque-mode method are applied to a 2.75 MW wind turbine. It is shown through some simulation results for real turbulence winds that torque control methods based on torque-mode has the merit of reducing fluctuations of generated power than PI controller based on speed-mode.

Keywords: Wind turbine, optimal-mode gain, speed-mode, torque-mode, generator acceleration, aerodynamic torque

1. INTRODUCTION

Recently, the increasing wind turbine size and the greater penetration of wind turbine energy have been demanding the use of active controlled speed. Multi-MW variable-speed and variable-pitch (VSVP) wind turbines have been used to improve power quality in their power control systems. The main objective of torque control is to extract maximum power below rated wind speed from the potential aerodynamic power of the wind. To meet the objective power coefficient must be controlled to be a maximum value. Torque control methods of wind turbines are classified into two cases; torque-mode control and speed-mode control[1,2]. In speed-mode control, a well-known PI controller is mostly used to generate appropriate torque demand of generator. In the traditional torque-mode control, a well-known method using optimal-mode gain is used in many real wind turbines and its torque demand of generator is produced proportional to square of the generator speed.

The quadratic algorithm of the traditional torque mode control works well and gives smooth and stable control. But it is necessary to make its response faster when real turbulence winds and large rotor inertia are considered. In this paper, torque control methods based on the traditional torque-mode control are investigated to manipulate the generator torque to cause the rotor speed to change faster.

2. SPEED-MODE CONTROL METHOD

In speed-mode control method, error signal for speed is calculated and torque demand of generator is determined by a well-known PI controller as Eq. (1) to minimize the speed error($e = \Omega_{ref} - \Omega_g$).

$$C_q(s) = K_p + \frac{K_i}{s} \tag{1}$$

The measured or estimated wind speed(V) is used to compute the speed reference(Ω_{ref}). The main objective of torque control is to extract maximum power which means that tip speed ratio follows λ_{opt}. So, the speed reference is defined as $\Omega_{ref} = (V\lambda_{opt})/R$ in the optimal region.

Speed-mode method assures a fast response of rotor speed if speed control loop with a high bandwidth is used.

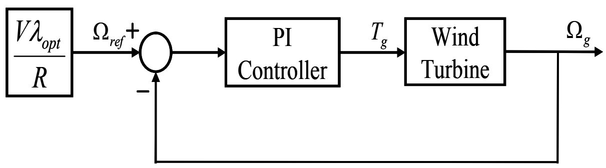

Fig. 1 Block diagram of speed mode control method.

3. TORQUE-MODE CONTROL METHOD

3.1 Traditional torque-mode control

In the traditional torque-mode method, torque demand of generator is determined proportional to square of the generator speed as Eq. (2) and Eq. (3).

$$T_g(t) = K_{opt}\Omega_g^2(t) \tag{2}$$

$$K_{opt} = \frac{\rho\pi R^5 C_{p,\max}}{2\lambda_{opt}^3 n_{gb}^3} \tag{3}$$

where Ω_g is the generator speed, ρ the air density, R the blade radius, n_{gb} the gear ratio, λ_{opt} the optimal value of tip speed ratio(λ), and $C_{p,\max}$ the maximum value of power coefficient(C_p).

Eq. (2) is obtained from the steady-state relation in torque-speed plane to extract maximum power. Its block diagram is shown in Fig. 2. Torque-mode method is intrinsically stable and very useful for small-scale wind turbines. However, it has been reported that its efficiency falls as turbine size increases due to slower response.

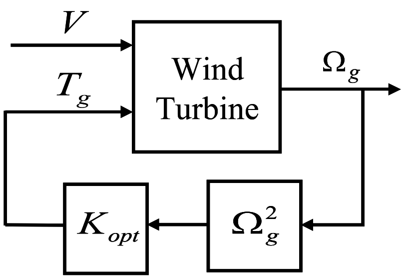

Fig. 2 Block diagram of the traditional torque-mode method.

3.2 Torque control method using generator acceleration

In this method, an additional torque demand that is proportional to rotor acceleration is used as Eq. (4). Its block diagram is shown in Fig. 3. This method allows the generator speed to respond more rapidly to changes in wind speed by reducing the effective inertia actively.

$$T_g(t) = K_{opt}\Omega_g^2(t) - K_d\dot{\Omega}_g(t) \qquad (4)$$

where K_d is proportional gain for generator acceleration signal.

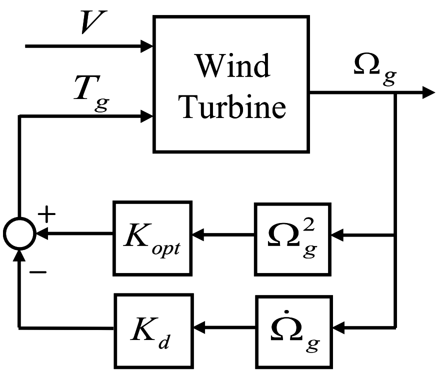

Fig. 3 Block diagram of the torque control method using generator acceleration

3.3 Torque control method using aerodynamic torque

In this method, an additional torque demand that is proportional to the torque error between original torque and aerodynamic torque is used as Eq. (5). Its block diagram is shown in Fig. 4. This method also allows the generator speed to respond more rapidly to changes in wind speed by reducing the torque error.

$$T_g(t) = K_{opt}\Omega_g^2(t) - K_a(T_a(t) - K_{opt}\Omega_g^2(t)) \qquad (5)$$

where K_a is proportional gain for the torque error signal.

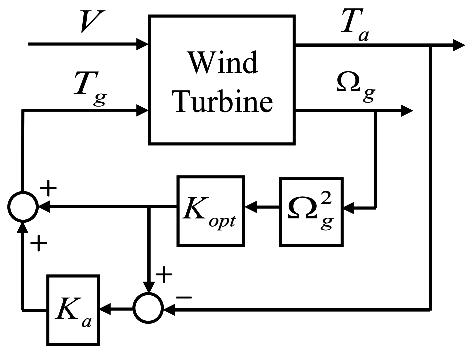

Fig. 4 Block diagram of the torque control method using aerodynamic torque

4. NUMERICAL SIMULATIONS

A comparative investigation into responses of the four control methods was made by using simulation results for a 2.75 MW wind turbine[3]. The closed-loop system behaviors have been simulated under realistic wind profiles as Fig. 5 of half sine wave wind and Fig. 6 which represents mean wind speed of 6.2m/s with turbulence intensity of 10%. The turbulence wind was obtained by using the Von Karman spectrum in the IEC standard. In the simulation results, Case 1 corresponds to the traditional torque-mode control method, Case 2 does to the speed-mode control method using PI controller, Case 3 does to the torque-mode control method using generator acceleration, and Case 4 does to the torque-mode control method using aerodynamic torque. The responses of Case 3 and Case 4 are almost same. Fig. 7 and Fig. 8 show that Case 2, Case 3, and Case 4 make response of generator speed faster than Case 1. Case 2 has overshoot in response of generator speed. But there are no overshoot in Case 3 and Case 4 which have an additional torque term based on torque-mode control method. Fig. 9 shows the responses when torque control is used under turbulence wind. More generator torque oscillations are produced and more power fluctuation occurs as a consequence of this in Case 2 than in Case 3(or Case 4).

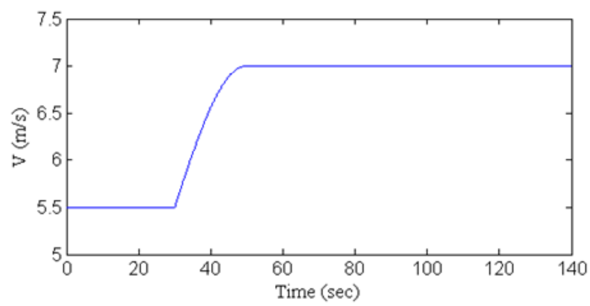

Fig. 5 Simulated half sine wave wind.

(2)

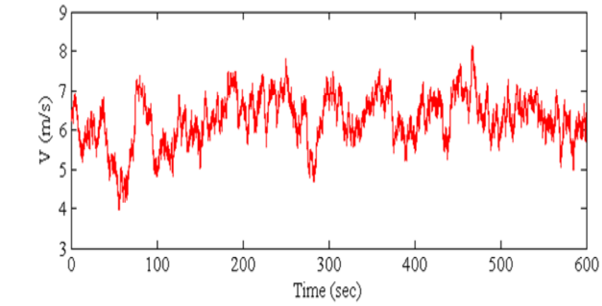

Fig. 6 Simulated turbulence wind.

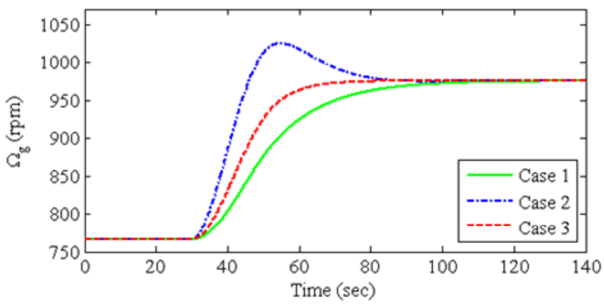

Fig. 7 Comparison of responses to half sine wave wind.

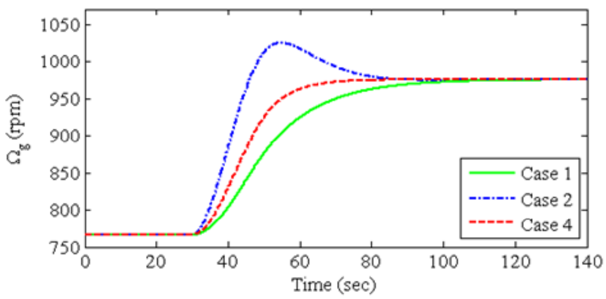

Fig. 8 Comparison of responses to half sine wave wind.

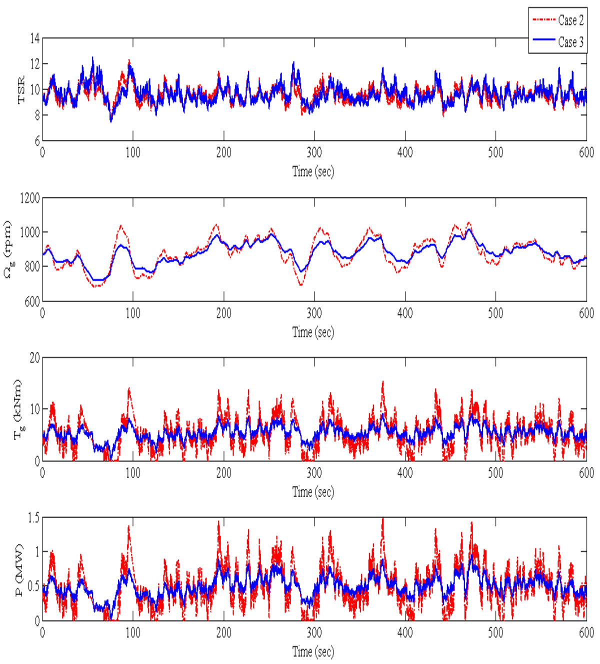

Fig. 9 Comparison of responses to turbulence wind.

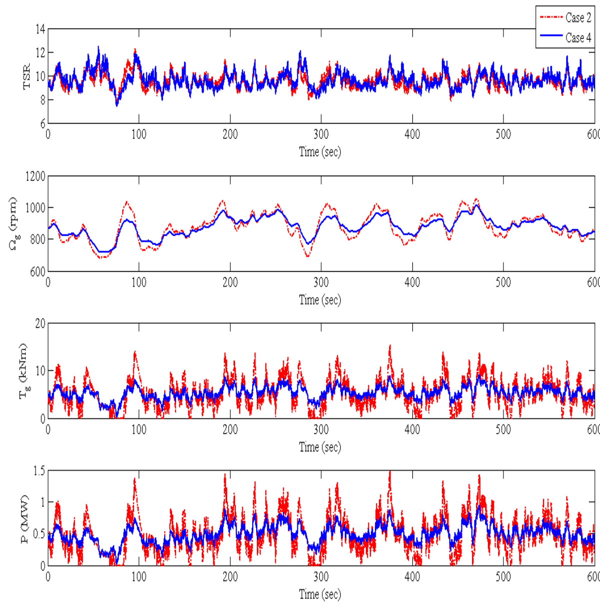

Fig. 10 Comparison of responses to turbulence wind.

4. CONCLUSION

In this paper, simulation results for four torque control methods were presented and compared for a 2.75 MW wind turbine. Realistic wind speeds as half sine wave wind and turbulence wind were used for simulations. Faster responses occur in PI controller based on speed-mode and two control methods(using generator speed and aerodynamic torque) based on torque-mode than the traditional torque-mode control method. However, speed-mode control method which has overshoot in response of generator speed produces more power fluctuations. Therefore, in the aspect of power fluctuations, torque control methods based on torque-mode are more adequate than speed-mode control.

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