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Mitigation of Wind Power Fluctuation by Active Current Control of Variable Speed Wind Turbines

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Abstract

Wind shear and tower shadow are the sources of power fluctuation of grid connected wind turbines during continuous operation. This paper presents a simulation model of a MW-level doubly fed induction generator (DFIG) based variable speed wind turbine with a partial-scale back-to-back power converter in Simulink. A simple and effective method of wind power fluctuations mitigation by active current control of DFIG is proposed. It smoothes the generator output active power oscillations by adjusting the active current of the DFIG, such that the power oscillation is stored as the kinetic energy of the wind turbine. The simulations are performed on the NREL 1.5MW upwind reference wind turbine model. The simulation results are presented and discussed to demonstrate the validity of the proposed control method.

Keywords: Doubly fed induction generator, active power control, power fluctuation, FAST

1. Introduction

Wind energy is one of the most promising renewable energy resources because of increased energy demand and environmental pollution in recent years. With the increase of the wind turbine capacity, wind power penetration into the grid increases prominently and the influence of wind turbines on the power quality becomes an important issue.

Grid connected variable speed wind turbines are fluctuating power sources during continuous operation. The power fluctuation is normally referred to as the 3p oscillations which are caused by wind speed variation, wind shear and tower shadow effects. As a consequence, the output power will drop three times per revolution for a three-bladed wind turbine.

In some literatures, several methods have been proposed for the mitigation of wind power fluctuations of grid connected wind turbines. Pitch control is used to mitigate the power fluctuations in [1], but the control algorithm is quite complex. Reactive power compensation is the most commonly used technique, however, this method shows its limits, when the grid impedance angle is low in some distribution networks [2]. Also active power control by varying the DC-link voltage of the back to back converter is presented to attenuate the power fluctuation [3]. But the big DC-link capacitor is required in the method due to the storage of the fluctuation power in the DC-link.

In this paper, a new and simple control scheme for mitigation of power oscillations by controlling the active current of DFIG is proposed. The power oscillations due to 3p and higher harmonics are absorbed by the wind turbine rotor due to its large inertia and rotating speed fluctuation, such that the output active power of the generator is smoothed prominently. The FAST (Fatigue, Aerodynamics, Structures, and Turbulence) code which is qualified to simulate the complexity of the wind turbine is adopted in the simulation. The traditional and new control schemes are described and analyzed and the validity of the proposed method is verified by the simulation results.

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2. Wind Turbine Model

The DFIG based wind turbine system is shown in Fig. 1. It consists of a wind turbine, gearbox, DFIG, a back-to-back converter which is composed of rotor side converter (RSC) and grid side converter (GSC) and a dc-link capacitor as energy storage placed between the two converters. In this paper, turbulent wind is simulated by TurbSim. Wind turbine code FAST is used to simulate the mechanical parts of wind turbine and the drivetrain. The controllers, DFIG, and power system are modeled by Simulink blocks.

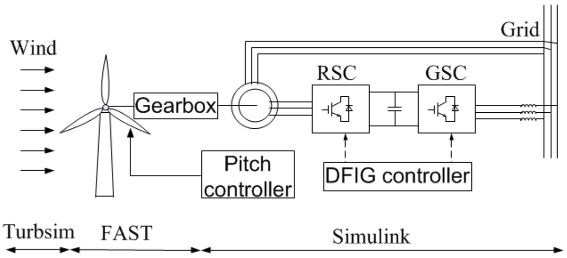

Fig. 1. The overall scheme of the DFIG based wind turbine system.

2.1. TurbSim and FAST

TurbSim and FAST are developed at the National Renewable Energy Laboratory (NREL) and they are accessible and free to the public. TurbSim is a stochastic, full-field, turbulent-wind simulator. It numerically simulates time series of three-dimensional wind velocity vectors at points in a vertical rectangular grid. TurbSim output can then be used as input into FAST [4]. The open source code FAST can be used to model both two and three bladed, horizontal-axis wind turbines. It uses Blade Element Momentum (BEM) theory to calculate blade aerodynamic forces and uses an assumed approach to formulate the motion equations of the wind turbine. For three-bladed wind turbines, 24 DOFs (Degree of Freedoms) are used to describe the turbine dynamics. Their models include rigid parts and flexible parts. The rigid parts include earth, base plate, nacelle, generator, and hub. The flexible parts include blades, shaft, and tower. FAST runs significantly faster than a large comprehensive code such as ADAMS because of the use of the modal approach with fewer degrees of freedoms (DOFs) to describe the most important parts of turbine dynamics.

2.2. Mechanical drivetrain

In order to take into account the effect of the generator and drivetrain to the wind turbine, a two-mass model is used which is suitable for transient stability analysis [5] shown in Fig. 2. The drivetrain modeling is implemented in FAST, and all values are cast on the wind turbine side.

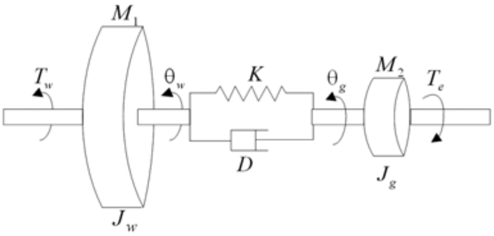

Fig. 2. Two-mass model of the drivetrain

The equations for modeling the drivetrain are given by:

$$J_w \frac{d^2\theta_w}{dt^2} = T_w - D(\frac{d\theta_w}{dt} - \frac{d\theta_g}{dt}) - K(\theta_w - \theta_g) \tag{1}$$

$$J_g \frac{d^2\theta_g}{dt^2} = D(\frac{d\theta_w}{dt} - \frac{d\theta_g}{dt}) + K(\theta_w - \theta_g) - T_e \tag{2}$$

where Jw, Jg are the moment of inertia of wind turbine and generator, respectively; Tw, Te are the wind turbine torque and generator electromagnetic torque, respectively; θw, θg are the mechanical angle of wind turbine and generator; K is the drivetrain torsional spring; D is the drivetrain torsional damper.

2.3. DFIG model

The model of the DFIG in Simulink is based on *d-q* equivalent model. All electrical variables are referred to the stator. The DFIG is controlled in a synchronously rotating *d-q* reference frame with the *d* axis aligned along the stator flux position.

The equations of DFIG can be written as:

$$T_e = \frac{3}{2} p \frac{L_m}{L_s} \psi_s i_{qr} \tag{3}$$

where p is the number of pole pairs, L_m is the magnetizing inductance, L_s is the stator inductance, ψ_s is the stator flux, i_{qr} is the rotor current q-axis component, which is the active current. The speed adjustment of the generator can be implemented by its active current control.

3. Basic Control Scheme

There are mainly two control modes for variable speed wind turbines according to different wind speed. When the wind speed is above the cut-in wind speed and below the rated wind speed, the goal of the wind turbine control is to maintain the optimal tip speed ratio such that the maximum wind power could be captured. Above the rated wind speed, the control objective is to keep the output power constant at the rated value by pitch control in order not to overload the system.

Vector control techniques are the most commonly used methods for the DFIG based wind turbine system. Two vector control schemes are designed respectively for the RSC and GSC, as shown in Fig. 3. The objective of RSC is to implement maximum power tracking by controlling the active current of DFIG, while the objective of GSC is to keep the DC-link voltage constant. Usually the values of reactive power of RSC and GSC are set to zero to ensure unity power factor operation and reduce the current of RSC and GSC.

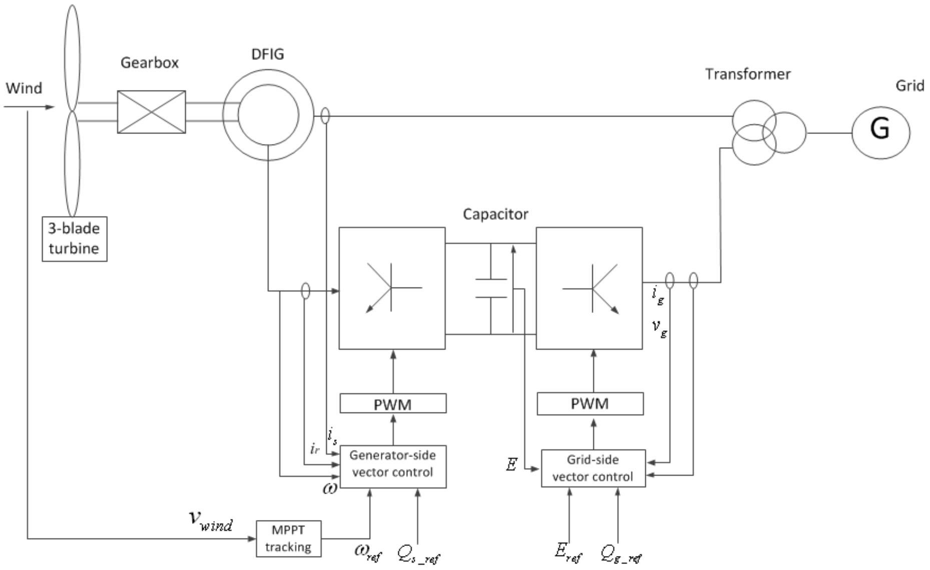

Fig. 3. Control diagram of RSC and GSC of grid-connected wind turbine with DFIG.

4. Mitigation of Electrical Power Fluctuation by Active Current Control

The traditional vector control of RSC shown in Fig. 3 varies the electromagnetic torque to implement the optimal speed tracking according to different wind speed. For a given wind speed, the RSC can control the generator rotating at a specific speed to capture maximum available wind power. For a three bladed wind turbine, due to the tower shadow effect which means when each blade in front of the tower the wind directly in front of the tower is redirected and thereby reduces the torque, so the wind turbine aerodynamic torque as well as the aerodynamic power will drop three times per revolution which will lead to the generator output power fluctuation three times per revolution.

Due to the large inertia of the wind turbine rotor, if the rotor speed contains a small component with 3p frequency, a large amount of 3p wind energy will be stored in the wind turbine rotor. Thus if the generator torque does not contain the 3p frequency, the 3p wind power will be automatically stored in the speed fluctuation of wind turbine rotor. Based on this concept, the new control scheme is proposed in Fig. 4.

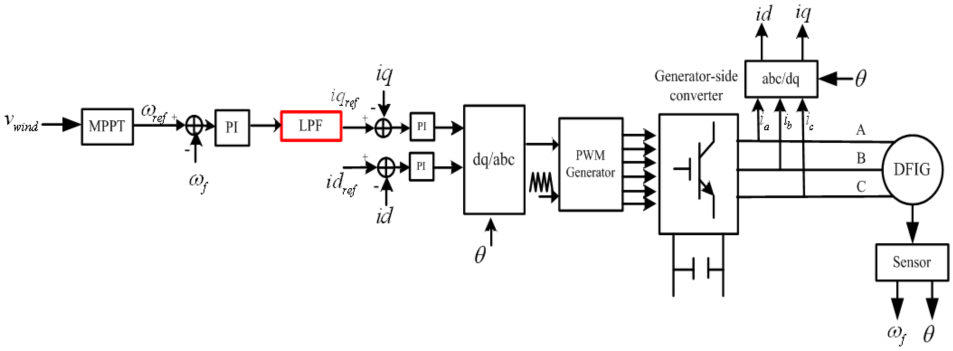

Fig. 4. New control diagram of RSC of DFIG.

A low pass filter which will let only the active current with low frequencies pass is added in the active current control path, such that the 3p, 6p and higher frequencies will not be involved in the active current as well as electromagnetic torque according to (3). In most cases, the mean wind speed is from 5 to 25 m/s. The optimal rotor speed is from 1 to 2.147 rad/s, which corresponds to the 3 p frequency from 3 to 6.441 rad/s. So the cut-off frequency of the LPF should be designed smaller than 3rad/s.

5. Simulation Results

In order to verify the validity of the proposed control strategy, some simulation results are obtained from different control modes. The parameters of the DFIG and NREL 1.5 MW wind turbine are shown in Table 1.

Fig. 5 shows the high wind speed with mean speed of 13m/s, so the pitch angle should be tuned to keep the output power at the rated value. The generator output power and its spectrum are shown in Fig. 6 and Fig. 7, from which the power oscillation with 3p and higher frequencies are prominently reduced by active current control. Fig. 8 is the generator speed fluctuation which shows the generator speed and rotor speed fluctuate in a wider range by active current control, and Fig. 9 and 10 are the electrical torque and aerodynamic torque, from which it is shown that the both the aerodynamic torque and electrical torque oscillate in a smaller range proving the capability of the proposed active current control. Fig. 11 and 12 are the wind turbine output mechanical power and its spectrum, from which the output mechanical power with 3p and higher frequencies are reduced significantly which is an obvious advantage. This is because the energy with 3p and higher frequencies are stored in the wind turbine rotor as kinetic energy. So the active current control of the generator can mitigate not only the generator output power oscillation, but also the wind turbine mechanical power oscillation, such that the wind turbine load can be reduced so as to prolong the lifetime of the wind turbine.

Similar simulation results can be obtained under low wind speed. Here only the low wind speed and generator power are given in Fig. 13 and 14.

Table 1. Parameters of DFIG and wind turbine

Parameter	Value	Parameter	Value
Rated capacity (MW)	1.5	Blade radius (m)	35
Rated stator voltage (V)	690	Number of blades	3
Rated frequency (Hz)	50	Cut-in/cut-out wind speed (m/s)	3/25
Stator resistance (pu)	0.022	Gearbox ratio	81
Rotor resistance (pu)	0.026	Drivetrain torsional spring (Nm/rad)	5.6e9
Stator leakage inductance (pu)	0.177	Drivetrain torsional damper (Nm/s)	1.0e7
Rotor leakage inductance (pu)	0.116	Hub height (m)	82
Magnetizing inductance	4.68	Rated power (MW) of wind turbine	1.5
Number of pole pairs	2	Max/min pitch angle (degree)	45/0
Lumped inertia constant (s)	3.0	Max pitch rate (degree/s)	10

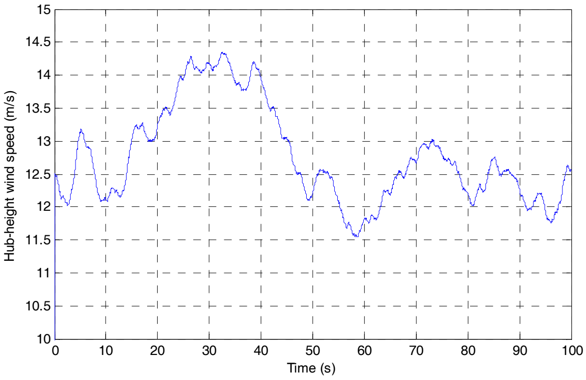

Fig. 5. High wind speed

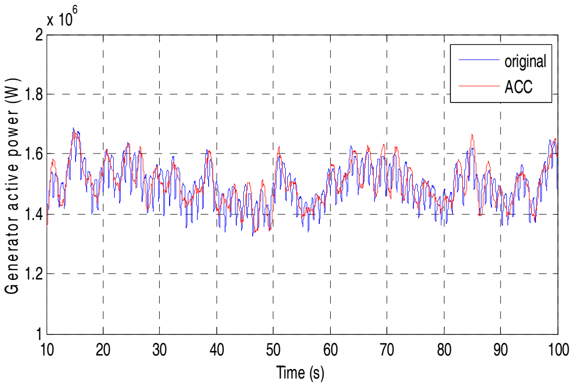

Fig. 6. Generator output power (long time)

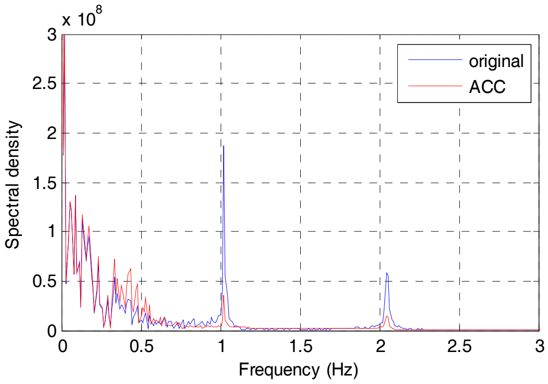

Fig. 7. Spectral density of generator power

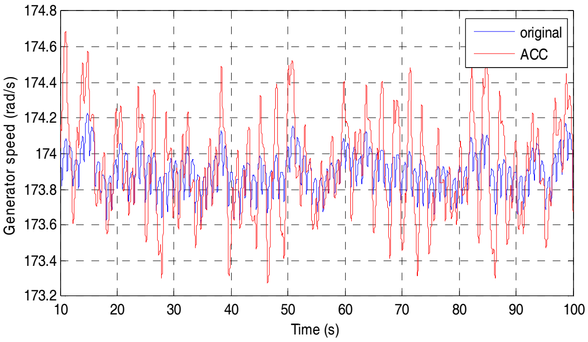

Fig. 8. Generator speed

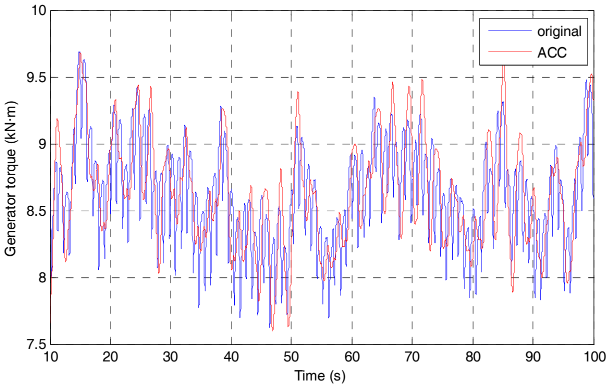

Fig. 9. Generator torque

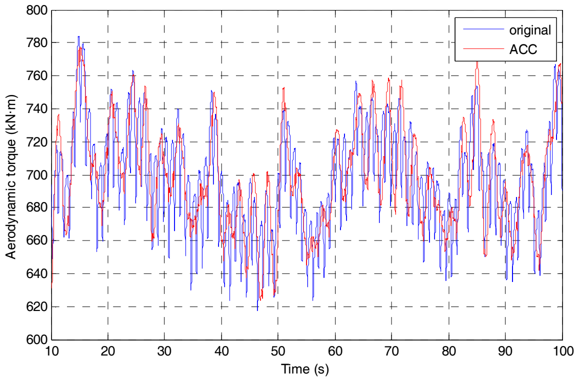

Fig. 10. Aerodynamic torque

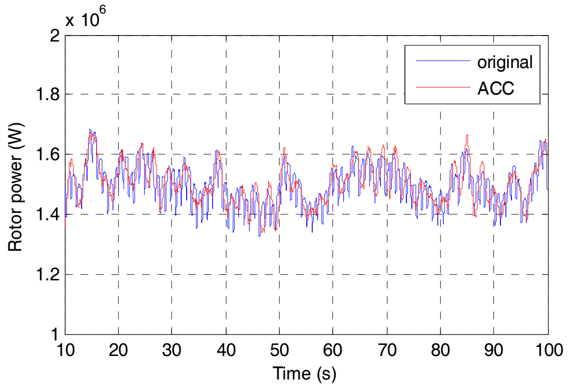

Fig. 11. Wind turbine mechanical power

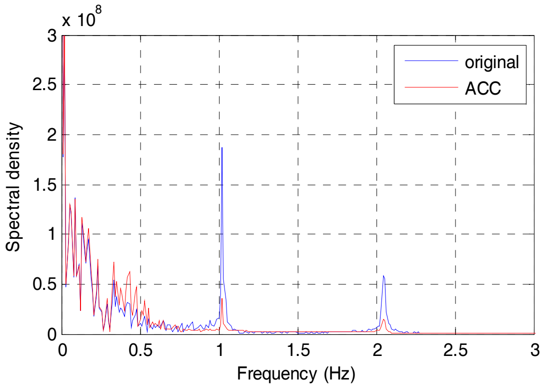

Fig. 12. Spectral density of wind turbine mechanical power

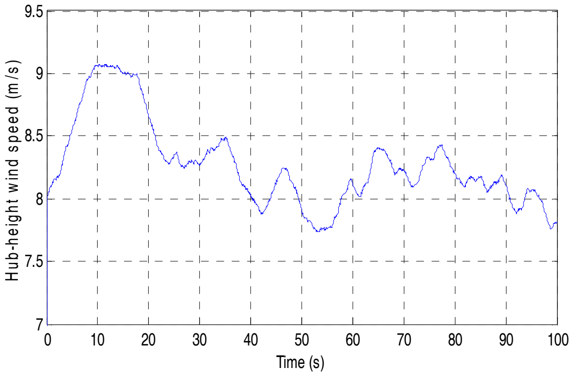

Fig. 13. Low wind speed

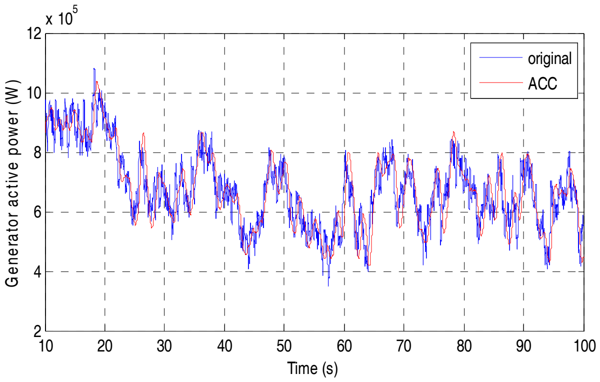

Fig. 14. Generator output power

6. Conclusion

A MW-level DFIG based variable speed wind turbine system and control schemes are described using Simulink, Turbsim and FAST. A new and simple method of active current control of DFIG is proposed to mitigate the output power fluctuation due to wind shear and tower shadow effects. The wind power with 3p and higher frequencies are stored in the wind turbine rotor by controlling the electromagnetic torque of DFIG with a low pass filter. The simulation results demonstrate the active current control can not only reduce the generator power oscillation, but also reduce the wind turbine output mechanical power, demonstrating the capability of the proposed strategy.

References

[1] Senjyu T, Sakamoto R, Urasaki N, Funabashi T, Fujita H, Sekine H. Output power leveling of wind turbine generator for all operating regions by pitch angle control. *IEEE Transactions on Energy conversion*, 2006; 21(2):467-475.

[2] Sun T, Chen Z, Blaabjerg F. Flicker study on variable speed wind turbines with doubly fed induction generators. *IEEE Transactions on Energy Conversion*, 2005; 20(4):896-905.

[3] Hu W, Chen Z, Wang Y, Wang Z. Flicker mitigation by active power control of variable-speed wind turbines with full-scale back-to-back power converters. *IEEE Transactions on Energy Conversion*, 2009; 24(3):640-649.

[4] Jonkman BJ, Buhl MLJ. *FAST User's Guide*. National renewable energy laboratory (NREL). [Online]. Available: http://wind.nrel.gov/designcodes/simulators/fast/

[5] Muyeen SM, Hasan MD, Takahashi R, Murata T, Tamura J, Tomaki Y, Sakahara A, Sasano E, Comparative study on transient stability analysis of wind turbine generator system using different drive train models. *IET Renewable Power Generation*, 2007; 1(2):131-141.