

Individual Pitch Control of Variable Speed Wind Turbines with DFIG by Flicker Mitigation

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ABSTRACT:

Due to the wind speed variation, wind shear and tower shadow effects, grid connected wind turbines are the sources of power fluctuations which may produce flicker during continuous operation. This paper presents a model of an MW-level variable speed wind turbine with a doubly fed induction generator to investigate the flicker emission and mitigation issues. An individual pitch control (IPC) strategy is proposed to reduce the flicker emission at different wind speed conditions. The IPC scheme is proposed and the individual pitch controller is designed according to the generator active power and the azimuth angle of the wind turbine. The simulations are performed on the NREL (National Renewable Energy Laboratory) 1.5-MW upwind reference wind turbine model. Simulation results show that damping the generator active power by IPC is an effective means for flicker mitigation of variable speed wind turbines during continuous operation.

Index Terms—Flicker, flicker mitigation, individual pitch control (IPC), variable speed wind turbine

INTRODUCTION:

DURING the last few decades, with the growing concerns about energy shortage and environmental pollution, great efforts have been taken around the world to implement renewable energy projects, especially wind power projects. With the increase of wind power penetration into the grid, the power quality becomes an important issue. One important aspect of power quality is flicker since it could become a limiting factor for integrating wind turbines into weak

grids, and even into relatively strong grids if the wind power penetration levels are high. Flicker is defined as “an impression of unsteadiness of visual sensation induced by a light stimulus, whose luminance or spectral distribution fluctuates with time”. Flicker is induced by voltage fluctuations, which are caused by load flow changes in the grid. Grid-connected variable speed wind turbines are fluctuating power sources during continuous operation. The power fluctuations caused by wind speed variation, wind shear, tower shadow, yaw errors, etc., lead to the voltage fluctuations in the network, which may produce flicker. Apart from the wind power source conditions, the power system characteristics also have impact on flicker emission of grid-connected wind turbines, such as short-circuit capacity and grid impedance angle. The flicker emission with different types of wind turbines is quite different. Though variable-speed wind turbines have better performance with regard to the flicker emission than fixed-speed wind turbines, with the large increase of wind power penetration level, the flicker study on variable speed wind turbines becomes necessary and imperative

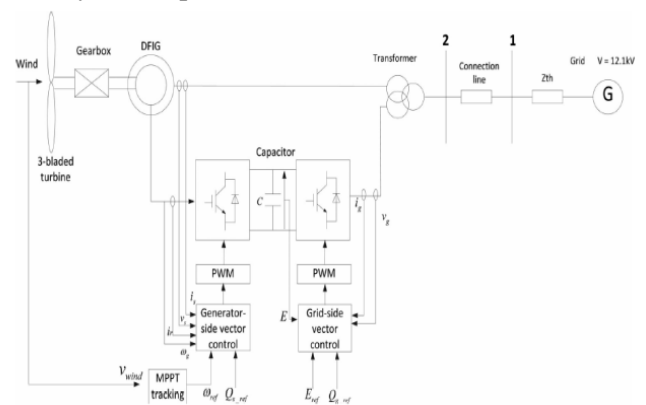


Fig. 1. Overall scheme of the DFIG-based wind turbine system.

Existing System:

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

FAST

The open source code FAST is developed at the National Renewable Energy Laboratory (NREL) and accessible and free to the public. FAST can be used to model both two and three bladed, horizontal-axis wind turbines. It uses Blade Element Momentum 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 degree of freedoms (DOFs) 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 fast because of the use of the modal approach with fewer DOFs to describe the most important parts of turbine dynamics.

Proposed System:

For a DFIG-based variable speed wind turbine, the control objective is different according to different wind speed. In low wind speed, the control goal is to keep the tip speed ratio optimum, so that the maximum power can be captured from the wind. In high wind speed, since the available power is beyond the wind turbine capacity, which could overload the system, the control objective is to keep the extracted power constant at its rated value. Vector control techniques are the most commonly used methods for a back-to-back converter in a wind turbine system. Two vector control schemes are illustrated, respectively, for the RSC and GSC, as shown in Fig. 1, where v_s , and i_s

are the stator voltage and current, i_r is the rotor current, v_g is the grid voltage, i_g is the GSC currents, w_g is the generator speed, E is the dc-link voltage, P_s ref, and Q_s ref are the reference values of the stator active and reactive power, Q_r ref is a reference value of the reactive power flow between the grid and the GSC, E_{ref} is the reference value of the dc-link voltage, C is the dc-link capacitor. The vector control objective for RSC is to implement maximum power tracking from the wind by controlling the electrical torque of DFIG. The reference value of the generator speed ω_{ref} is obtained via a lookup table to enable the optimal tip speed ratio.

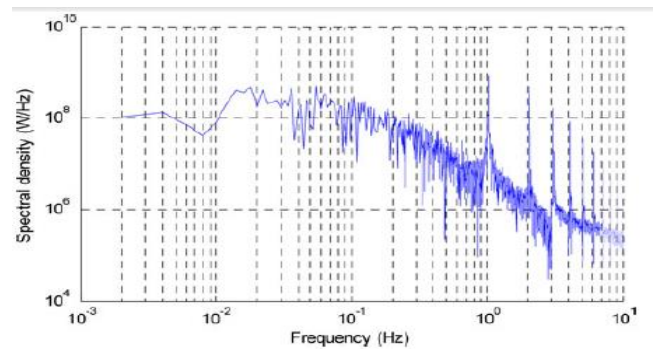
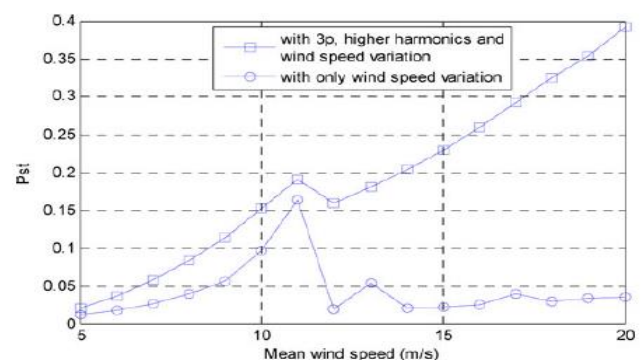


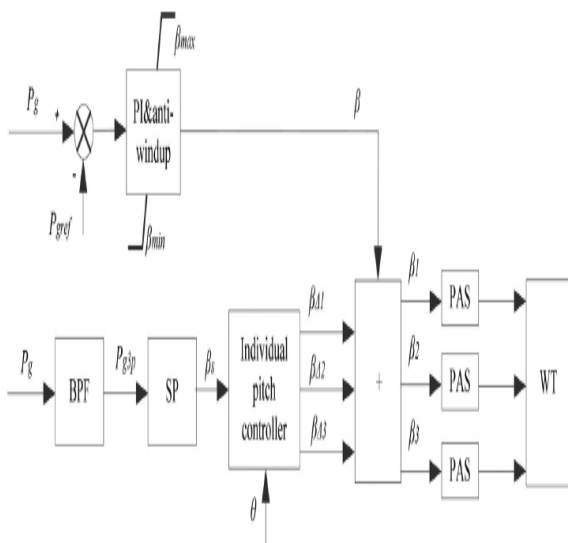
Fig. 5. Spectral density of the generator output power.



INDIVIDUAL PITCH CONTROL FOR FLICKER MITIGATION

This section concentrates on flicker mitigation of variable speed wind turbines with DFIG during continuous operation using IPC. The flicker emission produced by grid connected wind turbines during continuous operation is mainly caused by fluctuations in the generator active power. As illustrated in Fig. 6, the flicker emission will be mitigated effectively if the

3p and higher harmonics of the generator power can be reduced. When the wind speed is above the rated wind speed, the pitch angle should be tuned by a traditional collective pitch control (CPC) to keep the output power at its rated value in order not to overload the system, and normally the 3p effect is not taken into consideration. For attenuating the generator power oscillation caused by the 3p effect, each of the three pitch angles can be added by a small pitch angle increment, which is dependent on the generator active power and wind turbine azimuth angle. When the wind speed is below the rated wind speed, usually the control objective of the wind turbine is to implement maximum power tracking by generator electrical torque control. Pitch control is not used in this area. However if the pitch angles can be adjusted around a small average value, the 3p effect can also be reduced. For this purpose, the output of the CPC should leave a small amount of residual for pitch movement. This means a small part of wind energy will be lost.



Proposed individual pitch control scheme

SIMULATION STUDIES USING IPC

The flicker mitigation using IPC is tested in many wind speed conditions. The variable speed wind turbine with DFIG and back-to-back converter are simulated with the proposed IPC method. The parameters of NREL 1.5-MW wind turbine with DFIG are shown in the Appendix.

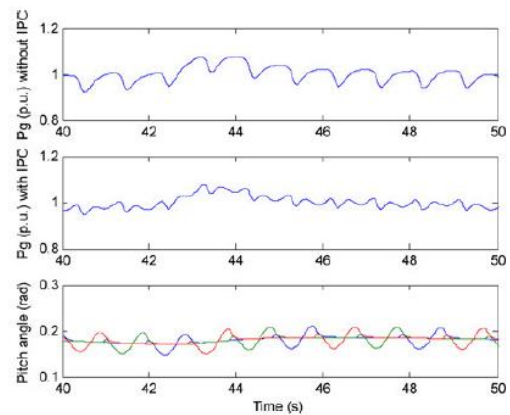


Fig. 9. Short-term view of the generator active power without and with IPC, and individual pitch angles (high wind speed).

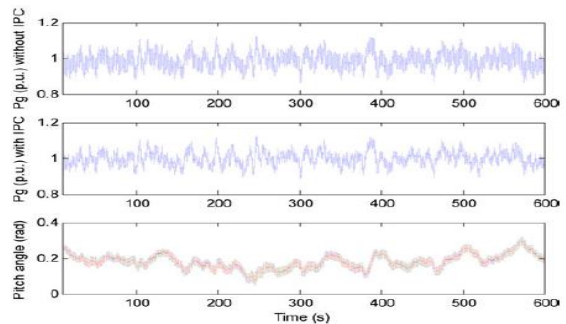


Fig. 10. Long-term view of the generator active power without and with IPC, and pitch angle (high wind speed).

Drop occurs which is caused by wind shear, tower shadow, and wind speed variation, etc., one of the blades will accordingly reduce its pitch angle, thus the generator active power will not drop so dramatically, in such a way that the power oscillation is limited in a much smaller range. A spectral density analysis of the generator active power into the grid has been conducted with IPC, as shown in Fig. 11. Compared with the spectral density of generator active power without IPC in Fig. 5, the 3p oscillation frequency component which is significant in flicker emission of variable speed wind turbines during continuous operation is damped evidently with IPC. As a consequence, the flicker level may be reduced by using IPC.

CONCLUSION

This paper describes a method of flicker mitigation by IPC of variable-speed wind turbines with MW-level DFIG. The modeling of the wind turbine system is carried out using FAST and Simulink. On the basis of

the presented model, flicker emission is analyzed and investigated in different mean wind speeds. To reduce the flicker emission, a novel control scheme by IPC is proposed. The generator active power oscillation which leads to flicker emission is damped prominently by the IPC in both high and low wind speeds. It can be concluded from the simulation results that damping the generator active power oscillation by IPC is an effective means for flicker mitigation of variable speed wind turbines during continuous operation.

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