Individual Pitch Control for Mitigation of Power fluctuation

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Abstract- **Grid connected wind turbines are the sources of power fluctuations during continuous operation due to wind speed variation, wind shear and tower shadow effects. This paper presents an individual pitch control (IPC) strategy to mitigate the wind turbine power fluctuation at both above and below the rated wind speed conditions. Three pitch angles are adjusted separately according to the generator output power and the azimuth angle of the wind turbine. The IPC strategy scheme is proposed and the individual pitch controller is designed. The simulations are performed on the NREL (National Renewable Energy Laboratory) 1.5MW upwind reference wind turbine model. The simulation results are presented and discussed to show the validity of the proposed control method.**

Index Terms- **Wind Turbine; IPC; Power Fluctuation; FAST**

I. INTRODUCTION

During the last few decades, with the growing concerns about environmental pollution and energy shortage, great efforts have been taken around the world to implement renewable energy projects. With advanced techniques, cost reduction and low environmental impact, wind energy is certain to play an important role in the world's energy [1]. With the capacity increase of the wind turbines, wind power penetration into the grid increases dramatically and 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 wind turbine aerodynamic power will drop three times per revolution for a three-bladed wind turbine. Several methods have been proposed for the mitigation of wind power fluctuations of grid connected wind turbines in some literatures. 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 a big DC-link capacitor is required in the method due to the storage of the fluctuation power in the DC-link. These papers use compensation or absorption methods to reduce the power oscillations, which have not solved the problem from the source part of wind turbine system for the power fluctuations.

A number of solutions have been presented to mitigate the flicker emission of grid-connected wind turbines. The most commonly adopted technique is the reactive power compensation [6]. However, the flicker mitigation technique shows its limits in some distribution networks where the grid impedance angle is low [7]. When the wind speed is high and the grid impedance angle is 10◦, the reactive power needed for flicker mitigation is 3.26 per unit [8]. It is difficult for a grid-side converter (GSC) to generate this amount of reactive power, especially for the doubly fed induction generator (DFIG) system, of which the converter capacity is only around 0.3 per unit. The STATCOM which receives much attention is also adopted to reduce flicker emission.

However, it is unlikely to be financially viable for distributed generation applications. Active power control by varying the dc-link voltage of the back-to-back converter is presented to attenuate the flicker emission [8]. However, a big dc-link capacitor is required, and the lifetime of the capacitor will be shortened to store of the fluctuation power in the dc link. An open-loop pitch control is used in [6] and [8] to investigate the flicker emission in high wind speeds, however, the pitch actuation system (PAS) is not taken into account. Because the pitch rate and the time delay of the PAS make great contributions to the results of the flicker emission of variable-speed wind turbines, it is necessary to take these factors into consideration.

II.POWER FLUCTUATION ANALYSIS

Power generated by wind turbines is much more variable than that produced by conventional generators. The power fluctuations are due both to stochastic processes that determine wind speed at different times, and to periodic processes that are referred to as wind shear and tower shadow.

Wind shear is used to describe the variation of wind speed with height while tower shadow describes the redirection of wind due to the tower structure [4].

A. Wind shear

The increase of wind speed with height is known as wind shear. A common wind shear model, shown as (1), is taken directly from the literature on wind turbine dynamics [4]

B. Tower shadow

Today most wind turbines are constructed with a rotor upwind of the tower to reduce the tower interference of the wind flow. In the upwind rotor case, the wind speed V tow considering tower shadow effect can be modeled using potential flow theory [4].

C. Total aerodynamic torque

Fig. 1 illustrates the overall wind turbine aerodynamic torque, which obviously shows the 3p effect, and also the aerodynamic torque has the maximum drop when one of the three blades is directly in front of the tower.

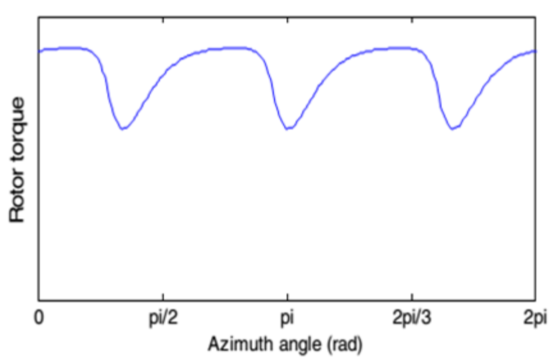


Figure 1. Aerodynamic torque involving 3p effects

III. SYSTEM CONFIGURATION

The overall scheme of DFIG based wind turbine system isshown in Fig 2, which 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 pitch and converter controllers, DFIG, and power system are modeled by Simulink blocks.

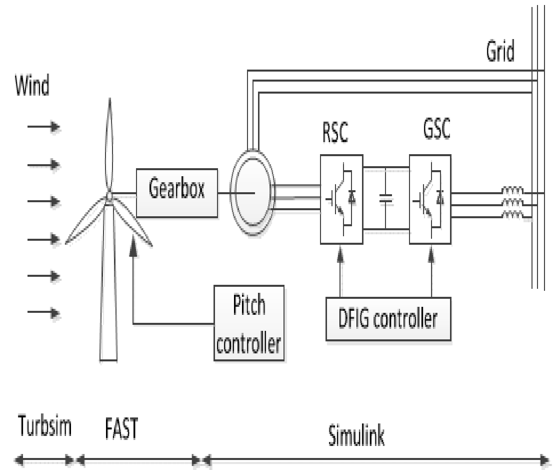


Fig. 2. The overall scheme of the DFIG based wind turbine system

A. 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 [5]. 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.

B. Mechanical Drivetrain

In order to take into account the effects of the generator and drivetrain to the wind turbine, two-mass model is used which is suitable for transient stability analysis [6] shown in Fig. 3. The drivetrain modeling is implemented in FAST, and all values are cast on the wind turbine side.

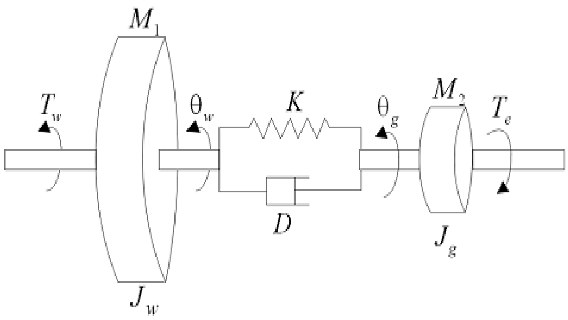


Figure 3. Two-mass model of the drivetrain

C. DFIG model and converters control

The model of the DFIG in Simulink is based on d-q equivalent model. All electrical variables are referred to the stator. Vector control techniques are the most commonly used methods for back to back converters in wind turbine system.

Two vector control schemes are illustrated respectively for the RSC and GSC, as shown in Fig. 4. Normally the control objective of RSC is to implement maximum power tracking by controlling the electrical torque of DFIG, while the objective of GSC is to keep the DC-link voltage constant.

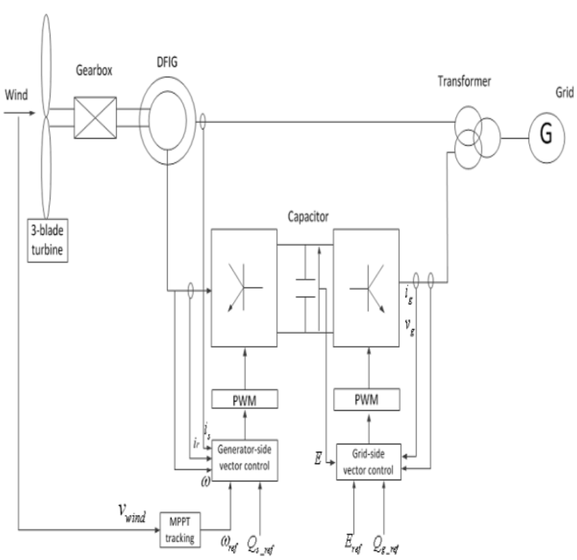


Figure 4. Control diagram of RSC and GSC of grid-connected wind turbine with DFIG

IV. INDIVIDUAL PITCH CONTROL FOR MITIGATION OF WIND TURBINE POWER FLUCTUATION

As illustrated in Fig. 1, the aerodynamic torque will drop three times per revolution, so that the aerodynamic power of the wind turbine as well as the generator output power will also drop three times in a cycle. If the aerodynamic torque can be controlled well to some extent that it will not drop or not drop So prominently when one of the blades is directly in front of the tower, the wind turbine aerodynamic power thus the generator output power will fluctuate in a much smaller range. When wind speed is above rated wind speed, pitch angle should be tuned by 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 account. For attenuating the power oscillation caused by 3peffect, one of the blade pitch angles can be added by a small pitch increment which is dependent on the wind turbine azimuth angle and the generator output power.

When wind speed is below the rated wind speed, usually the control objective of 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 pitch angle should leave a small amount of residual for pitch movement. This means part of the wind energy will be lost. Based on this control concept, a novel individual pitch control strategy is proposed. The control scheme is shown in Fig. 5.

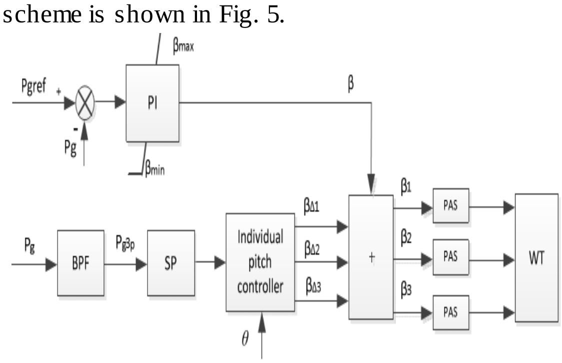


Figure 5. A novel individual pitch control scheme

The control scheme consists of two control loops: collective pitch control loop and individual pitch control loop. The collective pitch control is responsible for limiting the output power. In this loop, Pgref is the rated generator power, Pgis the generator output power, β is the collective pitch angle, of which the minimum value βmin can be obtained by simulations under different wind speeds such that power fluctuation mitigation may compromise the power loss. In the individual pitch control loop, the BPF (band pass filter) is to let the frequency of 3p generator active power through and block all other frequencies. Pg3p is the 3pcomponent of the generator power, and this component will be sent to the signal processing (SP) block, due to the fact that the power signal has to be transferred to the pitch signal.

In this paper, the wind turbine is simulated by FAST, in which blade 3 is ahead of blade 2, which is ahead of blade 1, so that the order of blades passing through a given azimuth is 3-2-1-repeat. The individual pitch controller will output a pitch increment signal which will be added to the collective pitch angle for a specific blade, dependent on the blade azimuth angle. The principle of the individual pitch controller is described in Table 1.

Table I. Control principle of individual pitch controller

Azimuth angle θ	$\beta_{\Delta i}$
$0 < \theta < 2\pi/3$	$\beta_{\Delta 2}$
$4\pi/3 > \theta > 2\pi/3$	$\beta_{\Delta 1}$
$2\pi > \theta > 4\pi/3$	$\beta_{\Delta 3}$

V. SIMULATION RESULTS

In order to verify the validity of the proposed individual pitch control strategy, the whole wind turbine system is built in Simulink, and some simulation results are obtained under both high and low wind speeds.

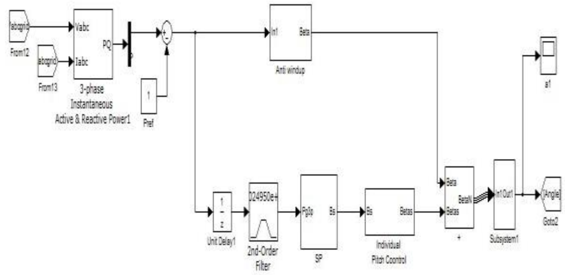
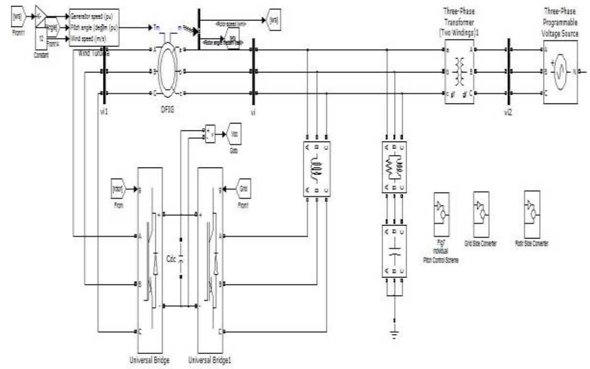


Figure 6



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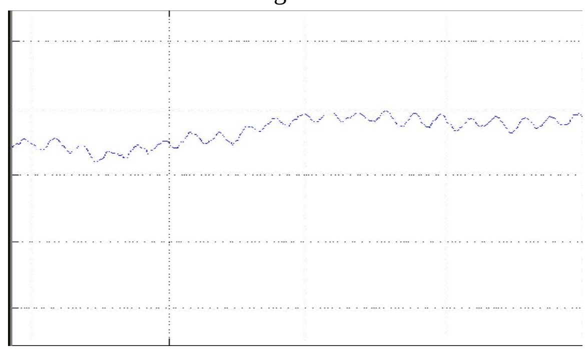

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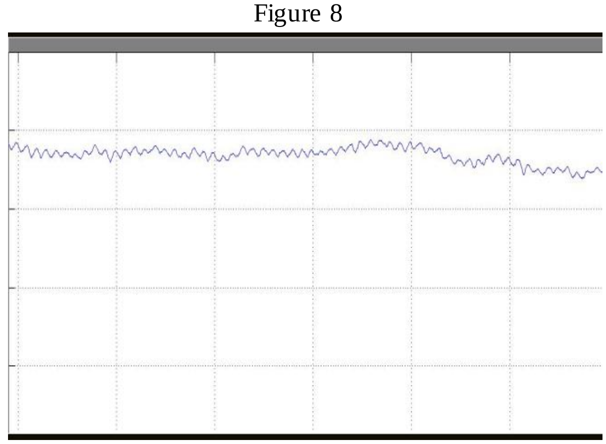

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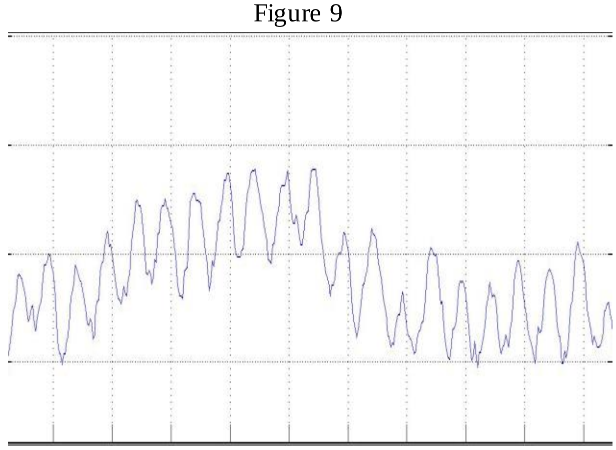

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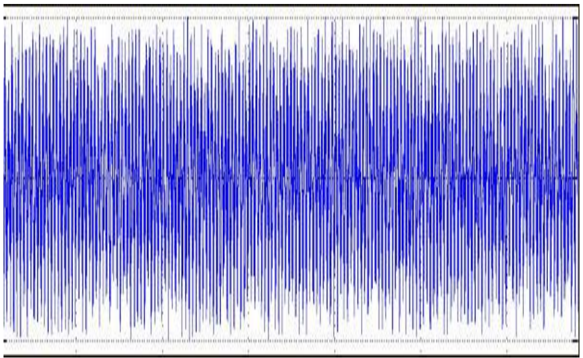

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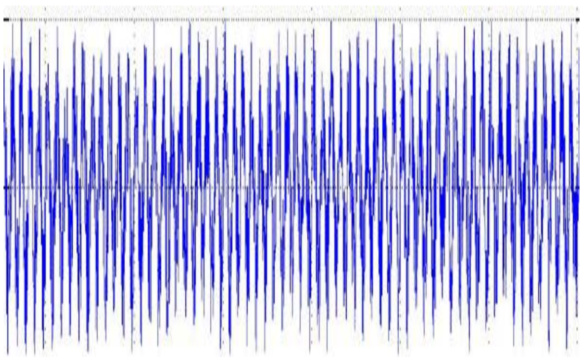

Figure 12

VI. CONCLUSION

The MW-level DFIG based variable speed wind turbine system is simulated using Simulink, Turbsim and FAST. A novel individual pitch control method is proposed to mitigate the wind turbine power fluctuation caused by wind shear and tower shadow effects. The individual pitch control scheme is presented and controller is designed. The simulations are performed on the NREL 1.5MW upwind reference wind turbine model. The simulation results demonstrate the capability of the proposed strategy.

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