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Individual Pitch Control for Mitigation of Power Fluctuation

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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 can turn out flicker throughout continuous operation. 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.*

KEYWORDS-wind turbine; IPC; power fluctuation; FAST

I. INTRODUCTION

Presently the reality vitality interest may be expandingbecause of number development and up to date modernculture persuading a considerable measure of venturesdone elective vitality wellsprings for example, Solar, Wind,bio-mass, energy units etc; "around the renewable vitalitysources, wind vitality reliably demonstrates its greatpossibility to serve Similarly as clean What's moreboundless vitality wellspring. For the increment aboutwind control infiltration under the grid, the energy calibergets to be a critical issue. We quit offering on that oneessential part from claiming force nature may be flickersince it might turn into a restricting component forcoordination wind turbines under feeble grids,Furthermore actually under generally solid grids assumingthat the wind force infiltration levels are secondary.Flicker is characterized as "an feeling of precariousness forvisual sensation prompted. Toward a light stimulus, whoseluminance or ghastly conveyance oscillates with time".Flicker may be prompted toward voltage fluctuations,which need aid initiated by load stream transforms in thegrid. Grid-connected variable velocity wind turbines arefluctuating force sources Throughout constant operation.The force variances created by wind pace variation, windshear, tower shadow, yaw errors, and so on. promptthose voltage variances in the network, which mighttransform flicker. Separated from the wind controlwellspring conditions, the control framework aspectslikewise bring effect on flicker emanation about gridconnected wind turbines, for example, such that impedeability Furthermore grid impedance point. The flickeremanation for diverse sorts for wind turbines will beexactly different. In spite of variable-speed wind turbinesare better regarding the flicker emission than fixed-speedwind turbines, with the large increase of wind powerpenetration level, the flicker study on variable speed windturbines becomes necessary and imperative.Previously there are number of ways to reduce the flickerin power generated. These are implemented by usingreactive compensation. When the grid has a very lowimpendence angle ie 100 these techniques will beredundant. For a large distributive networks the reactivepower needed for compensation will be as greater as3.26pu which is practically not possible to generate fromSTATCOM especially when DFIG is present in the system.

Another way by controlling the active power by varyingthe DC link capacitance can be used for reducing flickerbut this requires a large capacitance which is of high costand reduces the life of capacitor in storing the energy.Pitch actuating system can also be used for mitigation offlicker but time delay and pitch rate great affects thesystem. This affect is considerably large in case of variablespeed turbines.As a result of above mentioned drawbacks of existingsolutions there is a need to find an alternative solution forpower fluctuation mitigation. A novel scheme used inhelicopter industry for load reduction is applied to windturbine. That is pitching the blades individually as per thewind speed and direction of wind flow.IPC is a promisingsolution for reducing power oscillation in active powergeneration in case of distributive network systems.

II. POWER FLUCTUATION ANALYSIS

Power generated by wind turbines is much more variablethan that produced by conventional generators. The powerfluctuations are due both to stochastic processes that determinewind speed at different times, and to periodic processes that arereferred to as wind shear and tower shadow.Wind shear is usedto describe the variation of wind speed with height while towershadow describes the redirection of wind due to the towerstructure [4].

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]

Tower shadow: Today most wind turbines are constructed with a rotorupwind of the tower to reduce the tower interference of thewind flow. In the upwind rotor case, the wind speed Vtowconsidering tower shadow effect can be modeled usingpotential flow theory [4].

A. Total aerodynamic torque

Fig. 1 illustrates theoverall wind turbine aerodynamic torque, which obviouslyshows the 3p effect, and also the aerodynamic torque has themaximum drop when one of the three blades is directly in frontof the tower.

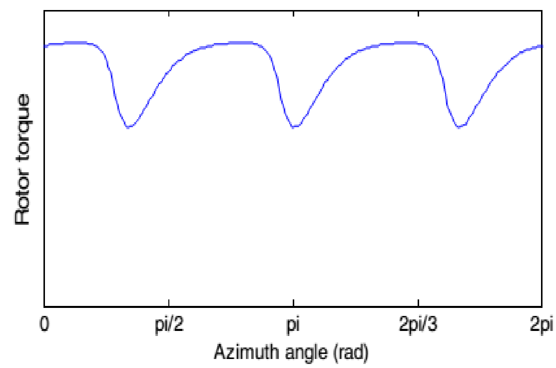

Figure 1. Aerodynamic torque involving 3p effects

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 rotorside converter (RSC) and grid side converter (GSC) and a dclink capacitor as energy storage placed between the twoconverters. In this paper, turbulent wind is simulated byTurbSim. Wind turbine code FAST is used to simulate themechanical parts of wind turbine and the drivetrain. The pitchand converter controllers, DFIG, and power system aremodeled by Simulink blocks.

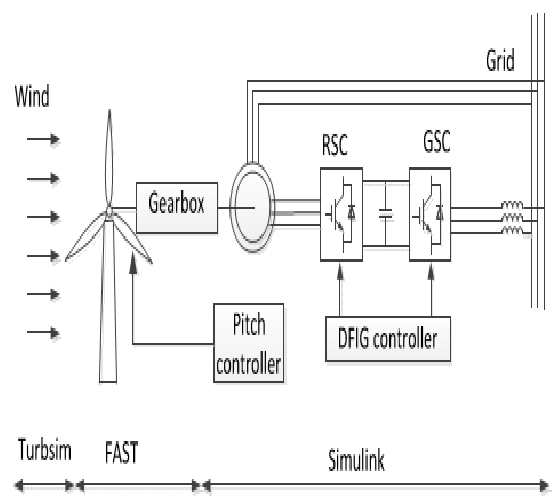

Fig. 2. The overall scheme of the DFIG based wind turbine system

A. TurbSim and FAST

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TurbSim and FAST are developed at the NationalRenewable Energy Laboratory (NREL) and they are accessibleand free to the public. TurbSim is a stochastic, full-field,turbulent-wind simulator. It numerically simulates time seriesof three-dimensional wind velocity vectors at points in avertical rectangular grid. TurbSim output can then be used asinput into FAST [5]. The open source code FAST can be usedto model both two and three bladed, horizontal-axis windturbines. It uses Blade Element Momentum (BEM) theory tocalculate blade aerodynamic forces and uses an assumedapproach to formulate the motion equations of the windturbine. For three-bladed wind turbines, 24 DOFs (Degree of Freedoms) are used to describe the turbine dynamics. Theirmodels include rigid parts and flexible parts. The rigid partsinclude earth, base plate, nacelle, generator, and hub. Theflexible parts include blades, shaft, and tower. FAST runssignificantly faster than a large comprehensive code such asADAMS because of the use of the modal approach with fewerdegrees 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 anddrivetrain to the wind turbine, two-mass model is used which issuitable for transient stability analysis [6] shown in Fig. 3. Thedrivetrain modeling is implemented in FAST, and all values are cast on the wind turbine side.

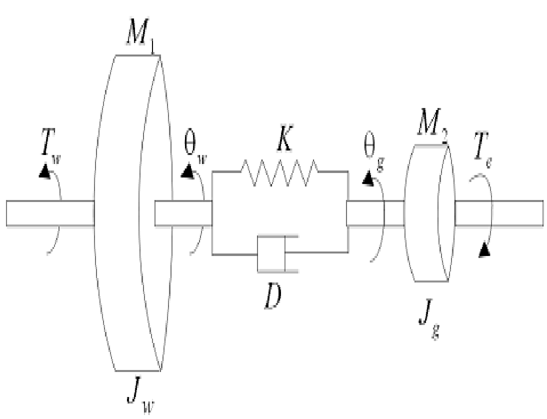

Figure 3. Two-mass model of the drivetrain

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 thestator.Vector control techniques are the most commonly usedmethods for back to back converters in wind turbine system.

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

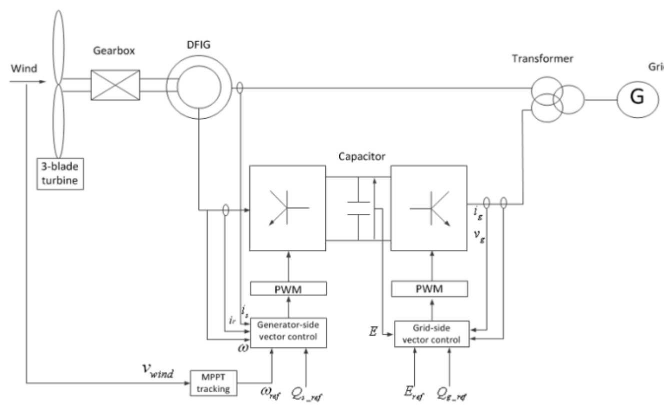

Figure 4. Control diagram of RSC and GSC of grid-connected wind turbine with DFIG

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

As illustrated in Fig. 1, the aerodynamic torque will dropthree times per revolution, so that the aerodynamic power ofthe wind turbine as well as the generator output power will alsodrop three times in a cycle. If the aerodynamic torque can becontrolled well to some extent that it will not drop or not drop so prominently when one of the blades is directly in front of thetower, the wind turbine aerodynamic power thus the generatoroutput power will fluctuate in a much smaller range.When wind speed is above rated wind speed, pitch angleshould be tuned by traditional collective pitch control (CPC) tokeep the output power at its rated value in order not to overloadthe system, and normally the 3p effect is not taken intoaccount. For attenuating the power oscillation caused by 3peffect, one of the blade pitch angles can be added by a smallpitch increment which is dependent on the wind turbineazimuth angle and the generator output power.

When wind speed is below the rated wind speed, usuallythe control objective of wind turbine is to implement maximumpower tracking by generator electrical torque control. Pitchcontrol is not used in this area. However if the pitch angles canbe adjusted around a small average value, the 3p effect can also be reduced. For this purpose, the pitch angle should leave asmall amount of residual for pitch movement. This means partof the wind energy will be lost.Based on this control concept, a novel individual pitchcontrol strategy is proposed. The control scheme is shown inFig. 5.

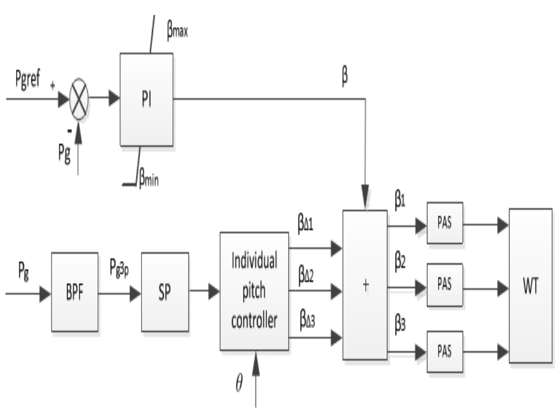

Figure 5. A novel individual pitch control scheme

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 theoutput power. In this loop, Pgref is the rated generator power, Pgis the generator output power, β is the collective pitch angle, ofwhich the minimum value βmin can be obtained by simulationsunder different wind speeds such that power fluctuationmitigation may compromise the power loss.In the individual pitch control loop, the BPF (band passfilter) is to let the frequency of 3p generator active powerthrough and block all other frequencies. Pg3p is the 3pcomponent of the generator power, and this component will besent to the signal processing (SP) block, due to the fact that thepower signal has to be transferred to the pitch signal.

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

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 individualpitch control strategy, the whole wind turbine system is built inSimulink, and some simulation results are obtained under bothhigh and low wind speeds.

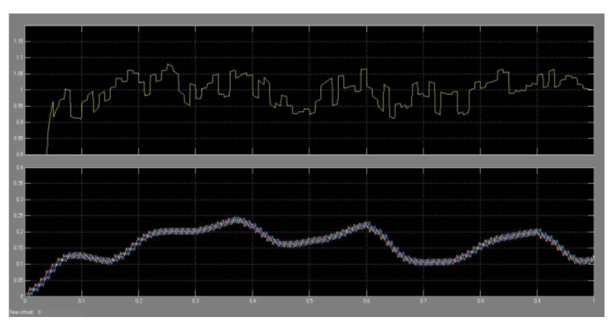

Figure 6 Matlab/simulink result for high wind with IPC scheme

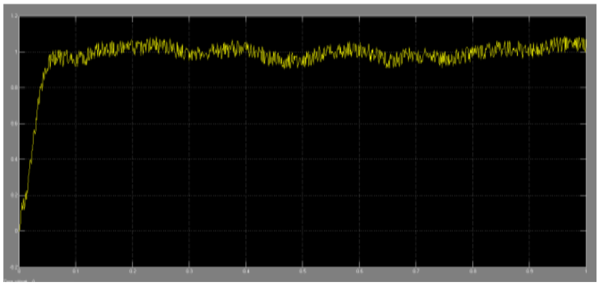

Figure 7Matlab/simulink result for high wind without IPC scheme

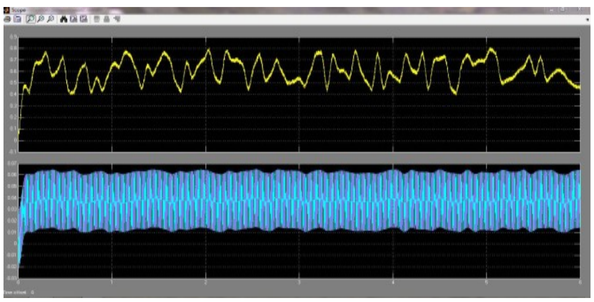

Figure 8 Matlab/simulink result for low wind with IPC scheme

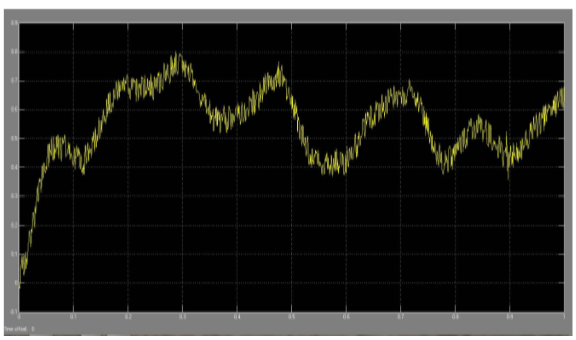

Figure 9.Matlab/simulink result for low wind without IPC scheme

VI. CONCLUSION

This paper designates a technique of flicker mitigation by IPC ofvariable-speed wind turbines with MW-level DFIG.The MW-level DFIG based variable speed wind turbinesystem is simulated using Simulink, Turbsim and FAST. Anovel individual pitch control method is proposed to mitigatethe wind turbine power fluctuation caused by wind shear andtower shadow effects. The individual pitch control scheme ispresented and controller is designed. The simulations areperformed on the NREL 1.5MW upwind reference windturbine model. The simulation results demonstrate thecapability of the proposed strategy.

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