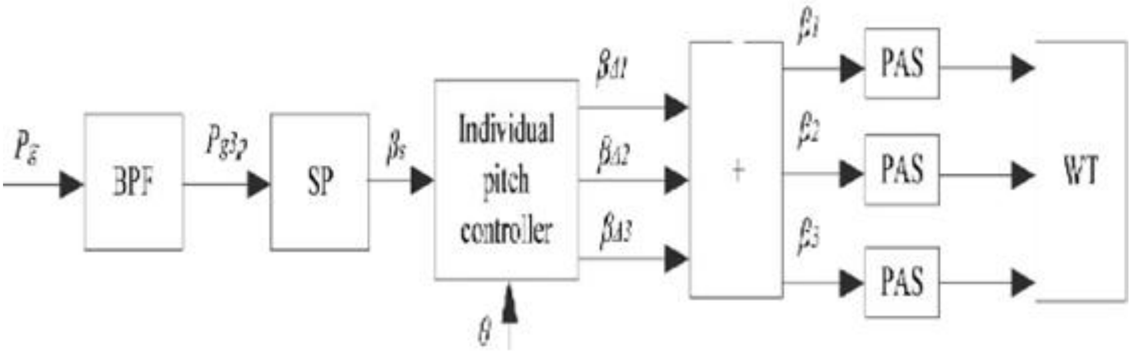

Figure 2: Proposed individual pitch control scheme.

4.4 Design of BPF

The transfer function of the BPF can be expressed as follows:

$F(s)=Ks/s2+(\omega c/Q)s + \omega c^2$

where ωc is the center frequency

K is the gain, and Q is the quality factor.

which corresponds to the 3p frequency can be calculated by the measurement of the generator speed

$\omega_c{*}\omega g=3\ \omega_g/N,$

where N is the gear ratio. The gain of the BPF at the center frequency is designed as 1 in order to let all the 3p frequencies pass the filter (F(s)=*KQ*/ωc= 1). Q which is responsible for the bandwidth of the BPF should be adjusted to let only the 3p component pass. In this case, Q is designed as

$Q = \omega_c$

Individual Pitch Controller Design The individual pitch controller will output the three pitch angle increments ß for each blade based on the pitch signal ßsΔ1,Δ2,Δ3 and the azimuth angle θ.

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 I. For example, if the azimuth angle belongs to the area of(0, 2p/3), then ßΔ2 equals ßs, and both ßΔ1and ß Δ3 equal 0. The three pitch increments will be, respectively, added with the collective pitch angle to give three total pitch angle demands. The three pitch angle signals will be sent to the PAS. The PAS can be represented using a first-order transfer function:

$F\ (s)= 1/T_{pas}s\ +1$

which is a turbine dependent time constant of the PAS. In this case T= 0.1.

The control scheme shown in Fig. 7 is used for mitigation pas of the 3p component of the generator active power, leading to the reduction of the flicker emission which is caused by the 3p effect. Similar method can also be used to reduce the 6p component of the generator active power. However, this 6p component mitigation needs a much faster pitch actuation rate.

5. Simulation Study

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.

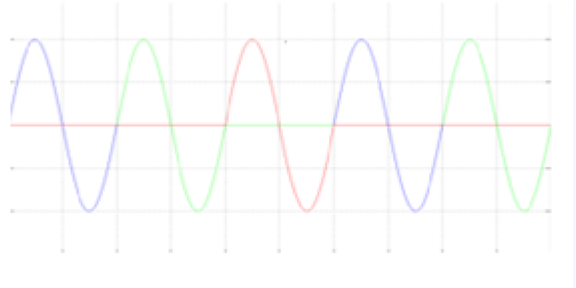

Figure 3: high wind speed individual pitch angles

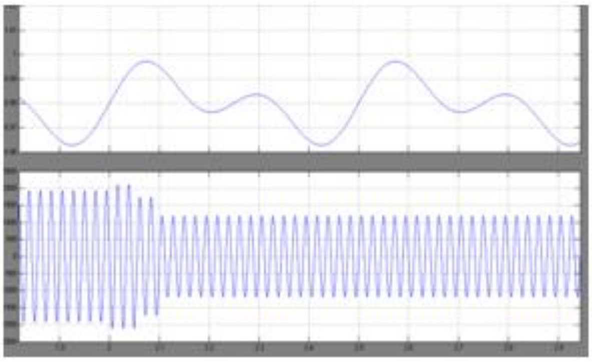

Figure 4: view of the generator active power and reactive power with IPC

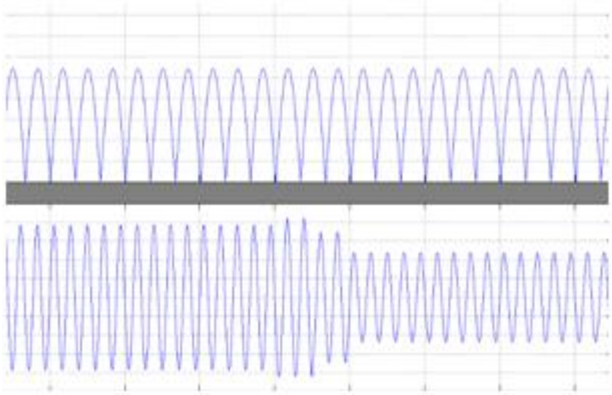

Figure 5: view of the generator active power and reactive power without IPC

There are also drawbacks of the proposed IPC method, such as loss of a small amount of wind energy in low wind speed and high demand of the PAS. There is an alternative flicker mitigation method, which is the turbine rotor speed control taking advantage of the large rotor inertia. In this way, the wind power fluctuations can be stored in the wind turbine rotor, leading to the flicker mitigation. However, this paper is focused on the IPC method. The IPC method for flicker mitigation proposed in this paper may be equally applicable to other types of variable speed wind turbines, such as a permanent magnet synchronous generator or a doubly salient permanent magnet generator, etc.

6. Conclusion

This paper describes a method of flicker mitigation by IPC of variable-speed wind turbines with high-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.

References

[1] T. Sun, "Power Quality of grid-connected wind turbines with DFIG and their interaction with the grid," Ph.D. dissertation, Aalborg Univ., Aalborg,Denmark, 2004.
[2] A. Larsson, "Flicker emission of wind turbines during continuous operation," *IEEE Trans. Energy Convers.*, vol. 17, no. 1, pp. 114–118, Mar. 2002.
[3] K. Yun-Seong and W. Dong-Jun, "Mitigation of the flicker level of a DFIG using power factor angle control," *IEEE Trans. Power Del.*, vol. 24, no. 4, pp. 2457–2458, Oct. 2009.
[4] W. Hu, Z. Chen, Y. Wang, and Z. Wang, "Flicker mitigation by active power control of variable-speed wind turbines with full-scale back-toback power converters," *IEEE Trans. Energy Convers.*, vol. 24, no. 3, pp. 640–649, Sep. 2009.
[5] E. A. Bossanyi, "Individual blade pitch control for load reduction," *Wind Energy*, vol. 6, pp. 119–128, 2002.
[6] E. A. Bossanyi, "Further load reductions with individual pitch control," *Wind Energy*, vol. 8, pp. 481–485, 2005.
[7] Y. Zhang, Z. Chen, M. Cheng, and J. Zhang, "Mitigation of fatigue loads using individual pitch control of wind turbines based on FAST," in *Proc. 46th Int. Conf. Universities' Power Eng.*, Soest, Germany, 2011.
[8] L. Rossetto, P. Tenti, and A. Zuccato, "Electromagnetic compatibility issues in industrial equipment," *IEEE Ind. Appl. Mag.*, vol. 5, no. 6, pp. 34–46, Nov./Dec. 1999.
[9] A. Larsson, "Flicker emission of wind turbines during continuous oper- ation," *IEEE Trans. Energy Convers.*, vol. 17, no. 1, pp. 114–118, Mar. 2002.
[10] H. Sharma, S. Islam, T. Pryor, and C. V. Nayar, "Power quality issues in a wind turbine driven induction generator and diesel hybrid autonomous grid," *J. Elect. Electron. Eng.*, vol. 21, no. 1, pp. 19–25, 2001.
[11] *Electromagnetic Compatibility (EMC)—Part 4: Testing and Measurement Techniques—Section 15: Flickermeter—Functional and Design Specifications*, IEC Std. 61 000–4–15, Nov. 1997.
[12] A. Larsson, "Flicker emission of wind turbines during continuous operation," *IEEE Trans. Energy Convers.*, vol. 17, no. 1, pp. 114–118, Mar. 2002.
[13] *Grid Code 3.2.5 Wind Power Plant above 11 kW.* [Online]. Available:http://energinet.dk/

Author Profile

B. Srinu is Assistant Professor in Anurag Engineering College

B. Rajanikanth is PG Scholar in Anurag Engineering College