ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

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



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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, fuzzy logic controller.***

I. INTRODUCTION

During the previous few decades, with the growing issues concerning energy shortage and environmental pollution, nice efforts are taken round the world to implement renewable energy comes, particularly wind generation comes. With the rise of wind generation penetration into the grid, the facility quality becomes a vital issue. One necessary facet of power quality is flicker since it may become a limiting issue for desegregation wind turbines into weak grids, and even into comparatively sturdy grids if the wind generation penetration levels square measure high [1]. Flicker is outlined as "an impression of unsteadiness of sense experience evoked by a lightweight stimulant, whose luminosity or spectral distribution fluctuates with time" [2].

Flicker is evoked by voltage fluctuations, that square measure caused by load flow changes within the grid. Grid-connected variable speed wind turbines square measure unsteady power sources throughout continuous operation. the facility fluctuations caused by wind speed variation, wind shear, tower shadow, yaw errors, etc., cause the voltage fluctuations within the network, which can turn out flicker [3]. except for the wind generation supply conditions, the facility system characteristics even have impact on flicker emission of grid-connected wind turbines, like short-circuit capability and grid electric resistance angle [4]. the sparkle emission with differing kinds of wind turbines is sort of totally different.

The' variable-speed wind turbines have higher performance with respect to the sparkle emission than fixed-speed wind turbines, with the big increase of wind generation penetration level, the sparkle study on variable speed wind turbines becomes necessary and imperative. variety of solutions are conferred to mitigate the sparkle emission of grid-connected wind turbines. The foremost normally adopted technique is that the reactive power compensation [5].

However, the sparkle mitigation technique shows its limits in some distribution networks wherever the grid electric resistance angle is low [6]. once the wind speed is high and also the grid electric resistance angle is 10◦, the reactive power required for flicker mitigation is three.26 per unit [7]. it's tough for a grid-side convertor (GSC) to come up with this quantity of reactive power, particularly for the doubly fed induction generator (DFIG) system, of that the convertor capability is simply around zero.3 per unit. The STATCOM that receives a lot of attention is additionally adopted to scale back flicker emission. However, it's unlikely to be financially variable for distributed generation applications. Active power management by varied the dc-link voltage of the consecutive convertor is conferred to attenuate the sparkle emission [7].

However, a giant dc-link condenser is needed, and also the period of the condenser are going to be shortened to store of the fluctuation power within the dc link. AN open loop pitch management is employed in [5] to analyze the sparkle emission in air current speeds, however, the pitch actuation system (PAS) isn't taken into consideration. as a result of the pitch rate and also the time delay of the PAS build nice contributions to the results of the sparkle emission of variable-speed wind turbines, it's necessary to require these factors into thought. In recent years, IPC that may be a promising method for hundreds reduction has been projected [7], from that it's notable that the IPC for structural load reduction has very little impact on the wattage. but during this paper, An IPC theme is projected for flicker mitigation of grid-connected wind turbines with mathematical logic controller. The facility oscillations square measure attenuated by individual pitch angle adjustment per the generator active power feedback and also the turbine AZ angle in such some way that the voltage fluctuations square measure ironed conspicuously, resulting in the flicker mitigation.

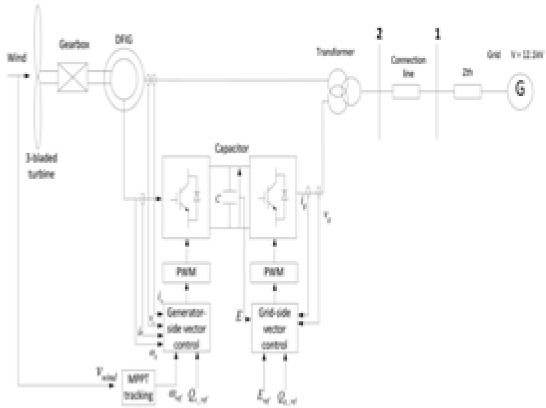

Fig 1 Overall scheme of the DFIG-based wind turbine system

The influence of the flicker emission on the structural load is additionally investigated. The quick (Fatigue, mechanics, Structures, and Turbulence) code [11] that is capable of simulating three-bladed wind turbines is employed within the simulation.

II. CONFIGURATION OF WIND TURBINE

The overall scheme of a DFIG-based windturbine system is shown in Fig. 1, which consists of awind turbine, gearbox, DFIG, a back-to-backconverter which is composed of a rotorside converter(RSC) and GSC, and a dc-link capacitor as energystorage placed between the two converters. In thispaper, FAST is used to simulate the mechanical partsof wind turbine and the drivetrain. The pitch andconverter controllers, DFIG, and power system aremodeled by Simulink blocks.

A. (Fatigue, Aerodynamics, Structures, and Turbulence) FAST

The open source code FAST is developed at the National Renewable Energy Laboratory (NREL) and

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International Journal & Magazine of Engineering, Technology, Management and Research
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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.

B. Mechanical drive-train

In order to take into account the effects of the generator and drive-train on the wind turbine, twomass model shown in Fig. 2.

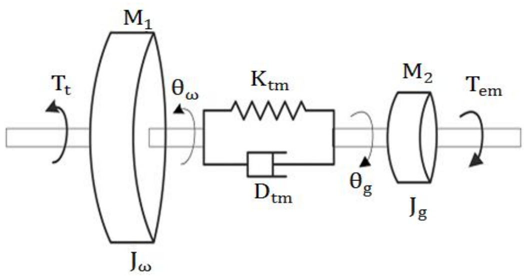

Fig 2 Two-mass model of the drive-train.

Which is suitable for transient stability analysis is used. The drive train modeling is implemented in FAST, and all values are referred to the wind turbine side. The equations for modeling thedrive-train are given by

$$J_\omega \frac{d^2\theta_\omega}{dt^2} = T_t - D_{tm}\left(\frac{d\theta_\omega}{dt} - \frac{d\theta_\omega}{dt}\right) - K_{tm}(\theta_\omega - \theta_g) \qquad (1)$$

$$J_g \frac{d^2\theta_\omega}{dt^2} = D_{tm}\left(\frac{d\theta_\omega}{dt} - \frac{d\theta_g}{dt}\right) + K_{tm}(\theta_\omega - \theta_g) - T_{em} \qquad (2)$$

Where J_ω and J_g are the moment of inertia of wind turbine and generator, respectively, T_t, T_{em} are the wind turbine torque and generator electromagnetic torque, respectively, θ_ω, θ_g are the mechanical angle of wind turbine and generator, $K_{tm}$is the drivetrain torsional spring, $D_{tm}$is the drive train torsion damper.

C. Doubly Fed Induction Generation Model (DFIG)

The equivalent circuit of DFIG model shown in fig.3. All electrical variables are referred to the stator.u_{ds} , u_{qs}, u_{dr}, u_{qr}, i_{ds}, i_{qs}, i_{dr}, $i_{qr}$and ψ_{ds}, ψ_{qs}, ψ_{dr}, $\psi_{qr}$are the voltages, currents, and flux linkages of the stator and,rotor in d- q-axes, r_s and $r_r$are the resistances of the stator and rotor windings, L_s,L_r,$L_m$are the stator, rotor, and mutual inductances,L_{1s},L_{1r} are the stator and rotor leakage inductances,w_1 is the speed of the reference frame, (w_s)is the slip angular electrical speed.

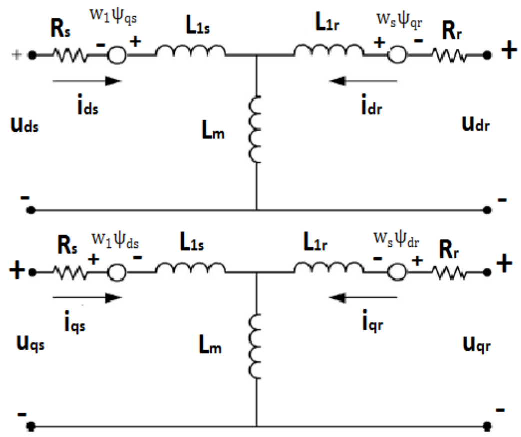

Fig. 3 d – qequivalent circuit of DFIG at synchronously rotating reference frame.

The RSC of DFIG is controlled in a synchronously rotating d-q reference frame with the d-axis aligned along the stator flux position. The electrical torqueT_e, active powerP_s, and reactive power Q_s of DFIG can be expressed by [1]:

$$T_e = \frac{3}{2} P \frac{L_m}{L_s} \psi_s i_{qr} \qquad (3)$$

$$P_s = -\frac{3}{2} u_s \frac{L_m}{L_s} i_{qr} \qquad (4)$$

$$Q_s = \frac{3}{2}\frac{\psi_s}{L_s} u_s - \frac{3}{2} u_s \frac{L_m}{L_s} i_{dr} \qquad (5)$$

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Where (p) is the number of pole pairs, ψ_s is the stator flux, u_s is the magnitude of the stator phase voltage. From (4) and (5) due to the constant stator voltage, the active power and reactive power can be controlled via i_{qr}andi_{dr}.

III. WIND TURBINE CONTROL AND FLICKER Emission Analysis

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.

A. Control of Back-To-Back Converter

To analysis a back-to back converter in a wind turbine system can be using Vector control technique. Two vector control schemes are illustrated, for the GSC and RSC, 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 the reference value of the reactive power flow between the grid and the GSC, $E_{ref}$is the reference value of the dc-linkvoltage, (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 objective of GSC is to keep the dc-link voltage constant, while keeping sinusoidal grid currents. It may also be responsible for controlling the reactive power flow between the grid and the grid-side converter by adjustingQ_{g-ref}. 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 [1].

B. Pitch Control

Normally, pitch control is used to limit the aerodynamic power captured from the wind. In low wind speeds, the wind turbine should simply try to produce as much power as possible, so there is no need to pitch the blades. For wind speeds above the rated value, the pitch control scheme is responsible for limiting the output power.

The fuzzy controller used for adjusting the pitch angles works well in normal operation, however, the performance of the pitch control system will degrade when a rapid change in wind speed from low to high wind speed is applied to the turbine rotor. It takes a long time for a positive power error contribution to cancel the effects of the negative pitch angle contribution that has been built up from integration of these negative power errors. This prevents the integrated power error from accumulating when the rotor is operating in low wind speeds.

C. Flicker Emission in Normal Operation

As discussed in Section I, flicker emission of a grid-connected wind turbine system is induced by voltage fluctuations which are caused by load flow changes in the network, so it is necessary to analyze the electrical power to the grid. Therefore, a simulation is conducted when the mean wind speed is 13 m/s based on the model as shown in Fig. 1.

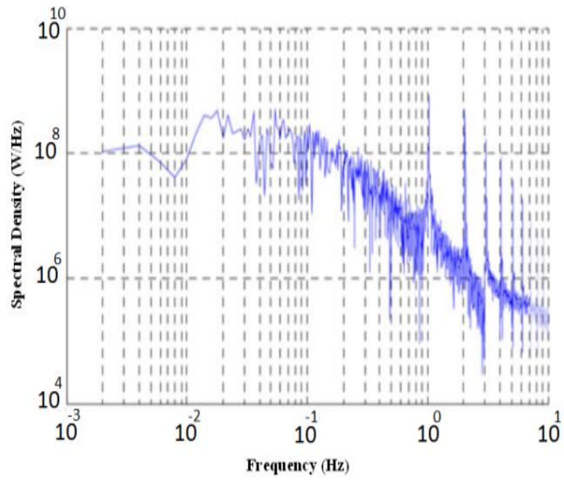

Fig.5 Spectral density of the generator output power

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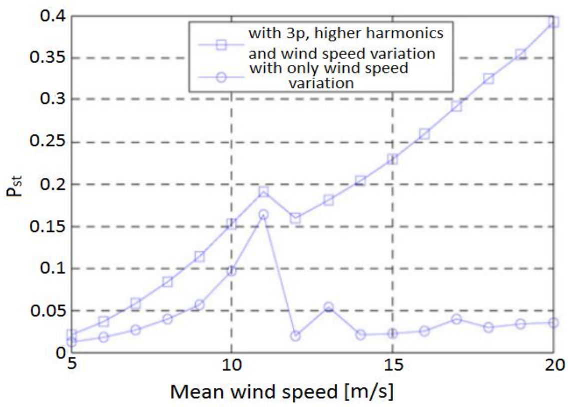

Fig.6 Flicker severity P_{st} between the cases with 3p, higher harmonics and wind speed variation (square), and the case with only wind speed variation (circle).

In this case, the turbine speed is around 0.345 Hz, which corresponds to the 3p frequency of 1.035 Hz, which is in conformation with the spectrum shown in Fig. 5. It is clearly seen that in addition to the 3p frequency, 6p, 9p, and higher frequencies are also included in the generator output power.

Fig. 6 illustrates the variation of flicker severity Pst with different mean wind speed between the cases with 3p, higher harmonics and wind speed variation and with only wind speed variation, respectively. In the first case, in low wind speeds, with the increase of mean wind speed the P_{st} increases accordingly, because higher mean wind speed with the same turbulence intensity means larger power oscillation and larger wind shear and tower shadow effects, leading to higher flicker severity.

From this figure, it can be concluded that the 3pand higher harmonics make a great contribution to the flicker emission of variable speed wind turbines with DFIG during continuous operation, especially in high wind speeds as shown in Fig. 6. It is recommended that the flicker contribution from the wind farm at the point of common coupling shall be limited so that a flicker emission of Pst below 0.35 is considered acceptable [9]. From Fig. 6, it shows the maximum P_{st} is above 0.35 in this investigation where the turbulence intensity is 10%. As proved in [5], Pst will increase with the increase of the turbulence intensity; therefore, it is necessary to reduce the flicker emission.

IV. INDIVIDUAL PITCH CONTROL FOR FLICKER MITIGATION

This section concentrates on flicker mitigation of variable speed wind turbines with DFIG during continuous operation using individual pitch control (IPC). The flicker emission produced by grid connected wind turbines during continuous operation is mainly caused by fluctuations in the generator active power. 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, 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. 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. Based on this concept, a novel IPC strategy is proposed. The control scheme is shown in Fig. 7 .The control scheme consists of two control loops:

- Collective pitch control CPC loop
- Individual pitch control IPC loop.

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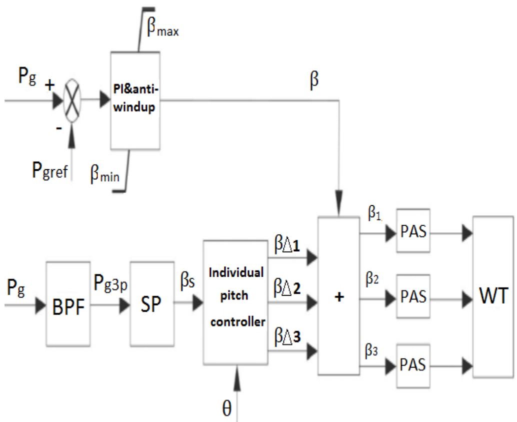

Fig..7 Proposed individual pitch control scheme..

The CPC loop is responsible for limiting the output power. In this loop, $P_{gref}$is the reference generator power which can be calculated according to different wind speed ,P_g is the generator active power, β is the collective pitch angle, of which the minimum value β_{min} can be obtained by simulations under different wind speed such that the mitigation of generator power fluctuation should compromise the wind power loss. In the individual pitch control loop, the band pass filter (BPF) is to let the frequency of 3p generator active power P_{g3p} through and block all other frequencies.$P_{g3p}$is fed to the signal processing (SP) block, since the power signal has to be transferred to the pitch signal βs which subsequently is passed to the individual pitch controller to output a pitch increment for a specific blade. The three pitch angles $\beta_{1,2,3}$ which are, respectively, the sum of collective pitch angles, and three pitch angle increments are sent to the PAS to adjust the three pitch angles to implement the mitigation of the generator active power oscillation.

A. Design of Design of Band Pass Filter (BPF)

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

$$F(s) = \frac{K\,s}{s^2 + s(\omega_c/Q) + \omega_c^2} \qquad 6$$

Where $\omega_c$is the center frequency, K is the gain and Q is the quality factor. $\omega_c$which corresponds to the 3p frequency can be calculated by the measurement of the generator speed ω_g.corresponds to the 3p frequency can be calculated by the measurement of the generator speedω_g. ω_c =3 ω_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 frequenciespass the filter $F(s) = K\,Q/\omega_c = 1$. Q which is responsible for the bandwidth of the BPF should be adjusted to let only the 3p component pass. In this case,Qis designed as ($Q = \omega_c$). Fig. 8 shows the Bode diagram of the BPF when the wind speed is above the rated value. In this case, the 3p frequency is 6.44 rad/s, and the bandwidth of the BPF which is around is 0.16 Hz (1 rad/s) is shown with the dotted lines.

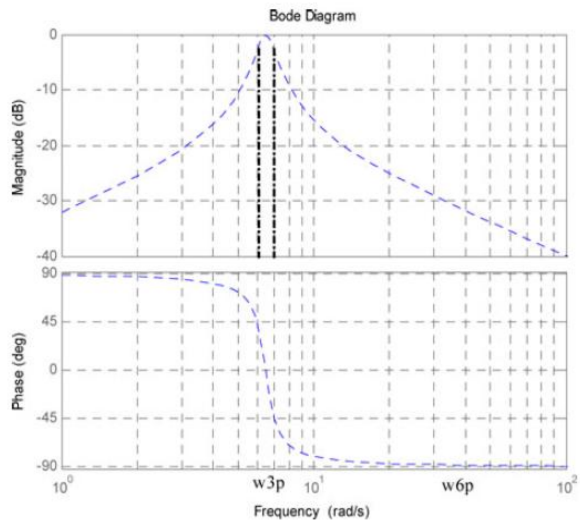

Fig. 8.Bode diagram of the BPF (high wind speed).

B. Signal Processing (SP)

The SP block has to produce a pitch signal to offset the power oscillation, in such a way that the generator power will oscillate in a much smaller range. Due to the time delay caused by the pitch actuation system (PAS) and the power transfer from wind turbine rotor to the power grid, etc., the phase of the generator active power lags the phase of the pitch signal. In order to produce the correct phase angle shift of the SP block, it is very important to get the phase deviation of the component with 3p frequency of βand Pg3p. For this reason, the system is operated in high wind speed without the IPC loop. In this case, the collective pitch angleβcontains the component with 3p frequency. The phase angle shift can be obtained by the component of β with 3p frequency and Pg3p. The SP block can be implemented with a first-order lag element, which delays the phase angle at 3p frequency. The SP block can be represented as follows:

$$F_{sp}(s) = \frac{K_{sp}}{T_{sp}s + 1} \quad (7)$$

The angular contribution of (7) is

$$\delta(\omega) = -\arctan(\omega T_{sp}) \quad (8)$$

Hence, the time constant T_{sp} can be calculated with the required angular contribution δ at ω_{3p}, shown as follows:

$$T_{sp} = -\frac{\tan\delta}{\omega_{3p}} \quad (9)$$

TABLE I
CONTROL PRINCIPLE OF INDIVIDUAL PITCH CONTROLLER

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

Where $\omega_{3p}$is the center frequency of the BPF. The gain K_{sp} can be tuned by testing, as it has no contribution to the phase shift of the SP block. Increasing K_{sp}can accelerate the flicker mitigation; however, a big value of K_{sp} might increase the flicker emission of the wind turbine.

C. Individual Pitch Controller Design

The individual pitch controller will output the three pitch angle increments $\beta_{\Delta 1}$,$\beta_{\Delta 2}$,$\beta_{\Delta 3}$for each blade based on the pitch signal β_s and the azimuth angle θ. 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, 2π/3), then $\beta_{\Delta 2}$equals β_s, and both $\beta_{\Delta 1}$ and $\beta_{\Delta 3}$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 transferfunction:

$$F(s) = \frac{1}{T_{pas}\,S + 1} \quad (10)$$

Where T_{pas} which is a turbine dependent time constant of the PAS. In this case T_{pas}=0.1. The control scheme shown in Fig. 7 is used for mitigation 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 .In this paper is not taken 6p component mitigation because it needs a much faster pitch actuation rate.

V. FUZZY PITCH ANGLE

Proposed fuzzy logic controller is implemented by using two signals one as input and second as output. The input signal, first signal is taken from deviation of active power generation of generator from rated value which is consider as 1 per unit and called as error signal. Consequently positive values lead to normal operation while negatives indicate excessive power generation during above rated wind speed. Therefore the controller should reform pitch angle degree by increase it from its initial value. In the normal situation pitch angle degree is adjusted on zero degree which means that the maximum amount of wind energy can convert to mechanical energy while by increasing pitch angle from zero degree the attach angle of wind to the blades become increase which lead to decreasing in aerodynamic force of the blade and consequently decreasing in power extraction from wind. The second input is taken from anemometer which is usually installed on the top of wind turbine nacelle.

ISSN No: 2348-4845
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By using wind speed as one of inputs in high capacity wind turbines with high amount of momentum inertia, response of controller become faster in comparison by taking input either from rotational speed of rotor or power generation by generator due to the high inertial turbine. Consequently mechanical fatigues in these wind turbines due to regulating will decrease which it is came from this fact that the speed of wind increase expeditiously in comparison by changing of output power in high capacity wind turbines due to the high inertia of their turbine and generator. A fuzzy logic based pitch angle designed to regulate generation power of wind turbine during above rated wind speed in its rated value. The gains which are used for error signal to scale the input of Fuzzy logic controller chosen as 10 and 0.5 for wind speed the rated wind speed of simulated wind turbine defined 12 m/s. the output signal of fuzzy logic controller is rescaled by multiply gain by 100. The pitch rate commanded by the actuator is physically limited to ±10°/s maximum [10].The limitation of blades position in the case of pitch regulating defined as zero to 90 degree which is extremely depend on the characteristic of each manufacture. Three triangle membership functions are adopted as input and output functions. Furthermore, Mamdani's maximum minimum method is implemented for the inference mechanism and center of gravity method is used for defuzzification to gain Beta command. Adopted membership functions are illustrated in Fig.(9) – (11) respectively.

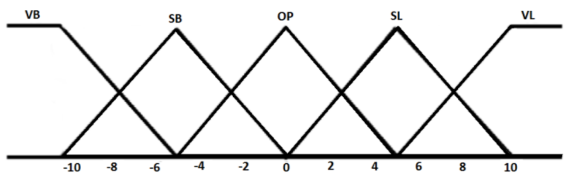

Figure 9.Error signal membership functions.

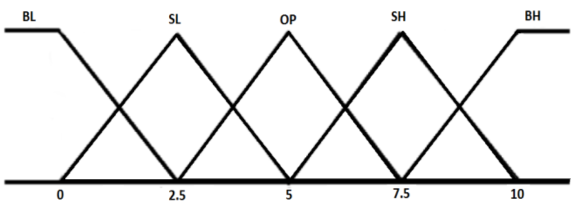

Figure 10.Wind speed signal membership functions.

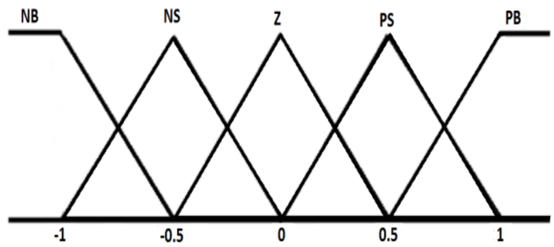

Figure 11.Output signal membership functions

There are 25 rules were implemented to achieve desire pitch angle are shown in Table I.

TableI Fuzzy Rule Table

Bcommand		Error				
Wind Speed		VB	SB	OP	SL	VL
	BL	PB	PS	Z	Z	Z
	SL	PB	PS	Z	Z	Z
	OP	PB	PS	Z	Z	Z
	SH	PB	PS	PS	PS	PS
	BH	PB	PB	PB	PB	PB

Where the linguistic variables are represented by VB (Very Big), SB (Small Big), OP (Optimum), SL (Small Low), and VL (Very Low) for error signal and BL (Big Low), SL (Small Low), OP (Optimum), SH (Small High), and BH (Big High) for wind speed signal and for output signal NB (Negative Big), NS (Negative Small), Z (Zero), PS (Positive Small), and PB (Positive Big) respectively.

VI. SIMULATION RESULTS

(1) Performance without and With 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.12illustratesthe long-term view of the generator active power as well as the three pitch angles when the mean wind speed is above the rated wind speed. From this figure, it is shown that the generator active power to the grid is smoothed prominently.

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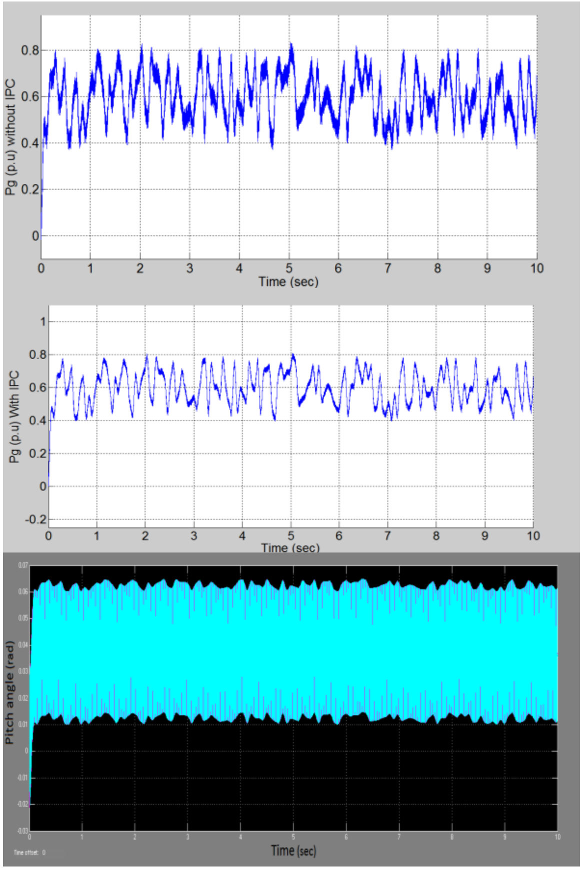

Fig.12 Long-term view of the generator active power without and with IPC,and pitch angle (high wind speed).

It is noted that when a power 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, the 3p oscillation frequency component which is significant in flicker emission of variable speed wind turbines during continuous operation is damped evidently with IPC.The wind turbine system employing IPCis also carriedout when the mean windspeed isbelow the rated wind speed. In this case, the minimum pitch angle β_{min}in the CPC loop is set to 2◦ (0.0349 rad), leaving a small amount of residual for IPC to mitigate the power oscillation.as shown in Fig. 13.

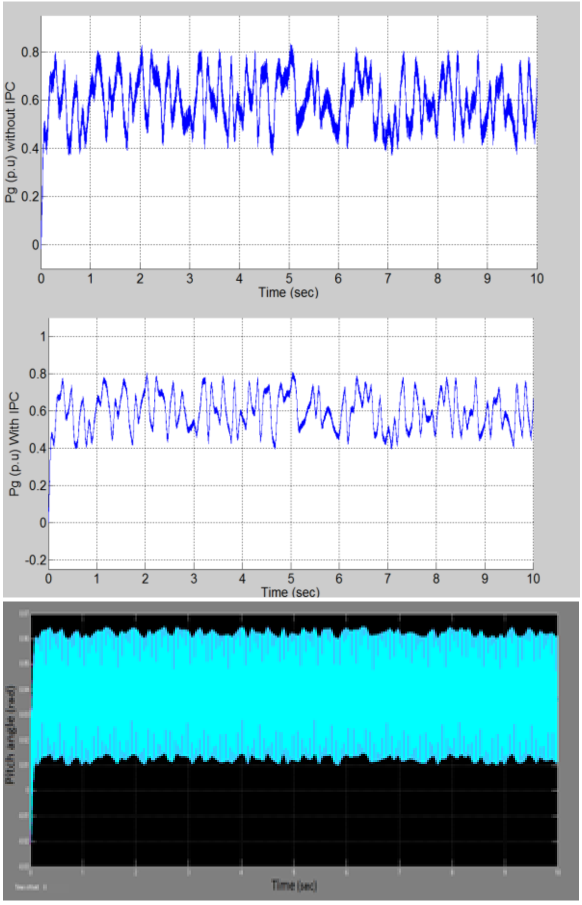

Fig. 13. Long-term view of the generator active power without and with IPC,and pitch angle (low wind speed).

(2)Performance with Fuzzy Logic Based IPC

Asimulation results using MATLAB / SIMULINK for both types of individual pitch control (conventional and fuzzy based) are shown Fig.14. The result has shown that by implementing designed fuzzy logic controller during above and down rated wind speed (12m/s) the output of wind turbine remains at its rated value by regulating pitch angle degree due to present of controller.Consequently, adopted wind turbine can operate as a variable speed wind turbine which is able to regulate its output during its operation based on wind speed fluctuation. The advantage which is taken is smooth output power in comparison of absence of controller which results to less mechanical damage.Fig.15 shows wind turbine active power in

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present of fuzzy logic controller during high wind speed.

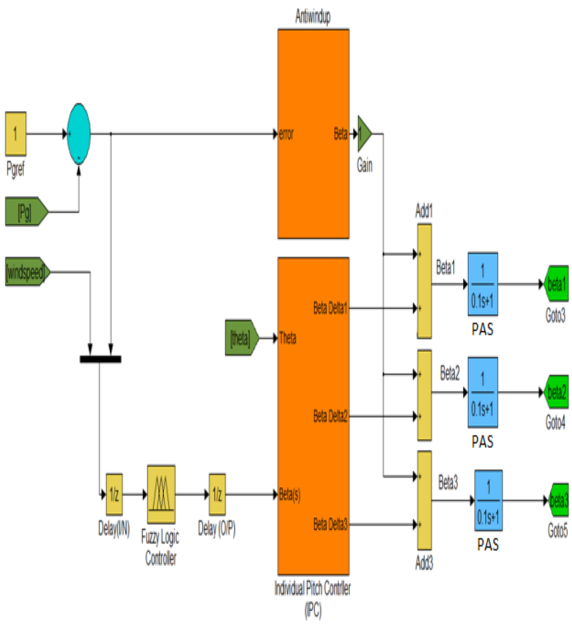

Figure 14: Test System for Proposed Fuzzy Logic Based IPC

In Fig 16 shows wind turbine active power and pitch angle in present of fuzzy logic controller during low wind speed.

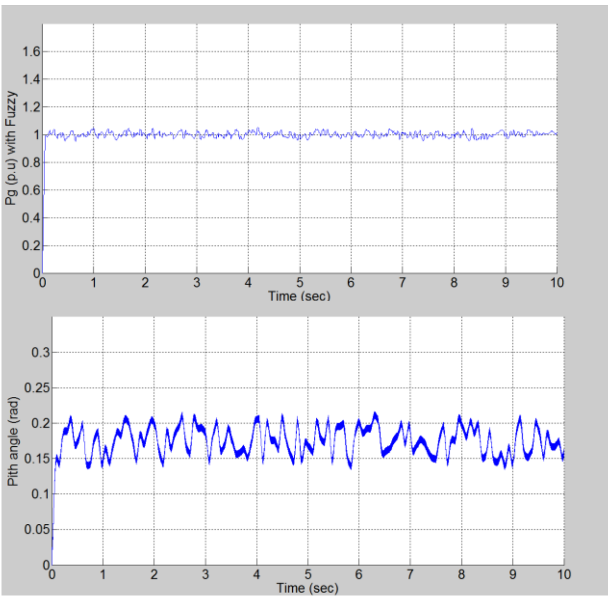

Fig 15 high wind speed with fuzzyactive power and Pitch angle.

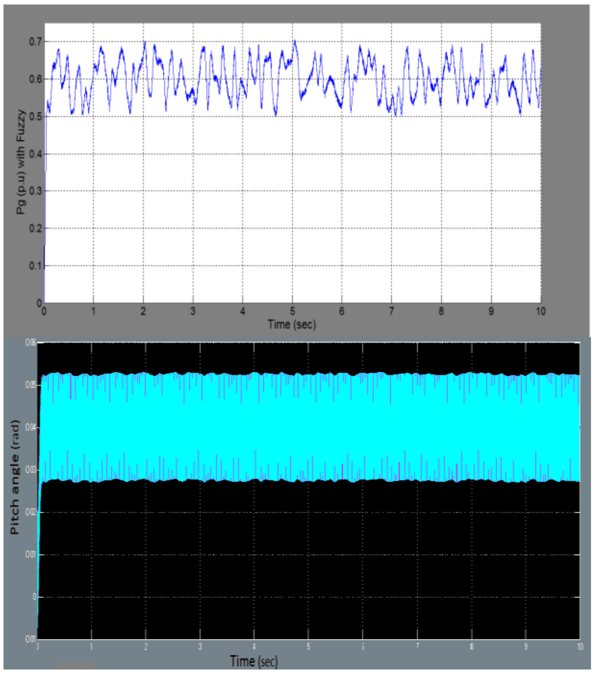

Fig 16 low wind speed with fuzzy active power and Pitch angle

VII .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 effectivemeans for flickermitigation of variable speed wind turbines during continuous operation.

PPENDIX PARAMETERS OF THE WIND TURBINE WITH DFIG	
DFIG and Wind Turbine	
Rated Capacity(MW)	1.5
Rated Stator Voltage(V)	690
Rated Frequency(Hz)	50

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Stator Resistance(p.u)	0.022
Rotor Resistance(p.u)	0.026
Stator Leakage Inductance(p.u)	0.177
Rotor Leakage Inductance(p.u)	0.116
Magnetizing Inductance	4.68
Number Of Pole Pairs	2.00
Lumped Inertia Constant(s)	3.00
Blade Radius(m)	35
Number Of Blades	3.00
Gearbox Ratio	81
Drivetrain Torsion Spring (Nm/rad)	5.6e9
Drivetrain Torsion Damper (Nm/s)	1.00e7
Hub Height(m)	82.39
Rated Power (MW) Of Wind Turbine	1.50
Max/Min Pitch Angle (degree)	45/0
Max Pitch Rate (degree/s)	10
Time Constant Of PAS	0.10
Turbulence Intensity	10%
Impedance Magnitude Of Line 1-2 (Ω)	0.7642
Short Circuit Impedance	1.5125+j2.619
Grid Impedance Angle (degree)	60

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