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# Scintillation Reduction By Individual Pitch Control of Variable Speed Wind Turbines By Using DFIG

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## 1.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 [1]. Flicker is defined as "an impression of unsteadiness of visual sensation induced by a light stimulus, whose luminance or spectral distribution fluctuates with time" [2]. 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 [3]. 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 [4], [5]. 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. 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. In recent years, IPC which is a promising way for loads reduction has been proposed [9]–[11], from which it is notable that the IPC for structural load reduction has little impact on the electrical power. However in this Project, an IPC scheme is proposed for flicker mitigation of grid-connected wind turbines. The power oscillations are attenuated by individual pitch angle adjustment according to the generator active power feedback and the wind turbine azimuth angle in such a way that the voltage fluctuations are smoothed prominently, leading to the flicker.

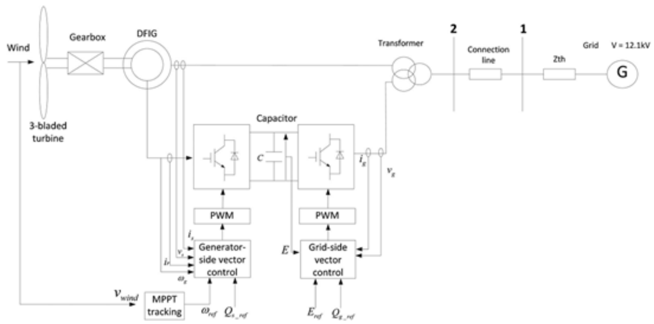


**FIG. 1:- Overall Scheme of the DFIG-Based Wind Turbine System.**

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Mitigation. The influence of the flicker emission on the structural load is also investigated. The FAST (Fatigue, Aerodynamics, Structures, and Turbulence) code [12] which is capable of simulating three-bladed wind turbines is used in the simulation.

## DOUBLE FED INDUCTION GENERATOR (DFIG):

DFIG is an abbreviation for Double Fed Induction Generator, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip ring assembly (see brushless doubly-fed electric machines), but there are problems with efficiency, cost and size. A better alternative is a brushless wound-rotor doubly-fed electric machine.

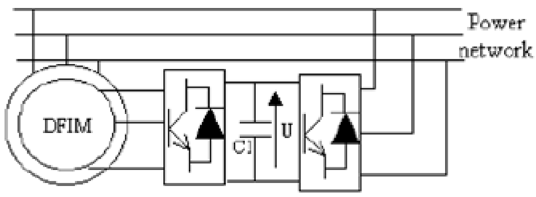


FIG. 2:-Doubly-fed induction generator

## WIND TURBINE CONTROL AND FLICKER EMISSION ANALYSIS

### Flicker

The reason of flicker Grid-connected wind turbines may have considerable fluctuations in the output power, as the wind is a weather-dependent power source. Reference [10] indicates that the grid suffers voltage fluctuations and flicker as the wind turbines' output power, which flows into the grid, varies. The flicker produced by grid-connected wind turbines during continuous operation is mainly caused by fluctuations in the output power due to wind speed variations, the wind gradient and the tower shadow effect. Asa consequence of the combination of wind speed variations, the wind gradient and the tower shadow effect, an output power drop will appear three times per revolution for a three-bladed wind turbine. This frequency is normally referred to as p 3 . For fixed speed wind turbines with induction generators, power pulsations up to 20% of the average power at the frequency of p 3 will be generated [12]. The tower shadow effect is produced because the wind turbine tower offers resistance to the wind flow, and it disturbs the wind flow both upstream and downstream.

Far from the tower influence, the wind speed is unchanged, while it increases when approaching the tower and decreases when coming closer. A Fourier series with harmonic multiples of p 3 frequency can represent this shadow effect [13]. The tower shadow effect is more important to the wind turbines having their blades downwind of the tower. The wind shear phenomenon also produces torque oscillations caused by the wind speed gradient along the height of the area swept by the blades. The wind speed gradient may be described in polar coordinates centered at the hub elevation by the binomial series [13]. As the rotor samples the incoming wind, it sees the wind profiles as a periodical varying function of the time with harmonic multiples of p 3 frequency. The output power of grid-connected wind turbines have been analyzed in the frequency domain [14, 15]. The results show that, in addition to the dominating periodic component p 3, the p 6, p 9 , p 12 and p 18 components are visible too. A possible reason for the existence of the p 1 component is that the rotor may be unbalanced. Another possibility is that one of the blades produces a higher torque than the other ones. The tower resonance frequency is also detectable which is assumed originating from side-ways oscillation of the turbine.

## INDIVIDUAL PITCH CONTROL FOR FLICKER MITIGATION

## FLICKER EMISSION AND MITIGATION:

The flicker emission of grid-connected wind turbines with DFIG during continuous operation has been investigated. The dependences of flicker emission on the mean wind speed, turbulence intensity, short circuit capacity ratio and grid impedance angle were illustrated in detail and compared with previous research results related to fixed speed wind turbines. This is believed new and will benefit understanding the nature of flicker emission of grid-connected wind turbines. Two measures have been proposed to mitigate the flicker levels produced by grid connected wind turbines with DFIG, respectively by wind turbine output reactive power control and using STATCOM. These two measures are based on the idea of reactive power compensation. In this way, the voltage fluctuations caused by the active power flow can be compensated by that caused by the reactive power flow. The two measures are considered – and have been proved to be– very effective and novel means for flicker mitigation of grid-connected wind turbines with DFIG.

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## VOLTAGE RECOVERY:

For grid-connected wind turbines with dynamic slip control, it is concluded that, after the clearance of an external short-circuit fault, the electromagnetic torque may be strengthened by adjusting the generator slip, and the aerodynamic torque may be reduced by regulating the pitch angle, which effectively helps to slow the rotor speed down and re-establish the voltage at the wind turbine terminal. The measure of combined control is considered novel for voltage recovery of grid-connected wind turbines with dynamic slip control.

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## INTRODUCTION TO INDIVIDUAL PITCH CONTROL (IPC):

Blade pitch control has primarily been used to limit aerodynamic power in above rated wind speeds in order to keep the turbine within its design limits and to optimize energy capture at below rated conditions. Collective pitch control techniques have been successfully utilized for this purpose [Bossanyi (2000); Van der Hooft et al. (2003); Wright and Balsa (2002)].But as rotor size increases there is an increased interest in utilizing pitch control to alleviate loads experienced by wind turbines by pitching the blades individually. The basic technique of individual pitch control is borrowed from the helicopter industry where scientists like Johnson [Johnson (1982)] and Lovera [Lovera et al. (2003)] have done work in this field.

## MODELING OF PROPOSED THEORY WIND TURBINE CONFIGURATION:

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 rotorside converter (RSC) and GSC, and a dc-link capacitor as energy storage placed between the two converters. In this Project, 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.

## 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.

## MECHANICAL DRIVE TRAIN:

In order to take into account the effects of the generator and drivetrain on the wind turbine, two-mass model shown in Fig. 2.Which is suitable for transient stability analysis is used [13]. The drive train modeling is implemented in FAST, and all values are referred to the wind turbine side. The equations for modeling the drivetrain are given by

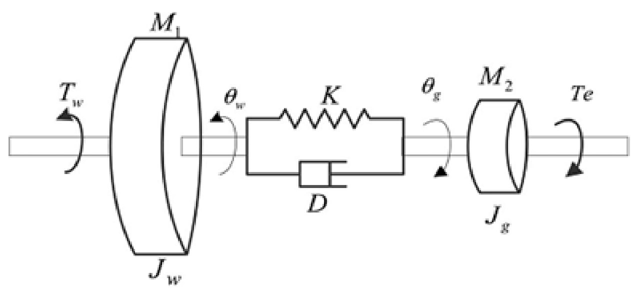


FIG.3:- Two-mass model if the drivertain.

$$J_w \frac{d^2\theta_w}{dt^2} = T_w - D\left(\frac{d\theta_w}{dt} - \frac{d\theta_g}{dt}\right) - K(\theta_w - \theta_g) \quad (1)$$

$$J_g \frac{d^2\theta_g}{dt^2} = D\left(\frac{d\theta_w}{dt} - \frac{d\theta_g}{dt}\right) + K(\theta_w - \theta_g) - T_e \quad (2)$$

Where Jw andJg are the moment of inertia of wind turbine and generator, respectively,Tw,Te are the wind turbine torque and generator electromagnetic torque, respectively,θw, θg are the mechanical angle of wind turbine and generator, Kis the drivetrain torsional spring,Dis the drivetrain torsional damper.

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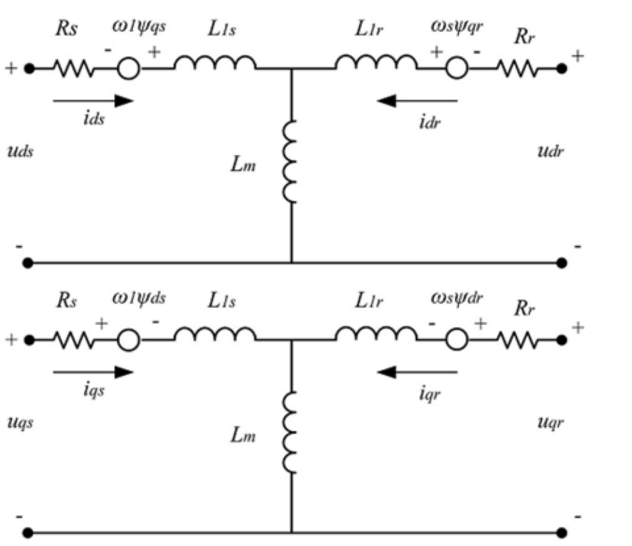


**FIG.13:- D-q equivalent circuit of DFIG at synchronously rotating reference.**

$$T_e = \frac{3}{2} p \frac{L_m}{L_s} \psi_s i_{qr} \tag{3}$$

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

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

## INDIVIDUAL PITCH CONTROL FOR FLICKER MITIGATION:

This section concentrates on flicker mitigation of variablespeed 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. 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: CPC loop and IPC loop.

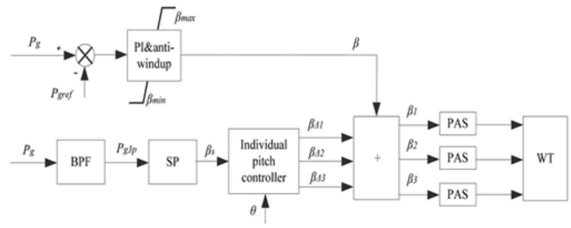


**FIG.4:- Proposed individual pitch control scheme.**

The CPC loop is responsible for limiting the output power. In this loop,Pg ref is the reference generator power which can be calculated according to different wind speed,Pg is the generator active power,βis the collective pitch angle, of which the minimum valueβmincan 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 Pg3p through and block all other frequencies.Pg3p is fed to the signal processing (SP) block, since the power signal has to be transferred to the pitch signalβs which subsequently is passed to the individual pitch controller to output a pitch increment for a specific blade. The three pitch anglesβ1,2,3 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.

## DESIGN OF BPF:

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

$$F(s) = \frac{Ks}{s^2 + (\omega_c/Q)s + \omega_c^2} \tag{6}$$

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whereωc is the center frequency, Kis the gain, and Qis the quality factor. ωc which corresponds to the 3p frequency can be calculated by the measurement of the generator speedωg. ωc =3ωg/N, whereNis 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,Qis designed asQ=ωc. 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.

## SIMULATION STUDIES AND RESULTS:

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. Figs. 9 and 10 illustrate the short-term view and 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 these figures, it is shown that the generator active power to the grid is smoothed prominently. It is noted that when a power.

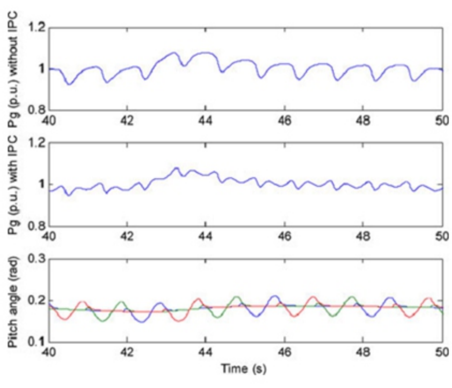


**FIG.5:- Short-term view of the generator active power without and with IPC,and individual pitch angles (high wind speed)**

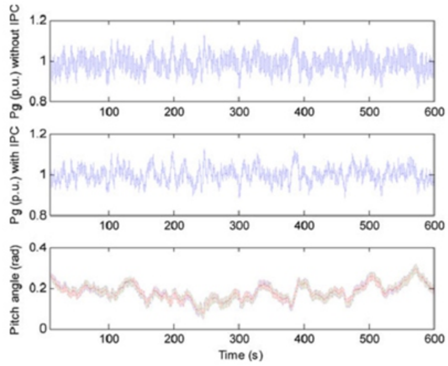


**FIG.6:- Long-term view of the generator active power without and with IPC, and pitch angle (high wind speed)**

Drop occurs which is caused by wind shear, tower shadow, andwind 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. The wind turbine system employing IPC is also carried out when the mean wind speed is below the rated wind speed, as shown in Fig. 12. As a small pitch angle movement will contribute to high power variation, in this case, the minimum pitch.

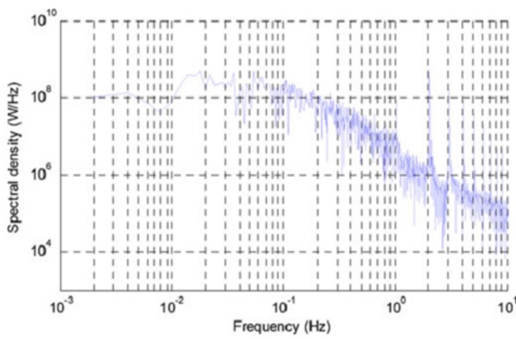


**FIG.7:- Spectral density of the generator active power.**

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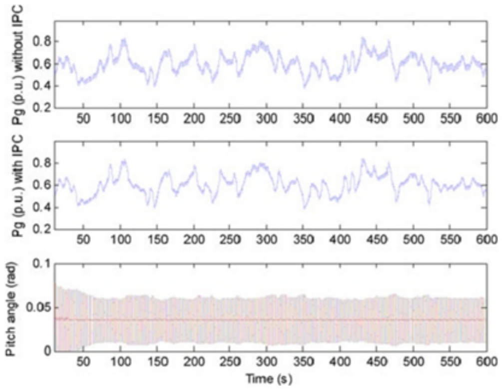


FIG.8:-Long-term view of the generator active power without and with IPC, and pitch angle (low wind speed)

Angleβminin the CPC loop is set to 2◦ (0.0349 rad), leaving a small amount of residual for IPC to mitigate the power oscillation. The performance of the generator active power in Fig. 12 demonstrates that the IPC also works well in low wind speeds at the cost of some power loss due to the pitch movement. Fig. 13 illustrates the variation of short-term flicker severity Pst with different mean wind speed between the case without IPC and the case with IPC. It can be concluded that damping the active power oscillation by using IPC is an effective means for flicker mitigation of variable speed wind turbines during continuous operation at different wind speed. Since many IPC algorithms can mitigate the wind turbine loads [9]–[11], the proposed new IPC which can mitigate the flicker emission might have some impact on the wind turbine load. Therefore, the spectra of the blade root bending moment of blade 1 without and with IPC are plotted, respectively, in Fig. 14, which obviously shows that the load on the blade consists of 1p, 2p, 3p, and higher harmonics, and it demonstrates that the proposed IPC has little impact on the blade root bending moment. Due to the relationship between the rotor tilt and yaw moments and the blade root bending moments [9], it can also be

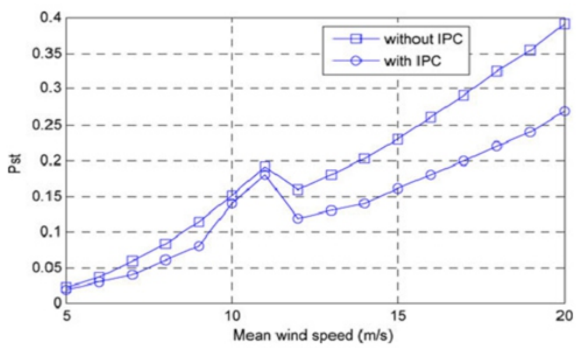


FIG.9:- Flicker severity P between the case without IPC (square),and the case with IPC (circle)

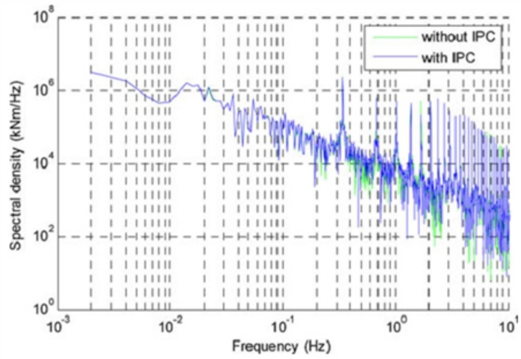


FIG.10:- Spectra of the blade root bending Moment.

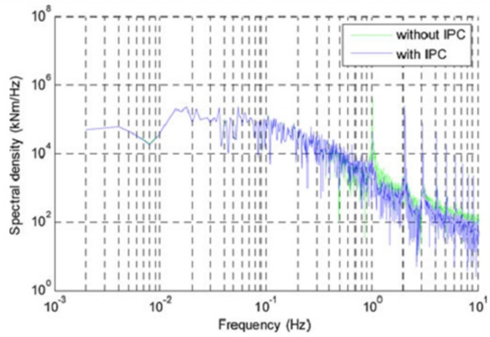


FIG.11:- Spectra of the wind turbine mechanical torque.

inferred that the proposed IPC has little impact on the tilt and yaw loads. The mechanical torque of the wind turbine by using the proposed IPC is illustrated in Fig. 15, showing that compared with previous flicker emission methods [6]–[8], the 3p component of the mechanical torque is much reduced by using the presented IPC algorithm. As a consequence, the fatigue load of the wind turbine rotor is relatively smaller in comparison with the previous flicker mitigation methods, leading to the lifetime increase of the drive train. 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 Project is focused on the IPC method. The IPC method for flicker mitigation proposed in this Project 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.

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## CONCLUSION:

This Project 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.

## FUTURE SCOPE:

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC. The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as; i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mamdani‟s „min‟ operator. v. Defuzzification using the „height‟ method.In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection..Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalve logic.

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