Flicker Mitigation In Variable Speed Wind Turbine With DFIG by Using Fuzzy Logic Controller For Individual Pitch Control

J. Pavan Kumar Reddy[1], K. Nagarjuna[2], T. Kranthi Kumar[3]
[1,2,3]Dept. of Electrical and Electronics Engineering
Avanthi Institute of Engineering and Technology
Hayathnagar, Rangareddy, Telanagana, INDIA.

pavanreddy7117@gmail.com[1],nagarjunakadiri@gmail.com[2],kranthikumarthallapalli@gmail.com[3]

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 a model of associate MW-level variable speed turbine with a doubly fed induction generator to analyze the flicker emission and mitigations. Individual pitch control(IPC) strategy is projected to cut back the flicker emission at totally different wind speed conditions. The IPC theme is projected with fuzzy controller and also the IPC is meant per the generator active power and also the Azimuth angle of the turbine. The simulations are performed using matlab simulink . Simulation results show that damping the generator active power by IPC is a good suggests that for flicker mitigation of variable speed wind turbines throughout continuous operation.

Index Terms—Flicker, flicker mitigation, individual pitch control (IPC), variable speed wind turbine.

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 fact 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], [5]. 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 [6].

However, the sparkle mitigation technique shows its limits in some distribution networks wherever the grid electric resistance angle is low [7]. Once the wind speed is high and also the grid electric resistance angle is 10◦, the reactive power required for flicker mitigation is 3.26 per unit [8]. 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 0.3 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 [8]. 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 [6] and [8] 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 [9] 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 Azimuth angle in such some way that the voltage fluctuations square measure ironed conspicuously, resulting in the flicker mitigation.

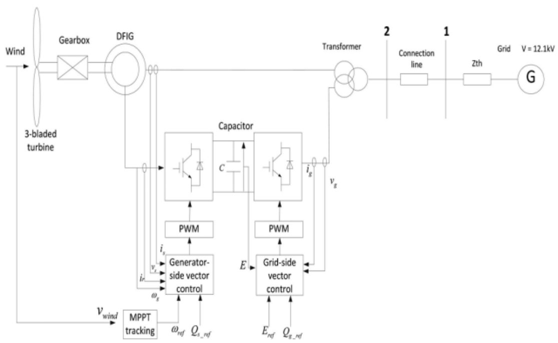

Fig 1 Overall scheme of the DFIG-based wind turbine system.

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

II 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 rotor side converter (RSC) and GSC, and a dc-link capacitor as energy storage placed between the two converters. The pitch and converter controllers, DFIG, and power system are modeled by Simulink blocks.

A. MECHANICAL DRIVETRAIN

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

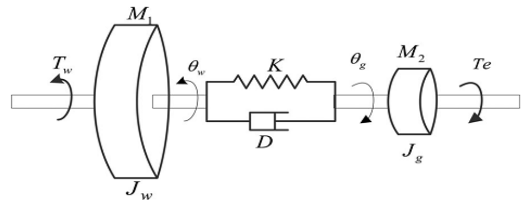

Fig 2 Two-mass model of the drive train.

which is suitable for transient stability analysis is used . The equations for modeling the drive train are given by

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

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

Where Jw and Jg 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, K is the drive train torsional spring, D is the drive train torsional damper.

B. DFIG MODEL

The model of the DFIG is based on d-q equivalent model shown in Fig. 3. All electrical variables are referred to the stator. uds, uqs, udr, uqr, ids, iqs, idr, iqr and ψds, ψqs, ψdr, ψqr are the voltages, currents, and flux linkages of the stator and rotor in d- and q-axes, rs and rr are the resistances of the stator and rotor windings, Ls, Lr, Lm are the stator, rotor,

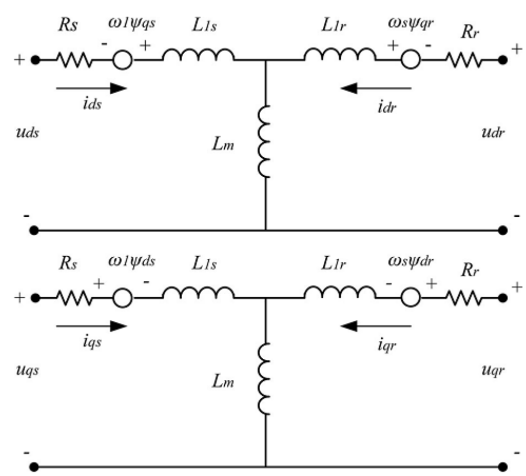

Fig.3.$d - q$ equivalent circuit of DFIG at synchronously rotating reference frame.

and mutual inductances,L1s,L1r are the stator and rotor leakage inductances,w1 is the speed of the reference frame, ws is the slip angular electrical speed. 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 torque Te, active power Ps, and reactive power Qs of DFIG can be expressed by [1].

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

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

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

Where p is the number of pole pairs, ψs is the stator flux, us 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 .

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

Vector control techniques are the most commonly used methods for a back-to back converter in a wind turbine system. Two vector control schemes are illustrated, respectively, for the RSC and GSC, as shown in Fig. 1, where vs, and is are the stator.

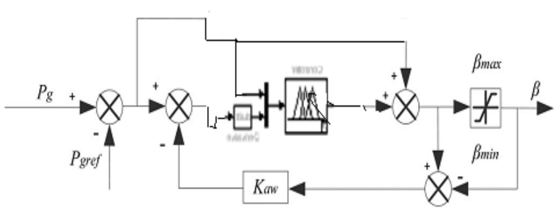

Fig. 4. Fuzzy logic controller with anti windup

voltage and current , ir is the rotor current, vg is the grid voltage, ig is the GSC currents, wg is the generator speed, E is the dc-link voltage, Ps ref, and Qs ref are the reference values of the stator active and reactive power, Qr ref is the reference value of the reactive power flow between the grid and the GSC, Eref is the reference value of the dc-link voltage, 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 reference value of the generator speed ωref is obtained via a lookup table to enable the optimal tip speed ratio. 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 adjusting Qg ref. Usually, 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. The integrator anti windup scheme is implemented as shown in Fig. 4, in which the anti windup term with gain Kaw is fed back to the integrator only. This prevents the integrated power error from accumulating when the rotor is operating in low wind speeds. The value for Kaw may be turbine dependent. When the pitch angle is not saturated, this anti wind up feedback term is zero.

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. The parameters of the wind turbine system are given in the Appendix. In this case, the turbine speed is around 0.345 Hz, which corresponds to the 3p frequency of 1.035 Hz, It is clearly seen that in addition to the 3p frequency, 6p, 9p, and higher frequencies are also included in the generator output power.

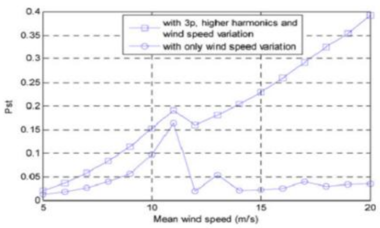

Fig. 5. Flicker severity *P*st between the cases with 3rd harmonics and higher harmonics wind speed variation (square), and the case with only wind speed variation(circle).

These components will induce voltage fluctuations and flicker emission in the power grid. Further, the flicker emission of a variable-speed wind turbine with DFIG is studied. The level of flicker is quantified by the short-term flicker severity Pst, which is normally measured over a 10-min period. According to IEC standard IEC 61000-4-15, a flicker meter model is adopted to calculate the short-term flicker severity Pst [6]. Fig. 5 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 Pst 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. For high wind speeds, where the wind turbine reaches rated power, the flicker level decreases due to the introduction of fuzzy blade pitch control which could reduce the power oscillation in low frequency prominently, but it cannot effectively mitigate the power oscillations with 3p, 6p, 9p, and higher frequencies. As the power oscillation is bigger for higher wind speeds when the wind speed is above the rated wind speed, the flicker level continues to rise with the increase of mean wind speed. In the case with only the wind speed variation, in low wind speeds the flicker emission has the similar situation, only the Pst is relatively smaller. In high wind speed, the Pst is much smaller, since the power oscillation contains little 3p and higher harmonics. 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. From Fig. 5, it shows the maximum Pst is above 0.35 in this investigation where the turbulence intensity is 10%. As proved in [6], Pst will increase with the increase of the turbulence intensity; therefore, it is necessary to reduce the flicker emission. For this reason, a new control scheme for flicker mitigation by individual pitch control is proposed in next section.

IV INDIVIDUAL PITCH CONTROL FOR FLICKER MITIGATION

This section concentrates on flicker mitigation of variable speed 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 consists of two control loops: CPC loop and IPC loop.

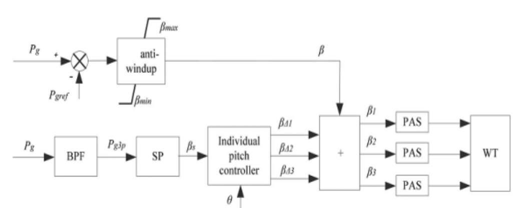

Fig 6 Proposed individual pitch control scheme.

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, β is the collective pitch angle, of which the minimum value βmin 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 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 signal βs 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.

A. BPF

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

$$F(s) = \frac{Ks}{S^2 + \left(\frac{\omega_c}{Q}\right)s + \omega_C^2} \quad (6)$$

Where ωc is the center frequency, K is the gain, and Q is the quality factor. ωc which corresponds to the 3p frequency can be calculated by the measurement of the generator speed ωg. ωc =3ωg/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=ωc. 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.

B. SIGNAL PROCESSING

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 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 ofβandPg3p. For this reason, the system is operated in high wind speed without the IPC loop. In this case, the collective pitch angle β contains 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 ω 3p is the center frequency of the BPF. The gain Ksp can be tuned by testing, as it has no contribution to the phase shift of the SP block. Increasing Ksp can accelerate the flicker mitigation; however, a big value of Ksp 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 βΔ1,Δ2,Δ3for each blade based on the pitch signal βs and the azimuth angle θ. In this paper, the simulations are performed using matlab simulink, 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 βΔ2 equals βs, and both βΔ1 and βΔ3 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:

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

Where Tpas which is a turbine dependent time constant of the PAS. In this case Tpas=0.1. The control scheme shown in Fig. 6 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. However, this 6p component mitigation needs a much faster pitch actuation rate, which is not taken into account in this paper.

V SIMULATION STUDIES USING 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. Figs. 7and 8 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

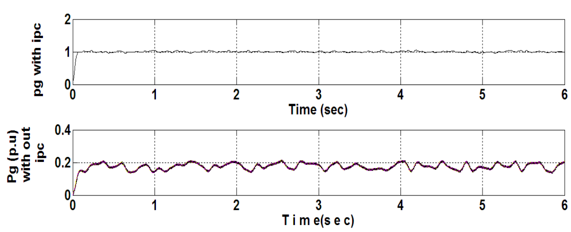

Fig 7 Generator active power without and with IPC, and pitch angle (high wind speed)

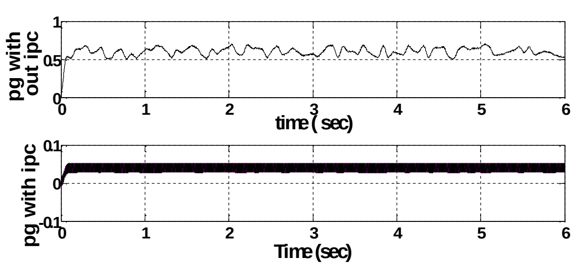

Fig 8 Generator active power without and with IPC, and pitch angle (low wind speed).

without and with IPC, and individual pitch angles (high wind speed).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 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. 7. As a small pitch angle movement will contribute to high power variation, 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. The performance of the generator active power demonstrates that the IPC also works well in low wind speeds at the cost of some power loss due to the pitch movement.

VI CONCLUSION

This paper describes a technique of flicker mitigation by IPC of variable-speed wind turbines with MW-level DFIG. The modeling of the turbine system is disbursed mistreatment quick and Simulink. On the premise of the given model, flicker emission is analyzed and investigated in numerous mean wind speeds. To scale back the sparkle emission, a unique management theme by IPC is projected. The generator active power oscillation that ends up in flicker emission is damped conspicuously by the IPC in each high and low wind speeds. It are often terminated from the simulation results that damping the generator active power oscillation by IPC is a good suggests that for flicker mitigation of variable speed wind turbines throughout continuous operation.

VII 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] 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.
[3] ˚ A. Larsson, "Flicker emission of wind turbines during continuous operation,"IEEE Trans. Energy Convers., vol. 17, no. 1, pp. 114–118, Mar. 2002.
[4] 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.
[5] M. P. Papadopoulos, S. A. Papathanassiou, S. T. Tentzerakis, and N. G. Boulaxis, "Investigation of the flicker emission by grid connected wind turbines," inProc. 8th Int. Conf. Harmonics Quality Power, Athens, Greece, 1998, vol. 2, pp. 1152–1157.

[6] T. Sun, Z. Chen, and F. Blaabjerg, "Flicker study on variable speed wind turbines with doubly fed induction generators,"IEEE Trans. Energy Convers., vol. 20, no. 4, pp. 896–905, Dec. 2005.
[7] 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.
[8] 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.
[9] E. A. Bossanyi, "Individual blade pitch control for load reduction,"Wind Energy, vol. 6, pp. 119–128, 2002.
[10] E. A. Bossanyi, "Further load reductions with individual pitch control," Wind Energy, vol. 8, pp. 481–485, 2005.

J.Pavan kumar reddy

Completed his post-graduation in EPS at Avanthi Institute Of Engineering And Technology,Hyderabad in 2016,and he completed his graduation in EEE from Gurunanak Engineering college,Hyderabad in 2014

K.Nagarjuna,

Working as assistant professor in Avanthi Institute of Engineering &Technology, Hyderabad. He completed his graduation in EEE department at QIS Engineering college, Ongole in 2009. He completed post graduation in QIS Engineering college, Ongole in 2014.

T.Kranthi kumar,

Head of EEE Department in Avanthi Institute of engineering &technology, Hyderabad. He completed his Graduation in EEE from Adam's Engineering College (Accredited by NBA), Paloncha. He completed M. Tech in P. Indra Reddy Memorial Engineering College in 2012. His papers published in International Journals, National and International Conferences.