Fuzzy Logic Blade Pitch Angle Control Of A Hybrid Wind-Diesel-Battery Energy Conversion System

Aarti Gupta D.K. Jain Surinder Dahiya

ABSTRACT

Wind energy conversion system integrated with diesel is used in autonomous operation worldwide. The paper investigates the operation of hybrid system employing Fuzzy Logic Controller for a wide range of wind speed capture. Power conditioning is achieved using a combination of fuzzy logic pitch controller and battery energy storage

Key words: WECS (wind energy conversion system), FLC (Fuzzy Logic Controller), BPA (Blade Pitch Angle Control

1.INTRODUCTION

Stand-alone systems are generally used to power remote houses or remote technical applications (e.g. for telecommunication systems). The wind turbines used for these purposes can vary from between a few watts and 50KW 1. For village or rural electrification systems of up to 300 kW, wind turbines are used in combination with a diesel generator and sometimes a battery system. The required power for the connected load can be effectively delivered using appropriate control and effective coordination among the various subsystems. the proposed wind-diesel hybrid generator feeding isolated loads can be properly operated to achieve system power-frequency balanced condition The WECS adopts an AC-DC-AC converter system with fully controlled PWM voltage-source converters (VSC). The DC-link voltage command is determined according to output power fluctuations of the PMSG. The aerodynamic power captured by wind turbine is the cosine function of pitch angle. The pitch angle is kept zero for lower to medium wind velocities [2] but the effect of gust cannot be ignored due to the highly unpredictable nature of wind. The output power fluctuations in low- and high-frequency domains are smoothed by the Fuzzy logic Blade Pitch angle control of the WECS and the DC link voltage control, respectively. By using the proposed method, the wind turbine blade stress is mitigated as the pitch action in high-frequency domain is reduced. Variable speed wind turbines are preferable as they offer many advantages over fixed speed wind turbines such as increased energy capture, operation at maximum power point, better efficiency and power quality. However, the operation and control of variable speed wind turbines are more complicated than fixed speed wind turbines. Multi-pole design can be easily realized in the synchronous generator as increasing the number of poles type Felicitates gearless operation and hence, the features of lightweight and low maintenance can be obtained in this type of wind generation system [3].In addition, it is also easier to accomplish the fault ride through and grid support capabilities in a synchronous generator system than in other types of generators due to the fact that the full-rated power converter decouples the generator system from the micro grid [4],[5]. Taking the fore mentioned factors into consideration, a PMSG-based generation system is an important trend in the development of wind generation systems 6.7. There is enhanced awareness about power quality as Load equipments with microprocessor-based controls and power electronic devices used in the present are more sensitive to power quality variations. To increase the system efficiency, high efficiency devices based on power electronics equipments have been increasingly used in many applications. This causes increasing harmonic levels on power systems and concerns about the future impact on system capabilities. Active filter control coupled with robust FLC of BPA addresses this issue and helps to increase the life of the generator, in addition, fluctuations on the DC link are further smoothened. .The paper is arranged as follows, section 2. Explores the wind turbine dynamics and PI and fuzzy logic scheme employed in the paper is described in the next section. Section 4, discusses in brief the various methodologies adopted to design the control scheme of the hybrid WECS. The results obtained are discussed next section and the last section includes the list of references.

Schematic of the Proposed System

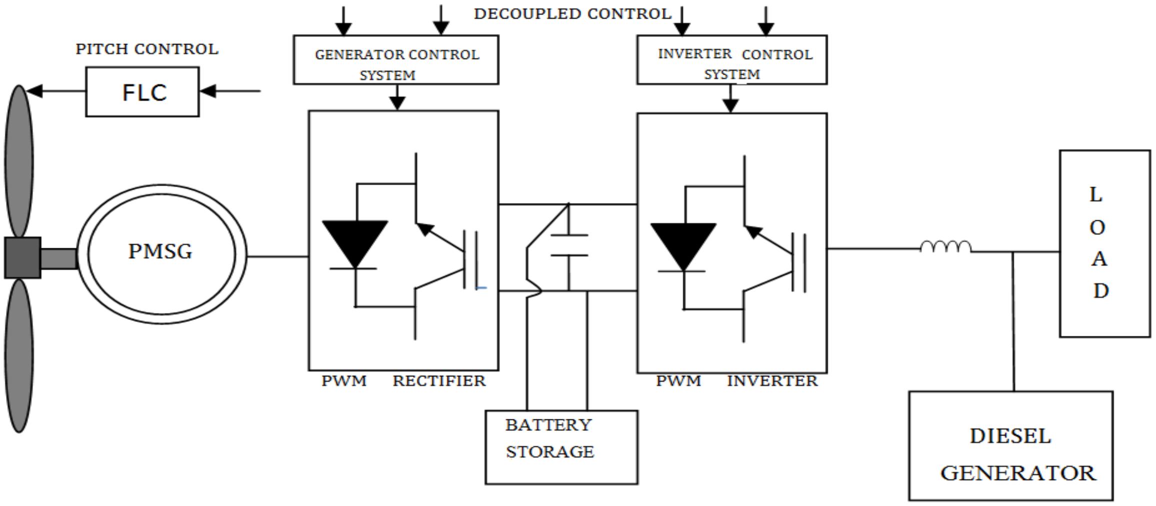


Fig.1

2.WIND TURBINE DYNAMICS

Power in the wind turbine varies as the cubic function of the wind speed.

$$P=0.5\rho AV_W^3 \qquad (1)$$

wind turbine can only extract part of the power from the wind, which is limited by the Betz limit (maximum 59%). This fraction is described by the power coefficient of the turbine, *Cp*, which is a function of the blade pitch angle and the tip speed ratio.6.,7.Therefore the mechanical power of the wind turbine extracted from the wind is where *Cp* is the power coefficient of the wind turbine, β is the blade pitch angle and λ is the tip speed ratio.

$$P_w=0.5Cp(\beta,\lambda)\rho AV_W^3 \qquad (2)$$

The tip speed ratio λ is defined as the ratio between the blade tip speed and the wind speed V_W where Ω is the turbine rotor speed and *R* is the radius of the wind turbine blade

$$\lambda=\Omega R/V_W \qquad (3)$$

Thus, any change in the rotor speed or the wind speed induces change in the tip speed ratio leading to power coefficient variation. In this way, the generated power is affected. Fig. 2 shows a group of typical *Cp*-λ curves where optimum values of tip speed ratio, λ*opt*, correspond to the maximum power coefficient, *Cp.max*. Fig. 3 shows that the mechanical power converted from the turbine blade is a function of the rotational speed, and the converted power is maximized at the particular rotational speed for various wind speeds

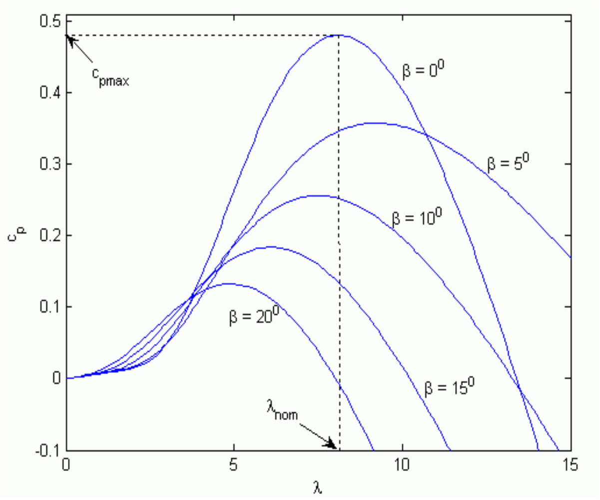


Fig.2

The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds.

$$W=\sqrt{V_W(1-a^2)+\Omega^2 r^2(1+b^2)} \qquad (4)$$

The resultant relative velocity gives rise to Aerodynamic forces on the blade, therefore a lift force is produced given by

$$F_L=1/2\rho CW^2C_L \qquad (5)$$

and drag force is given by

$$F_D=1/2\rho CW^2C_D \qquad (6)$$

where C_L is lift coefficient, C_D is drag coefficient and *c* is the chord length of the blade. In the pitch-adjusting variable-speed wind turbines, the angle of attack, α, decreases when the pitch angle, β, increases,. The lift force, F_L, decreases as well and this causes reduction of the mechanical power of the wind turbine. According to the pitch angle control, the initial angle the power of the wind turbines will increase at the increasing wind. The wind turbine must be protected against mechanical overloads and possible risk of damages at strong wind.

This is achieved by pitching the blades into the position where a part of incoming wind will pass by the wind turbine.6. The power will be kept at its rated value at this region. By pitching, the thrust is reduced. Fig. 6 shows the curve of the pitch angle versus incoming wind speed which is computed with use of the BEM method for the given 1.5 MW wind turbine.

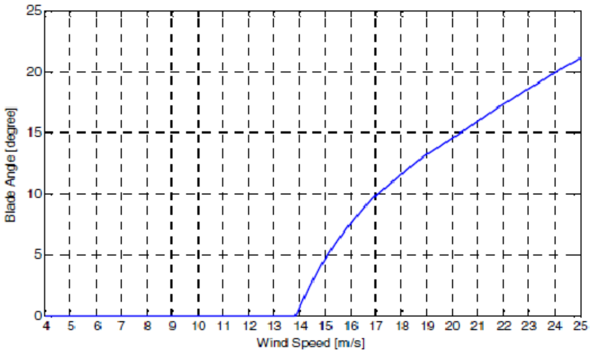
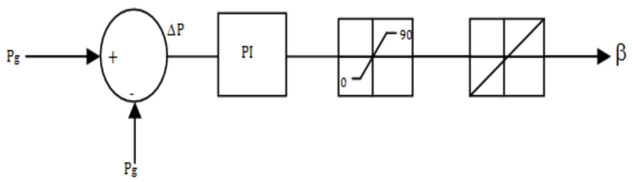


Fig.3

3. PI AND FUZZY LOGIC CONTROLLERS

B*opt*, the optimized pitch angle can be defined using the BEM method(fig.3) from the incoming wind and it is in very few degrees around zero. A Proportional-Integral (PI) controller fig.4 is used to control the blade pitch angle in order to limit the electric output power to the nominal mechanical power. The pitch angle is kept constant at zero degree when the measured electric output power is under its nominal value. When it increases above its nominal value the PI controller increases the pitch angle to bring back the measured power to its nominal value. The control system is illustrated in the figure:



(PI Controller) Fig.4

A FLC controller was designed to make the system more effective and increase the speed of the response. The fuzzy logic control strategy may have the potential when the system contains strong non-linearity, such as wind turbulence is strong, or the control objectives include fatigue loads. The design of the fuzzy logic controller and the comparisons with conventional pitch angle control strategies with various controlling variables are carried out. The simulation shows that the fuzzy logic controller can achieve better control performances than conventional pitch angle control strategies, namely lower fatigue loads, lower power peak and lower torque peak.

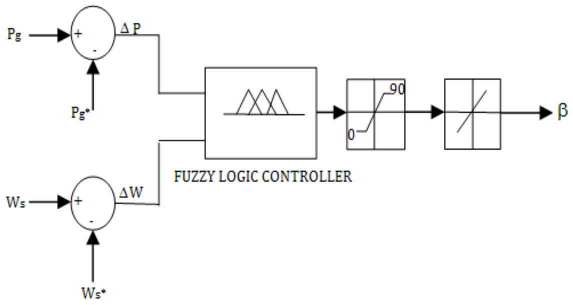


Fig.5

Rule based fuzzy logic controllers (fig.5) are useful when the system dynamics are not well known or when they contain significant non-linearity. The intermittency of wind introduces large turbulence. Fuzzy logic controllers apply intuitive reasoning, similar to how human beings make decisions, and thus the controller rules contain expert knowledge of the system. The big advantages of fuzzy logic control when applied to a wind turbine are that the turbine system neither needs to be accurately described nor does it need to be linear.6. Power smoothening is achieved which in turn enhances the power quality and increases the longevity of the generators protecting them against gust.

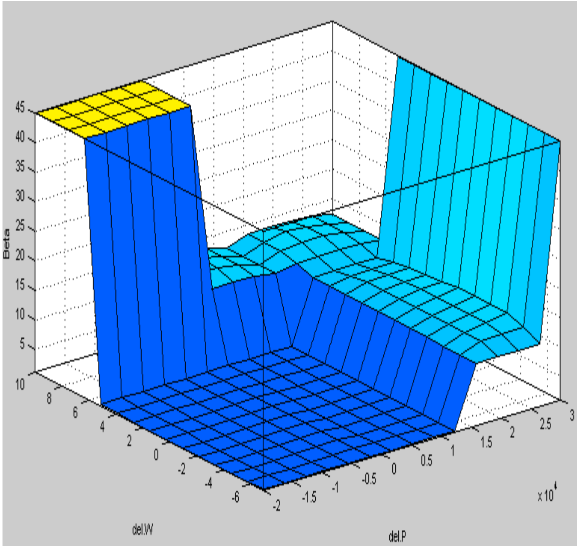


fig.6
Surface view of the rules of the FLC block

4.Modelling of PMSG, back to back PWM converter control and Battery energy storage

The PMSG is modelled in the dq frame of reference. The voltage and torque equations of the PMSG are given with the following equations.

$$V_d = R_a i_d + L di_d/dt - \omega_e L_q i_q \quad (7)$$

$$V_q=\omega_e L_q i_d+R_a i_q+L\, iq/dt \tag{8}$$

$$T_e=P\{Ki_q+(L_d-L_q)i_d i_q\} \tag{9}$$

V_d and V_q are the d and q axis voltages respectively and i_d and i_q are the dq axis currents. R_a is the stator resistance, L_d and L_q are the direct and quadrature axis inductances. ω_e is the generator rotational speed, K is the permanent magnetic flux and P is the number of pole pairs. The motion equation of the PMSG is given by

$$T_e=J_{eq}d\omega_m/dt+D\omega_m+T_w \tag{10}$$

The WECS adopts an AC-DC-AC converter system. The PMSG is connected to the grid through two PWM-VSCs: a generator-side converter and a grid-side inverter. Each of the four quadrant power converters is a standard 3-phase two-level unit, composed of six insulated gate bipolar transistors (IGBTs) and controlled by triangular-wave PWM law. The generator-side converter achieves variable-speed operation by controlling the rotational speed of the PMSG. On the other hand, the load-side inverter supplies the electrical power, which is synchronized with the grid frequency (diesel).The generator-side converter controls the rotational speed of the PMSG to achieve variable-speed operation with the MPPT control 8., 9. Vector control scheme is used in the control methodology 10.,11., The speed control of the PMSG is realized on a rotating reference frame, where the rotational speed error is used as the input to a speed controller, which produces *q*-axis stator current command i_q . A salient-pole synchronous machine is used in this paper. To achieve efficient operation of the PMSG, *d*-axis stator current command i_d** is set to zero* the actual *dq*-axis currents are used as inputs to the current controllers. The current controllers produce *dq*-axis voltage commands v_d and v_q after the decoupling. The dq axis voltages are transformed to phasor v_{abc} and fed to the pulse generator.

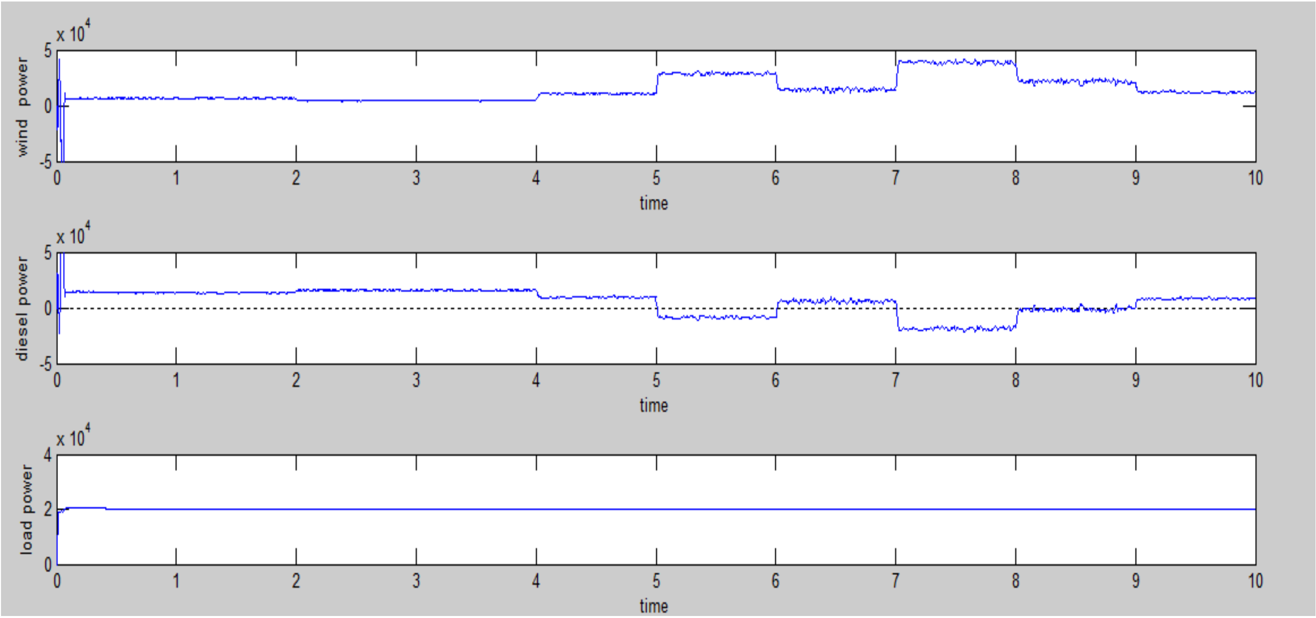
The load side converter control is realized by using a synchronous reference frame , the DC-link voltage (V_{DC}) is controlled by the grid-side inverter. The V_{DC}*(ref) is set to 1000V for UPF operation, iq*= 0, [10]. The active power exchange is directly proportional to the id and this direct-axis current id is also responsible for regulating the dc-link voltage.9.

The interfacing of the battery is done with the help of a buck boost converter. During high wind conditions, the buck converter utilizes the extra generated power to feed the battery whereas during low wind speeds it acts as a boost converter to compensate the fluctuations on the DC link. The PI controller compares the dc link voltage to a reference and generates the reference current signal

5. SIMULATION RESULTS AND DISCUSSION

The proposed system was simulated using MATLAB Simulink software and the results obtained for a direct drive PMSG rated for 20KW.

RESULTS FOR PI CONTROLLER



FUZZY LOGIC CONTROLLER

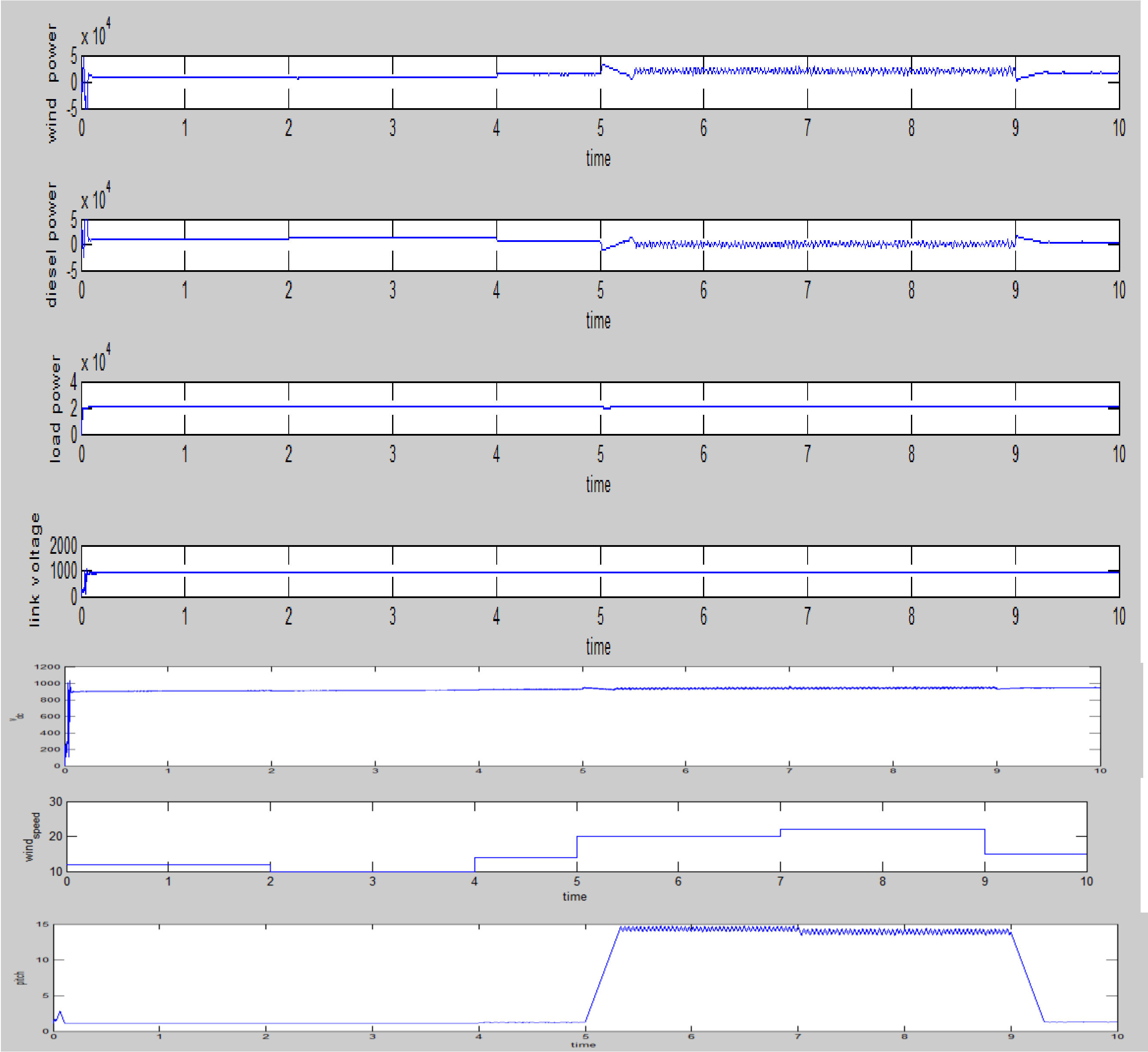


Fig.7

Analysis of results fig.7obtained during the simulation shows that the behaviour of the system as regards the variation in the generated wind power is much less using an FLC, than while using a PID controller. The DC link fluctuations are much less which translates to fewer fluctuations on the diesel group. Moreover, the generator is protected from gust as the pitch angle control facilitates the adjustment of generated power reducing the pressure on the PMSG and hence prolonging its life and efficiency. Without control, mechanical power can exceed nominal power in a wind turbine, Owing to wind speed increase above the nominal wind speed(12m/s) for the turbine. Hence, the WECS operation is unsustainable. For a horizontal axis wind turbine, pitch angle control is one method to control the peak of the mechanical power, returning to normal power condition without stopping the WECS. Simulation results indicate that the control of the pitch angle is able to limit the mechanical power excursion, but the response takes time to capture normal operation condition, depending on the inertia of the rotor. FLC is smoother and faster besides being more effective. For gust wind speeds between 20m/s and 22m/s, the response of the two controllers can be compared. At t=5sec, the wind speed changes to 20m/s and the power generated by the wind also increases. The response of the PI controller is sluggish, as the generated power settles down to the optimum value after a period 1 sec and again, when the wind speed further increases to 22m/s, the response takes time to stabilize. In contrast, the fuzzy logic controller stabilises the system response almost instantly and the power remains at the optimum till the gust remains. The DC link voltage is also smooth for a wide range of wind speed (10m/s to 22m/s). Hence power conditioning is realized using a combination of battery energy storage and FLC pitch controller, the results are validated using MATLAB simulink model .

6.REFERENCES

1.Thomas Ackermann, 'Wind power in power systems', John Wiley and sons Ltd.

2.. Mukhtiar Singh and Ambrish Chandra, 'Control of PMSG based Variable Speed Wind Turbine Battery Hybrid system in an Isolated Network,'*IEEE Trans. Energy Convers*., vol. 16, no. 2, pp. 134-139.

3. Abu Mohammad Osman Haruni, Ameen Gargoom, Md. Enamul Haque, and Michael Negnevitsky 'Voltage and Frequency Stabilisation of Wind-Diesel Hybrid Remote Area Power Systems',
Centre for Renewable Energy and Power Systems

4. S. Hurtado, G. Gostales, A. de Lara, N. Moreno, J. M. Carrasco, E. Galvan, J. A. Sanchez, and L. G. Franquelo, "A new power stabilization control system based on making use of mechanical inertia of a variablespeed wind-turbine for stand-alone wind–diesel applications," in *Proceeding of IEEE IECON*, Nov. 5–8, 2002, vol. 4, pp. 3326–3331.

5. J. A. Sanchez, N. Moreno, S. Vazquez, J. M. Carrasco, E. Galvan, C.Batista, S. Hurtado, and G. Costales, "A 800 kW wind–diesel test bench based on the MADE AE-52 variable speed wind turbine," *in Proceeding of IEEE IECON,* Nov. 2–6, 2003, vol. 2, pp. 1314–1319.

6. Ali Musyafa', Made Yulistya Negara, Imam Robandi 'Design Optimal in Pitch-controlled Variable-speed under Rated Wind Speed WECS using Fuzzy Logic Control', *Australian Journal of Basic and Applied Sciences,* 5(8): 781-788, 2011

7. Jianzhong Zhang, Ming Cheng, Zhe Chen, Xiaofan Fu, '*Pitch Angle Control for Variable Speed Wind Turbines',*

8..M. Singh, V. Khadkikar, A. Chandra, 'grid synchronisation with harmonics and reactive power compensation capability of a permanent magnet synchronous generator-based variable speed wind energy conversion system',*IET power electronics* vol.1, pg.(122-130) issue 2011

9..J. Y. Dai, D. D. Xu, and B. Wu, "A novel control scheme for current source-converter-based PMSG wind energy conversion systems," *IEEE Trans. Power Electron.*, vol. 24, no. 4, pp. 963–972, Apr. 2009.

10.. M. Malinowski, S. Stynski, W. Kolomyjski, and M. P. Kazmierkowski, "Control of three-level PWM converter applied to variable-speed-type turbines," *IEEE Trans. Ind. Electron.*, vol. 56, no. 1, pp. 69–77, Jan. 2009.

11.. Nishikata and F. Tatsuta, "A new interconnecting method for wind turbine/generators in a wind farm and basic performances of the integrated system," *IEEE Trans. Ind. Electron.*, vol. 57, no. 2, pp. 468–475, Feb. 2010.

.