HYBRID FUZZY-PI BASED DFIG WITH BESS FOR WIND GUSTS

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Abstract— **Due to the population growth and economic development in the world, the energy demand is increasing day by day. Fossil fuel sources like oil, coal, etc. are costly and cause serious pollution to the environment. From the renewable energy sources the solar and wind power plants are the two emerging technologies for the energy production. Wind energy generation coming under renewable energy source, is a feasible solution to energy shortage. In the proposed system the DFIG is capable of producing power in above and below synchronous speed. The power supplied to the grid through stator and rotor. In this paper, a battery energy storing system is introduced in between the inverter and converters section. The implementation of hybrid Fuzzy-PI controller improves transient performance of the system better than PI controller. The proposed system is simulated in MATLAB/SIMULINK and results are presented**.

Index Terms — **Doubly fed induction generator (DFIG), Battery energy storing system (BESS), Power electronic converters (PEC), Wind turbine, Rotor Side Converter(RSC), Grid Side Converter(GSC)**

I. INTRODUCTION

The first kind of wind turbines used asynchronous squirrel cage induction generator which are directly connected to the grid. The rotational speed of the wind turbine cannot be automatically regulated and will only vary with the wind speed [1]. This type of wind turbine needs a switch to prevent motoring operation during low wind speeds, and also suffers a major drawback of reactive power consumption since there is no reactive power control. This reactive power problem can be avoided by using locally installing capacitor banks. There will be electrical power fluctuations due to the fact that there are no speed or torque control loops. These electrical power fluctuations can lead to an impact at the point of connection in the case of a weak grid [2]. Based on the grid frequency and number of poles, the wind generator will rotate and based on the gearbox ratio the turbine will rotate. First generation wind power plants were commonly preferred due to some advantages like simple design, lower cost and easy maintenance. Reactive power problems and mechanical stresses in the drive trains produce unsteady output to the grid. Hence they not used now a days. The second generation wind turbines uses a wound rotor induction generator directly connected to the grid [3]. The rotor phase windings of the generator are connected in series with controlled resistances. In this way, the total rotor resistances can be regulated, and thus the slip and the output power can be controlled. The limitations of the series resistance size and the variable speed range is usually small, typically 0- 10% above synchronous speed. But the main problem of this type of wind turbine is that large amount of power loss occurs in the rotor resistance. The disadvantages associated with the first two types of wind turbines are :

_ They do not support any speed control
_ They do not have reactive compensation
_ They require a stiff grid
_ Their mechanical construction must be able to support high mechanical stress caused by wind gusts

The third generation is known as variable speed wind turbine with partial scale power converter (doubly-fed induction generator) [4]. The stator phase windings of the doubly fed induction generator are directly connected to the grid, while the rotor phase windings are connected to a back-to-back converter via slip rings. The power converters could control the rotor frequency and thus the rotor speed. Here, the speed range for the DFIG is around 30% of the synchronous speed. The power rating of the power converters is typically rated 30% around the rated power since the rotor of the DFIG would only deal with slip power. The smaller rating of the power converters makes this concept attractive from an economical point of view. This type of wind turbine can also achieve the desired reactive power compensation. The fourth generation is known as variable speed wind turbine with full scale power converter. The stator phase windings are connected to the grid through a full-scale power converter. The power electronic converters handle the entire output power of the generator. Thus, it provides a wide range of speed and operates at unity power factor because there is no reactive power exchange with the grid via the rotor or machine side converter. The machine side converter is used to control the generator torque loading at a particular speed, while the grid-side inverter is operated to maintain the DC bus voltage constant. The machines in the

fourth generation are two types; wound field and permanent magnet synchronous machine. Permanent magnet synchronous machine is often used in wind turbines which use a permanent magnet (PM).

Due advantages of the DFIG over other generators, it is being used for most of the wind power applications. Presently DFIG wind turbines dominate the market due to cost effective provision of variable speed operation. During generating mode, the torque is negative and during motoring mode the torque is positive. DFIG has the ability to control electrical torque and reactive power which helps to provide better performance considering the system stability. DFIG is basically an induction generator with the multiple winding that is directly connected to the electrical grid and three phase rotor winding which is also connected to the grid via slip rings. In a squirrel-cage induction generator the rotor is short circuited, while in a DFIG the rotor terminals are accessible. In the DFIG concept, the wound rotor induction generator is grid-connected at the stator terminals as well as the rotor terminals through a partially rated variable frequency ac/dc/ac converter (VFC), which only needs to handle a fraction (25%-30%) of the total power to achieve full control of the generator. The VFC consists of a rotor-side converter (RSC) and a grid-side converter (GSC) connected back-to-back. The dc link capacitor is introduced in between the inverter and converter sections. During super synchronous mode of operation, the wind speed rises above the rated speed. Then the stator as well as rotor is capable of injecting power to the grid. During sub synchronous mode of operation, the wind speed falls below the rated speed and the additional power required for keeping stator power constant is taken from the grid and it is injected to the rotor. Thus the power supplied by stator remains a constant. During synchronous mode of operation, the wind speed is the rated speed. Only the stator is supplying power; the rotor neither injects nor absorbs power. Thus, the power supplied by stator always remains a constant while the rotor power varies depending on the wind speed. Due to this, the power in the grid will change from time to time [5].
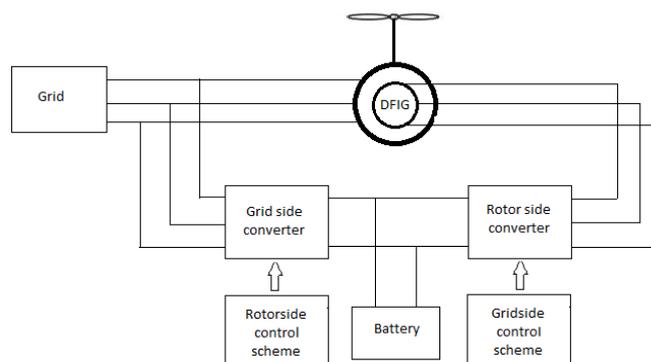
II. PROPOSED SYSTEM

Fig.1. DFIG with BESS

In the proposed model the DC link capacitor is replaced by using BESS, shown in figure1. The stator is directly connected to the grid and rotor is connected to the grid through PEC and in between PEC BESS is introduced. Here also three modes of operation are possible. When the wind speed is greater than the rated wind speed the stator and rotor is capable of supplying the power. Here the DFIG is designed to extract maximum power from the wind energy. So the grid power increases in-order to make the grid power constant the BESS will store the additional amount of power available in the grid. When the wind speed is less than the rated wind speed the stator is only capable of supplying the power the additional amount of power needed to the grid is supplied by the BESS. When the wind speed is rated speed the stator is only capable of supplying the power, i.e, rated power is supplied by the stator itself. During this condition the BESS working in floating mode

III. CONTROL STRATEGY

This section describes how the control scheme is implemented in DFIG. The main advantage is decoupled control of active and reactive power is possible. Here two back to back converters are used so we need to control these two converter sides. These two controllers are known as RSC and GSC Based on the wind speed the power is allowed to flow on both directions in the rotor side.
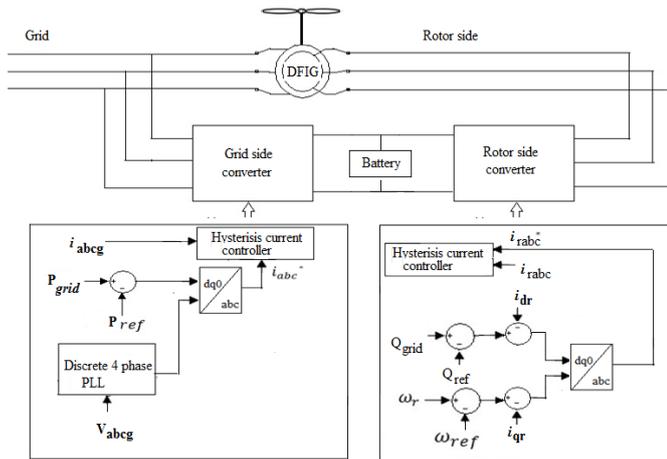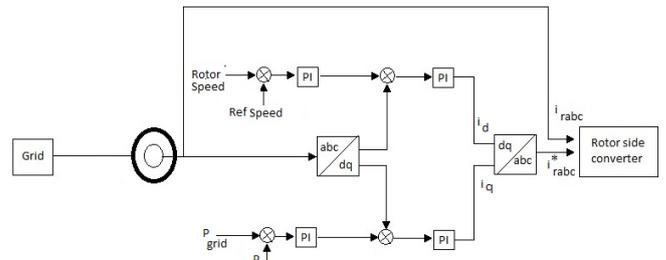
generated.

Fig. 2. DFIG control scheme

Fig .3.Control of Rotor Side Converter

Fig.4. Control of Grid Side Converter
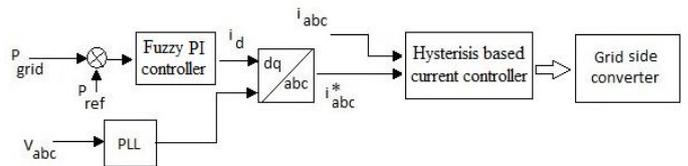
Fig .5.Control of Grid Side Converter using Fuzzy PI controller

1. Control of Rotor Side Converter (RSC)

The DFIG is controlled in the stator flux oriented reference frame. In stator flux oriented reference frame the d axis component of current is oriented along the stator flux position[6]. The RSC is mainly used for extracting maximum power from the wind turbines also for maintaining low reactive power in the DFIG. For this the reactive power set point is set to zero. The proportional-integral controller (PI) controller is used for the regulation of reactive power and rotor speed. The reference rotor currents i_{rdef} and i_{rqef} are obtained. Then "(1)" and "(2)" reference d-axis and q-axis components are compared with instantaneous values of d-axis and q-axis components of rotor currents i_{rd} and I_{rq} are the instantaneous values of d-axis and q-axis components of rotor currents [7]. Then this reference current is compared with the instantaneous values of rotor currents clock pulses are generated.

$$i_{dref} = (K_{prsc} + \frac{K_{irec}}{s})(i_{rd} - i_{rdef}) \qquad (1)$$

$$i_{qref} = (K_{prsc} + \frac{K_{irec}}{s})(i_{rq} - i_{rqef}) \qquad (2)$$

2. Control of Grid Side Converter (GSC)

The power which has to be maintained constant is obtained from the average power based on the wind speed variations calculated earlier. This power is given as reference power to the grid side converter[8]. This reference power is compared with instantaneous value of the grid power. The reference d axis component of the current is obtained as

$$i_{rdref} = (K_{prsc} + \frac{K_{irec}}{s})(Q_{grid} - Q_{ref}) \qquad (3)$$

$$i_{rqref} = (K_{prsc} + \frac{K_{irec}}{s})(\omega_{rotor} - \omega_{ref} \qquad (4)$$

d-q-o to a-b-c transformation it is compared with the instantaneous values of grid currents clock pulses are

During transient condition that is when there is a large change in wind speed variations the power oscillation is too high here. In order to limit this power oscillation the PI controller in the GSC is replaced by using hybrid Fuzzy PI controller [10]. The usage of hybrid fuzzy logic controller will reduce the settling time also small amount of overshoot also this variation
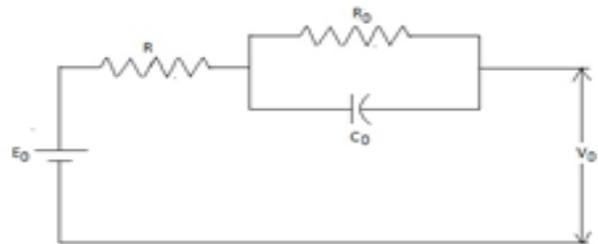
IV.   Battery Modeling

Fig.6 . Battery model

The most commonly used battery model is Thevenin battery model. Thevenin equivalent model consist of an ideal no load battery voltage represented by E_0. The equivalent resistance of internal and external series and parallel or series combination of battery is represented by R [11].   This equivalent resistance is usually taken as very small value. The R_0 and C_0 represents the capacitance of the parallel plates and non-linear resistance due to contact resistance. R_0 in parallel with the C_0 represents self-discharging of the battery. The self-

discharging of the battery is very small so this value is taken as large value [12]. The battery is an energy storing device so it is represented in kilowatt-hour (kWh). The value of capacitance C_0 is determined by

$$C_O = \frac{kWh \times 3600 \times 10^3}{0.5(V^2_{max} - V^2_{min})} \qquad (5)$$

The V_{max} and V_{min} are the maximum and minimum open circuit voltage of the battery when the battery is under fully charged and discharged condition. The lead acid battery is not allowed to discharge below 25%. If the battery discharge is falls below 25% it will affect the life of the battery[13].

V. SIMULATION RESULTS

The simulation time used is 10 sec. The wind speed is varied from 0 to 20 m/s during the simulation that is the wind speed is varied above rated wind speed, rated wind speed and below rated wind speed. The variation in wind speed is shown in 7. Initially the wind speed is 10 m/s for this step input is applied. The wind speed is kept 10 m/s upto 2. 5 sec then the wind speed is changed to 20 m/s. Then this speed is reduced to 13.7 m/s. Then at time t=6 sec the speed is reduced to 0 m/sec. Thus varying wind speed is applied to the wind turbine.
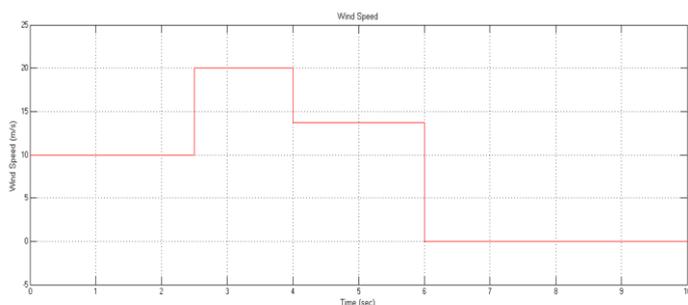

Fig . 7. Wind speed characteristics

The torque characteristic is shown in the figure 8. The negative torque shows generation of power. When the torque is zero that means the wind speed is zero. The wind speed is varied at 2. 5 sec, 4 sec and 6 sec correspondingly the torque is also varied. The maximum negative torque is obtained at time 2. 5 sec to 6 sec during this time wind speed is maximum i. e, 20 m/s.
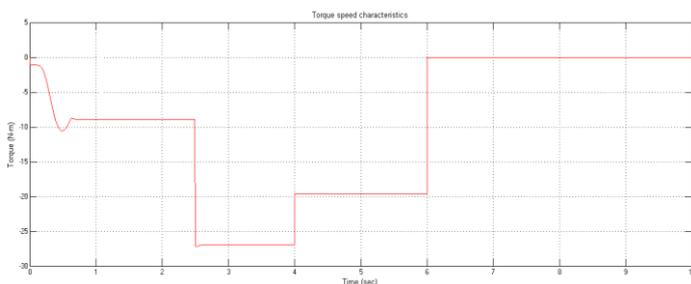

Fig . 8. Torque speed characteristics

The active power supplied by the stator of the DFIG is shown in the figure 9. During starting the wind speed is 10 m/s that is wind speed is less than rated wind speed at this time stator injected power is only nearly 500 W that is less than the rated power of the grid. During time t = 2. 5 sec wind speed is increased to 20 m/s at this time the stator will inject 1400 W that is greater than the rated power of the grid. When t = 4 sec the wind speed is rated wind speed i. e, 13.7 m/s. During this period the stator will inject rated power that is 1000W. Then at time t = 6 sec wind speed is reduced to zero.
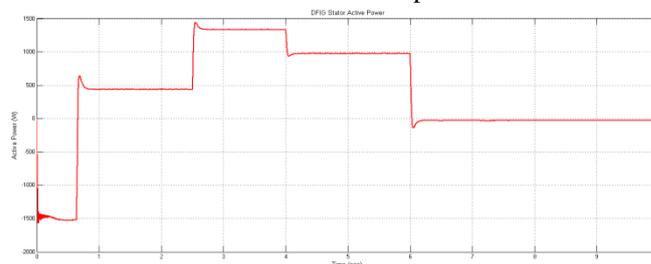

Fig. 9. Active power supplied by the stator of the DFIG

The active power supplied by the BESS of the DFIG is shown in the figure 10. During starting the wind speed is 10 m/s that is wind speed is less than rated wind speed at this time BESS injected power is nearly 500 W. During t= 2. 5 sec wind speed is increased to 20 m/s at this time 400 W will be stored by the BESS. When time t = 4 sec the wind speed is rated wind speed i. e, 13.7 m/s. During this period the BESS is in floating mode. Then at time t=6 sec wind speed is reduced to zero during this time the 1000 W to the grid supplied by the BESS.
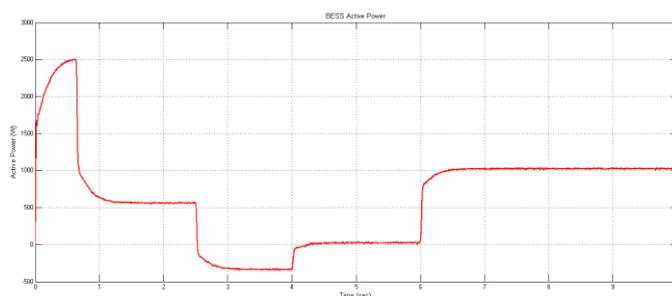

Fig. 10. Active power supplied by the stator of the BESS.

The active power of the grid is shown in the figure11. During starting the wind speed is 10 m/s that is wind speed is less than rated wind speed at this time stator injected power is nearly 500 W the additional amount of power will be supplied by the BESS During t= 2. 5 sec wind speed is increased to 20 m/s at this time the stator will inject 1400 W additional 400 W will be stored by the BESS. When time t = 4 sec the wind speed is rated wind speed i. e, at 13. 7 m/s the stator is capable of producing 1000 W

During this period the BESS is in floating mode. Then at time t = 6 sec wind speed is reduced to zero during

this time the 1000W to the grid supplied by the BESS. Thus the proposed system is capable of maintaining constant grid power (1000W) independent of the wind speed variations.
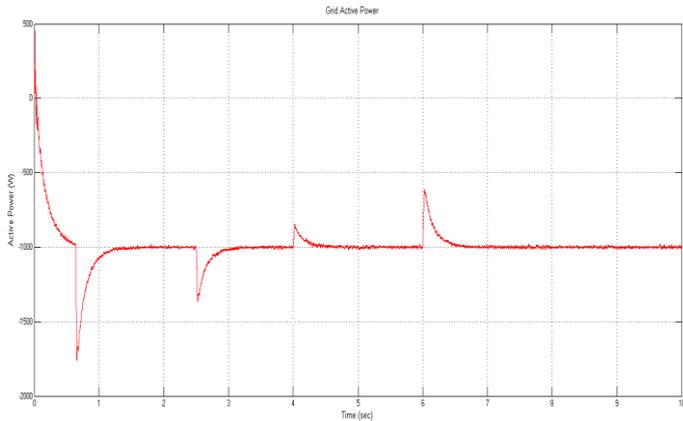

Fig. 11. Grid power variations with respect to time

The active power supplied by the DFIG stator and BESS at different wind speed is tabled in table I. Based on the wind speed the active power supplied by the DFIG stator is varying. This variation is overcome by BESS. If the wind speed is greater than the rated wind speed the BESS will store the additional amount power available in the grid. If the wind speed is less than the rated wind speed the BESS will supply

TABLE I: Active power of Stator, BESS and Grid

Time (sec)	Wind speed (m/s)	Stator power (W)	Battery power (W)	Grid power (W)
0-2. 5	10	450	550	1000
2. 5-4	20	1400	-400	1000
4-6	13. 7	1000	0	1000
6-10	0	0	1000	1000

additional amount of power needed to the grid. During rated wind speed the BESS will be in the floating mode The reactive power of grid is shown in figure 12. The reactive power of grid is maintained to zero. For maintaining reactive power of grid to zero the q axis component of grid side converter is set to zero. Thus we can conclude that the reactive power needed for the DFIG is supplied by the RSC.
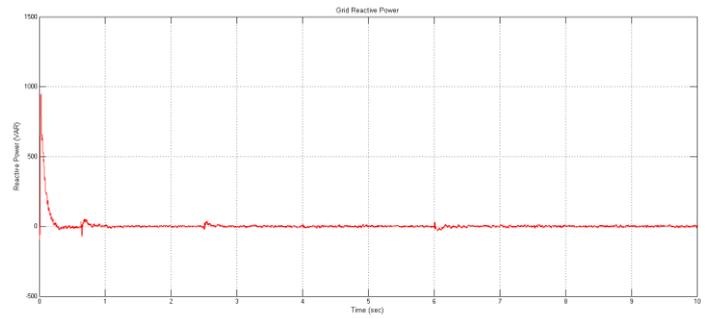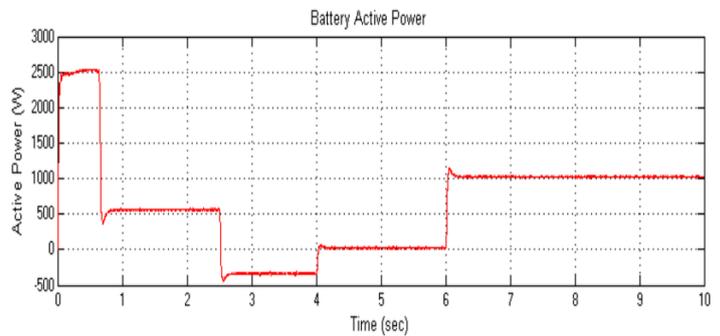

Fig. 12. Grid reactive power

Fig. 13 . BESS power using using hybrid Fuzzy PI controller

As compared to GSC using pi controller the fuzzy PI controller has fast response this is done by variation in speed of charging and discharging BESS. The active power supplied by the BESS using Fuzzy PI controller is shown in the figure 13. The comparison of settling time for BESS active power using PI and hybrid Fuzzy PI controller is shown in the table II. During transient conditions that are mainly due to large change in wind speed variations the power oscillation is too high here. Our aim is to maintain constant grid power. In order to limit this power oscillation during wind speed variations the PI controller in the GSC is replaced by using Fuzzy PI controller. By using Fuzzy-PI controller the settling time and also reduce the amount of overshoot this variation is easily identified in the figure 14. The comparison of settling time for grid active power using PI and hybrid Fuzzy PI controller is shown in the table II

Table II: SETTLING TIME FOR POWER SUPPLIED BY BESS USING PI AND FUZZY PI CONTROLLER

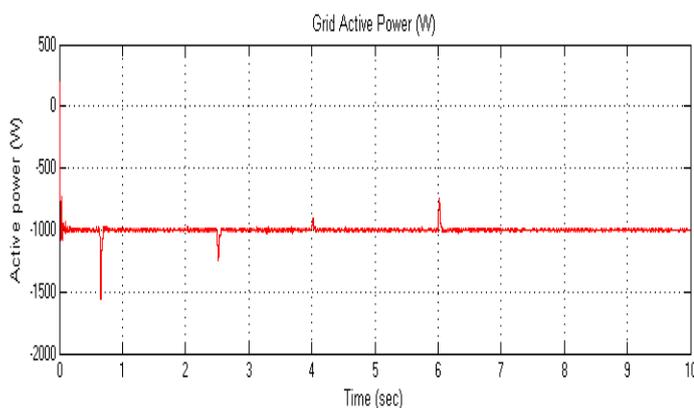| Wind speed (m/s)	10	20	13. 7	0
BESS Settling time (s)				
PI	1. 2	0. 5	0. 3	0. 4
Fuzzy PI	0. 8	0. 2	0. 1	0. 1

Fig. 14 Grid power using using Fuzzy PI controller

TABLE III. SETTLING TIME OF BESS AND GRID POWER

Wind speed (m/s)	10	20	13. 7	0
Grid power Settling time(s)				
PI	1. 2	0. 5	0. 3	0. 4
Fuzzy PI	0. 6	0. 2	0. 1	0. 1

TABLE IV. PEAK OVERSHOOT FOR GRID POWER

Wind speed (m/s)	10	20	13. 7	0
Grid Power Peak overshoot(%)				
PI	1. 2	0. 5	0. 3	0. 4
Fuzzy PI	0. 8	0. 2	0. 1	0. 1

VI. CONCLUSION

The wind profile of a particular area is highly variable. Therefore, new and improved technologies are required to make the electricity output from the wind turbines reliable. The work presented in this thesis is committed to control and grid-synchronization of the doubly-fed induction generator using BESS. A DFIG d-q steady state model is developed to study the real and reactive power control in stator-flux oriented frame. Modeling of RSC in the stator flux-oriented reference frame and modeling of GSC using inverter control schemes are done. The battery energy storage system is also modeled. The simulation results proves that the BESS operates effectively and maintain constant grid power under different wind speed conditions. In practical cases we cannot predict the exact wind speed variation. Hence transient stability analysis has a prominent role regarding wind speed variations. Therefore in this thesis, a hybrid Fuzzy PI controller is implemented in the GSC to improve transient response of the system

REFERENCE

[1] A. Miller, E. Muljadi, and D. Zinger, "A variable speed wind turbine power control," IEEE Trans. Energy Convers., vol. 12, no. 2, pp. 181–186, Jun. 1997

[2] Mustafa Jawad Kadhim, D.S.Chavan " Stability Analysis Of DFIG-based Wind Farms Using Different Bus Systems " IJITEE ,Volume-2,March 2010

[3] Sharad W. Mohod , and Mohan V. Aware "Micro wind power generator with battery energy storage for critical load," IEEE Systems Journal, Vol. 6, No. 1, March 2012.

[4] R. Pena,J.C.Clare' G.M.Asher " Doubly fed induction generator using back-to-back PWM converters and its application to variable speed wind-energy generation,"

[5] Vijay Chand Ganti, Bhim Singh, Shiv Kumar Aggarwal, and Tara Chandra Kandpal, "DFIG-based wind power conversion with grid power leveling for reduced gusts," IEEE transactions on sustainable energy, vol. 3, no. 1, January 2012

[6] Md.Arifujjaman, M.T.Iqbal,John E.Quaicoe " Vector control of a dfig based wind turbine ," vol. 9, no. 2, pp.1057-1066,2009

[7] J.S. Lather, S.S Dhillon, S.Marwaha "Modern control aspects in dfig based powersytstems :A review," International Journal of Advanced Research in Electrical, Electronics and Instrumentation EngineeringVol. 2, Issue 6, June 2013

[8] Balduino Cezar Rabelo, Wilfried Hofmann " Reactive power control design in doubly fed induction generators for wind turbines " ieee transactions on industrial electronics, vol. 56, no. 10, october 2009

[9]Bhim Singh, Fellow, Shiv Kumar Aggarwal, and Tara Chandra Kandpal "Performance of Wind Energy Conversion System using a Doubly Fed Induction Generator for Maximum Power Point Tracking" IEEE transactions on sustainable energy, vol. 3, no. 1, January 2010

[10] Marwan Rosyadi, S. M. Muyeen " Fuzzy-PI Controller Design for PM Wind Generator to Improve Fault Ride Through of Wind Farm" IJRER Vol.3, No.2, 2011

[11] Bhim Singh, Senior Member, IEEE, and Gaurav Kumar Kasal "Voltage and frequency controller for a three-phase four-wire autonomous wind energy conversion system,"IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 23, NO. 2, JUNE 2008

[12] Gonz´alez-Longatt, F. M., Circuit based battery models: a review. In Congreso Iberoamericano de estudiantes De Ingenieria Electrica. Cibelec. 2006..

[13] Salameh, Z. M., M. A. Casacca, andW. A. Lynch "A mathematical model for lead-acid batteries." Energy Conversion, IEEE Transactions on, vol 7,no 93–98, 1992

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