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Wind Power Conversion System Using Hybrid Fuzzy-PI Controller for Doubly Fed Induction Generator

[1]Sudheesh S, [2]Daina Shaji, [3]Jaison Cherian

[1,2,3] Saintgits college of engineering, kottayam, India

Abstract: **Due to population growth and economic development the energy demand is increasing day by day. Fossil fuel sources like oil, coal are costly and causing serious pollution to the environment. Wind energy generation is under renewable energy source it is a feasible solution to energy shortage. The wind speed variations cause's serious power quality problems during integration of wind turbine with the grid. For power control rotor side converter and grid side converter are used. 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 (BESS) is introduced in between the inverter and converters section. Since the converters and BESS are introduced in the rotor side their rating can be reduced. The implementation of Fuzzy-PI controller improves transient performance of the system. The system is simulated in MATLAB/SIMULINK and results are presented.**

Keywords: **Wind Energy Conversion System (WECS), 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

Wind energy generation is under renewable energy source it is a feasible solution to energy shortage. China has the most installed wind energy capacity, followed by the United States, Germany, Spain and India. Wind energy is one of the fastest growing energy production industries at present situation and it will continue to grow worldwide, as many countries have plans for future development. The Indian wind energy sector has an installed capacity of 18. 55 GW. However the output power of wind generator is fluctuating due to wind speed variations. This will causes serious problems in the distribution network. Wind turbines can either operate at fixed speed or variable speed. For a fixed speed wind turbine the generator is directly connected to the electrical grid. For a variable speed wind turbine the generator is controlled by power electronic equipment. Because of the advantages of the DFIG over other generators it is being used for most of the wind power applications. DFIG wind turbines dominate the market due to cost-effective provision of variable-speed operation.

The DFIG has the ability to control electrical torque and reactive power 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. A squirrel-cage induction generator, which has its rotor short-circuited, a DFIG has its rotor terminals 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 battery energy storing system is introduced in between the inverter and converter sections.

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II. TYPES OF WIND TURBINES

1. Fixed speed induction generator

The first kind of turbines uses one or two asynchronous squirrel cage induction generators. The power produced is made constant by varying the slip slightly. They are self-exiting and no need of slip rings and can be grid connected without the need of the power electronic devices. Due to some advantages like simple design, lower cost and easy maintenance they commonly used in power system. Figure 1 shows fixed speed induction generator [1].

2. Synchronous generator with full converter

These types of wind turbines uses full scale power electronic equipment's. The generator may be permanent magnet synchronous generator (PMSG) or wound rotor types. Instead of directly connecting the stator they are connected through rated power electronic converters the converter is back to back voltage source converter. The power control can be adjusted by pitch angle control. Due to fully rated power electronic converters they are more costly. Figure 2 shows synchronous generator with full converter.

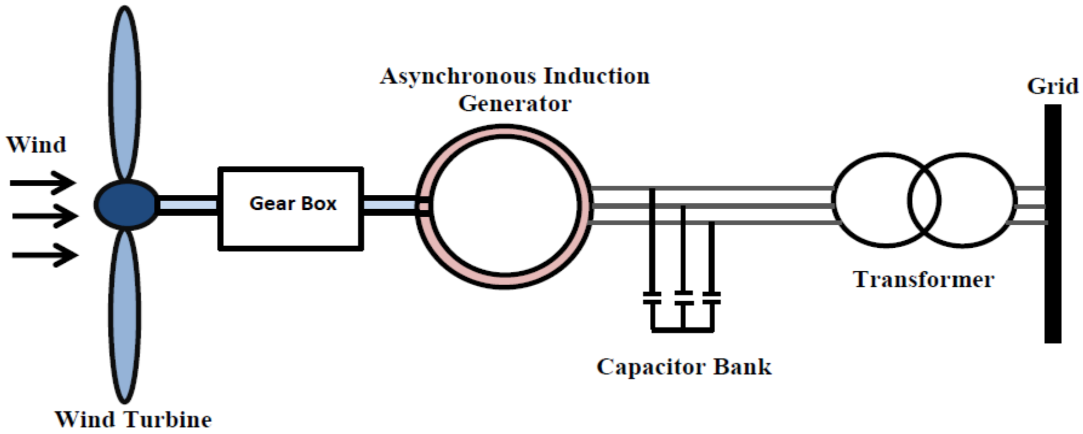

Fig.1. Fixed speed induction generator

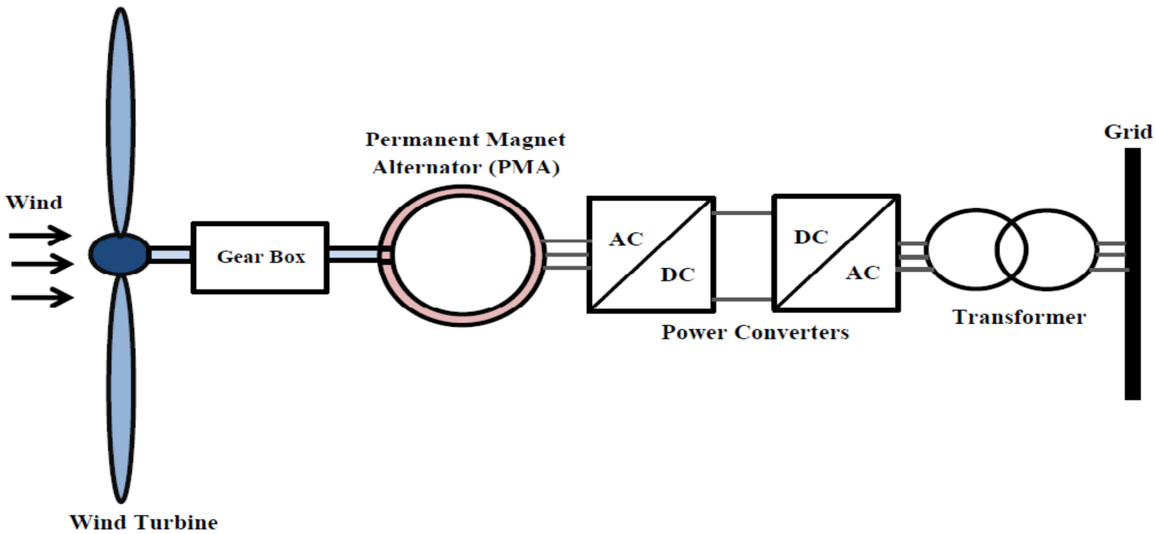

Fig.2. Synchronous generator with full converter

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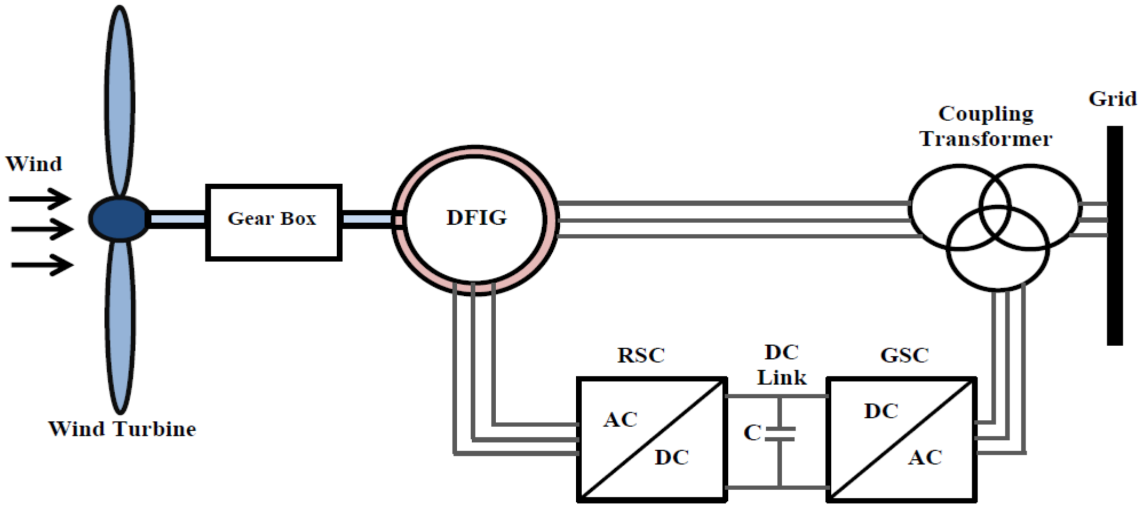

Fig.3. Doubly fed induction generator

3. Doubly fed induction generator (DFIG)

In DFIG the stator winding is directly connected to the grid and the rotor winding is connected to the grid through power electronic converters. The power electronic converter used is a voltage source converter. The power electronic converters will helps to compensate the difference between mechanical and electrical frequencies by providing rotor voltage with the changing frequencies. Thus the variable frequency of operation is possible. The converters used in the DFIG are only a fraction of the rated power of the turbine. Figure 3 shows doubly fed induction generator [2].

III. CONTROL STRATEGY

This section describes how the control scheme is implemented in DFIG. The main advantages 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 [3].

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. The RSC is mainly used for extracting maximum power from the wind turbines also for maintaining low reactive power in the DFIG [4]. For this the reactive power set point is set to zero [5]. 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

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

(1)

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

(2)

i_{rd} and I_{rq} are the instantaneous values of d-axis and q-axis components of rotor currents . Then this reference current is compared with the instantaneous values of rotor currents clock pulses are generated.

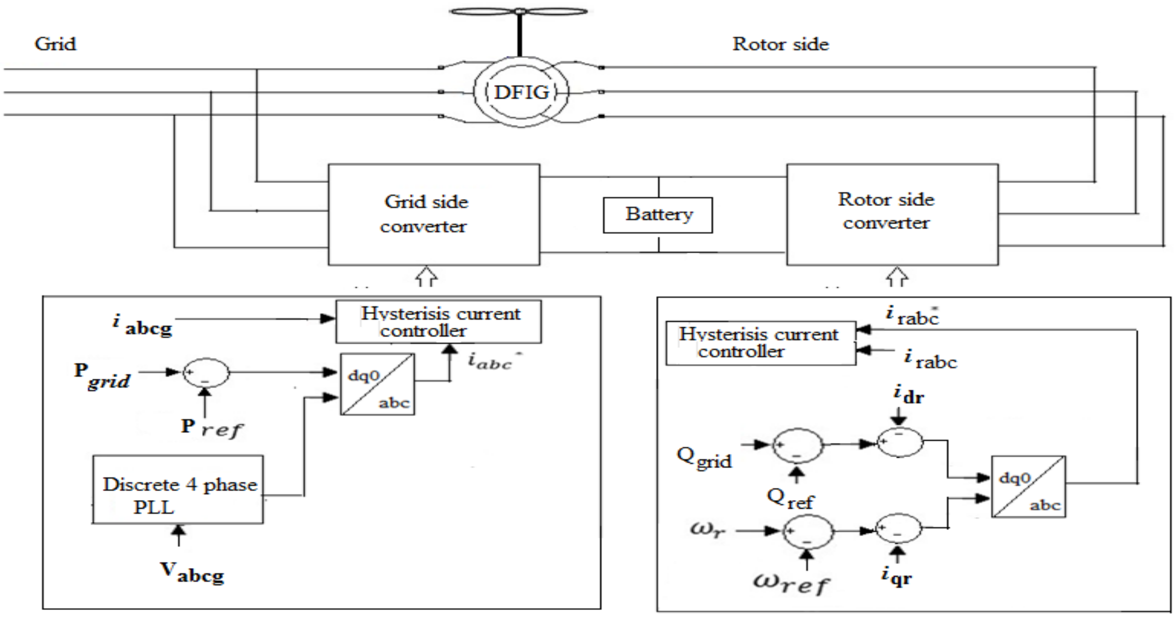

Fig.4. DFIG control scheme

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 [6]. This reference power is compared with instantaneous value of the grid power. The reference d axis component of the current is obtained as

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

(3)

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

(4)

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

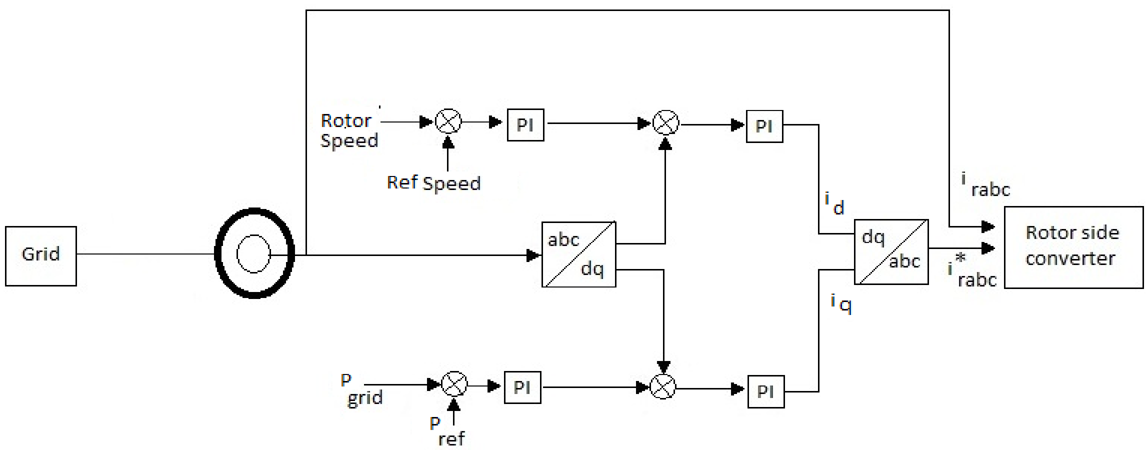

Fig.5. Control of Rotor Side Converter

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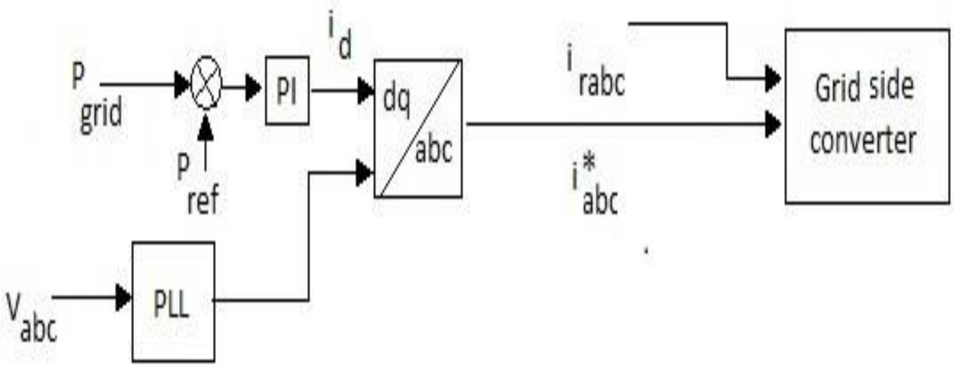

Fig.6. Control of Grid Side Converter

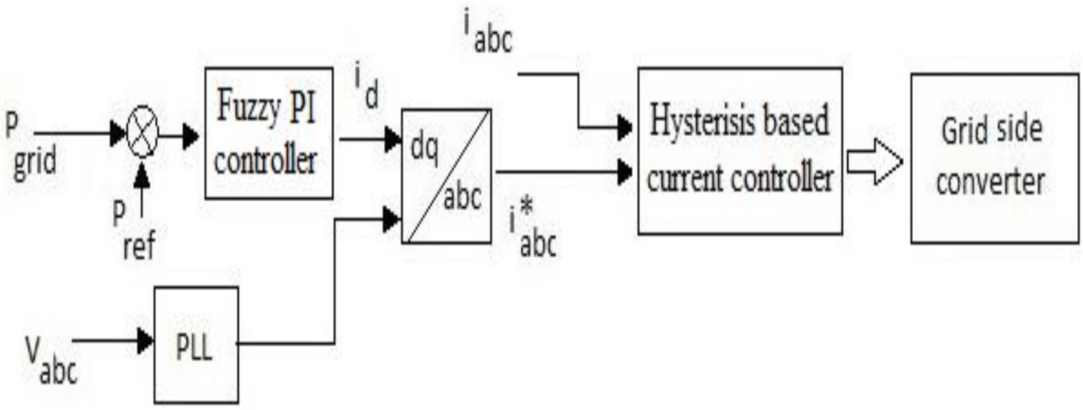

Fig.7. Control of Grid Side Converter using Fuzzy PI controller

TABLE I: FUZZY RULE TABLE

e\ Δe	E	PE
NP	PB	PM
NM	PM	PM
ZE	ZE	NM
PM	NM	NM
PB	NM	NB

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 Fuzzy PI controller. The usage of fuzzy logic controller will reduce the settling time also small amount of overshoot also this variation [7].

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II Battery Modeling

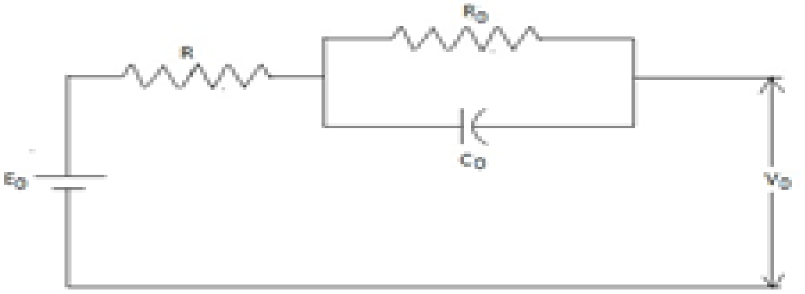

Fig.8. Battery model

The most commonly used battery model is Thevenin battery model [8]. 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. 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. The battery is an energy storing device so it is represented in kilowatt-hour (kWh) [9]. The value of capacitance C_0 is determined by

$$C_0 = \frac{\text{kWh} \times 3600 \times 10^3}{0.5(V^2{}_{max} - V^2{}_{min})} \qquad (5)$$

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% [10]. If the battery discharge is falls below 25% it will affect the life of the battery.

IV. 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 9. 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.

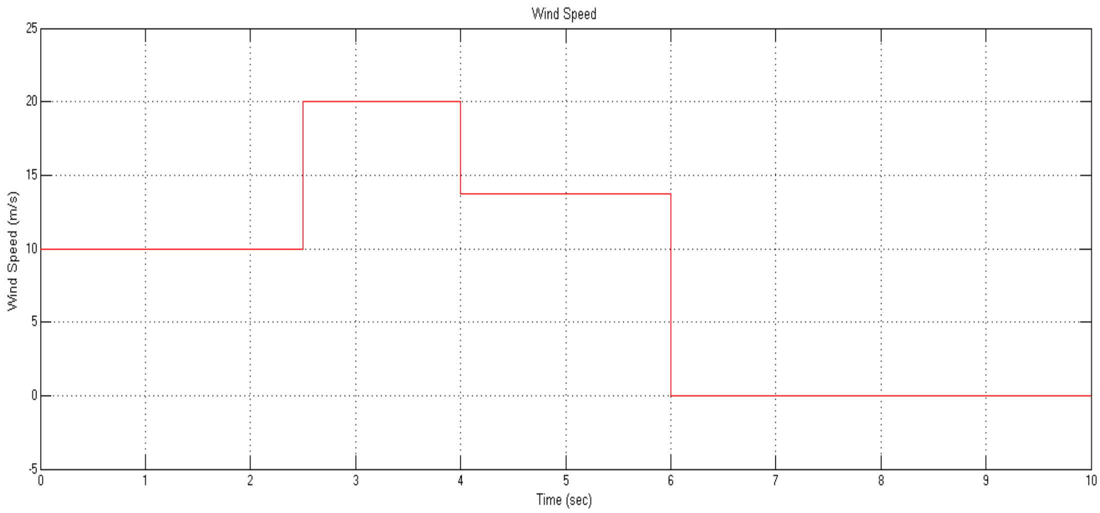

Fig.9. Wind speed characteristics

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The torque characteristic is shown in the figure 10. 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. Themaximum negative torque is obtained at time 2. 5 sec to 6 sec during this time wind speed is maximum i. e, 20 m/s.

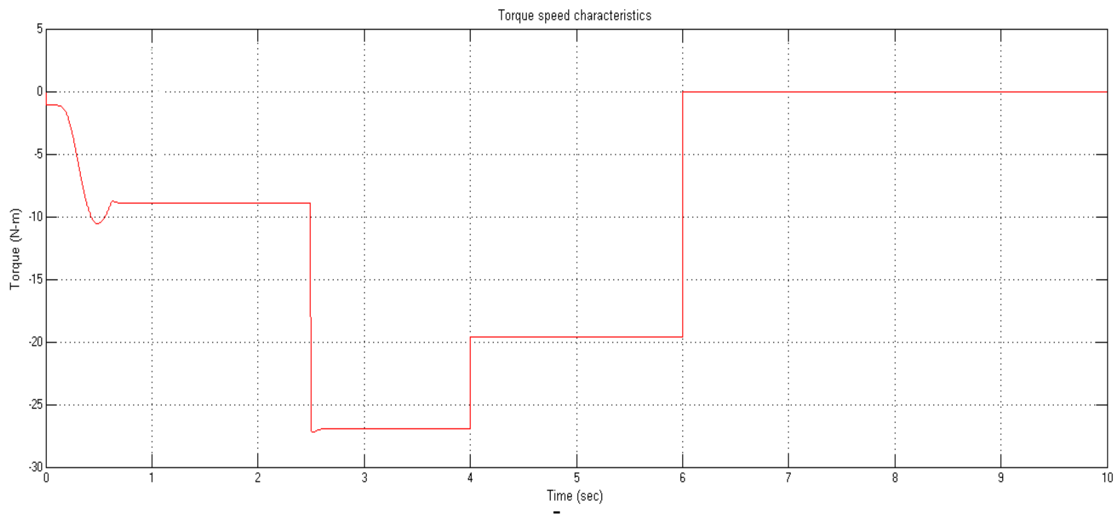

Fig.10. Torque speed characteristics

The active power supplied by the stator of the DFIG is shown in the figure 11. 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.

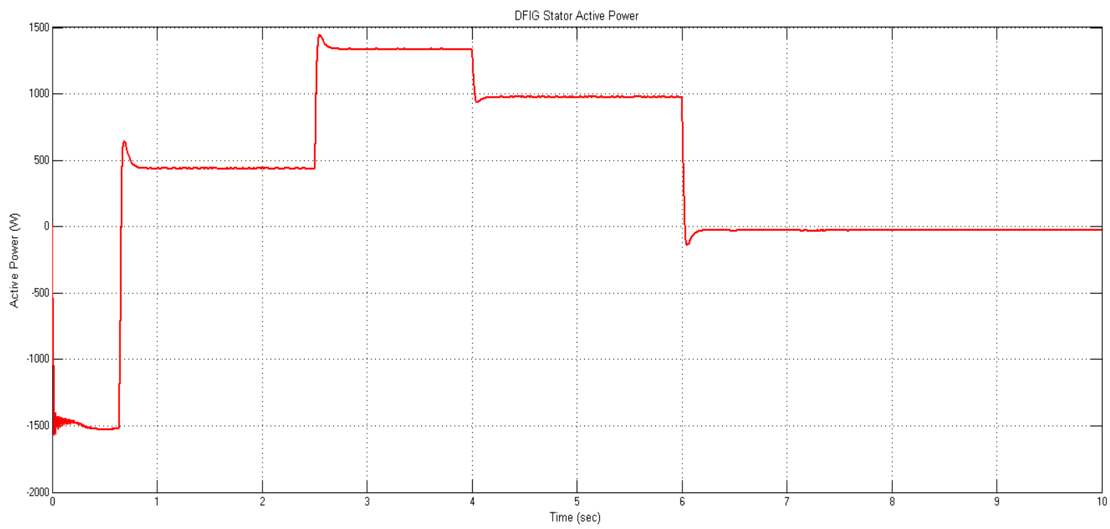

Fig.11. Active power supplied by the stator of the DFIG

The active power supplied by the BESS of the DFIG is shown in the figure 12. 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

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reduced to zero during this time the 1000 W to the grid supplied by the BESS. The active power of the grid is shown in the figure8. 10. 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

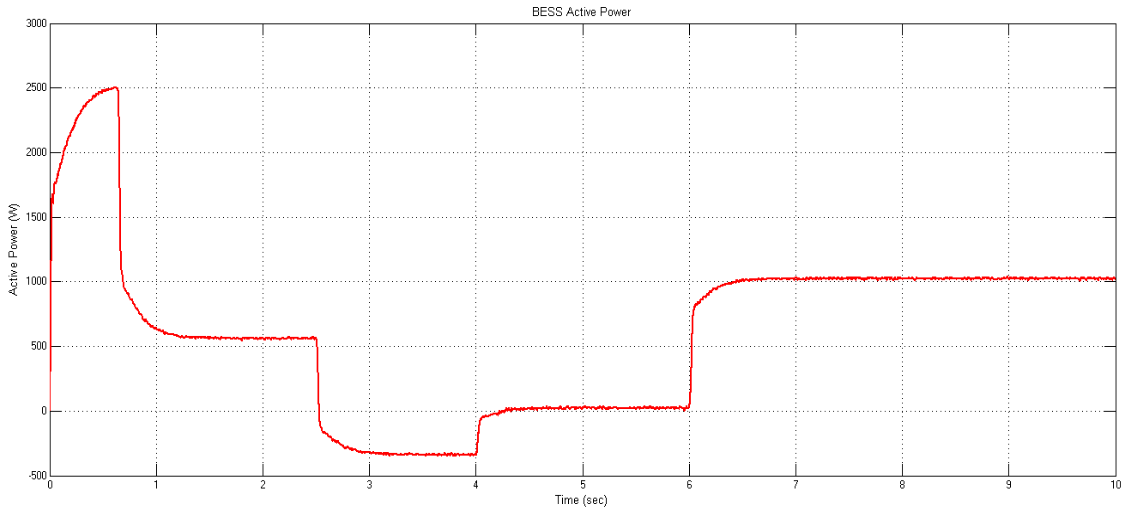

Fig.12. Active power supplied by the stator of the BESS. .

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

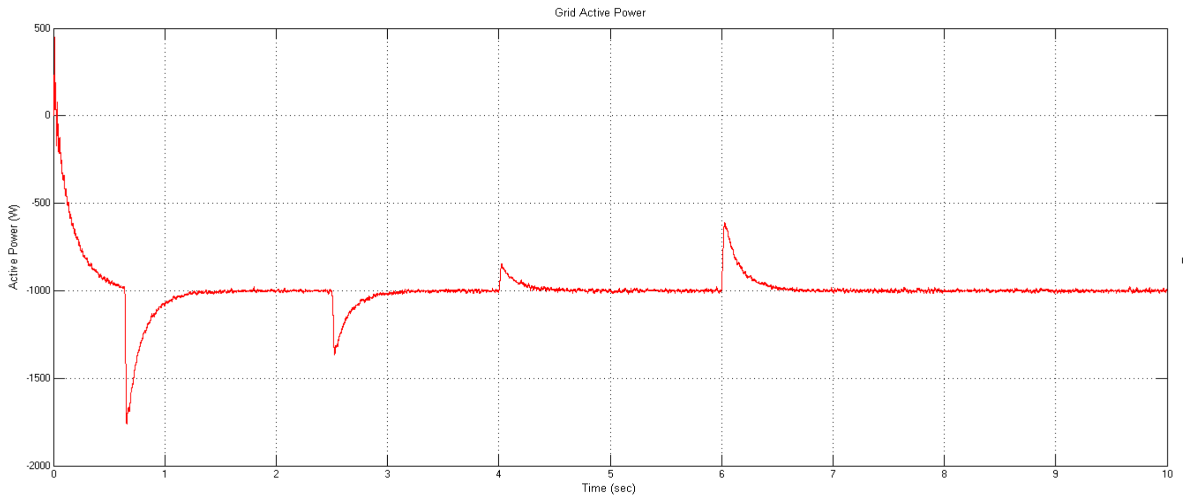

Fig.13. Grid power variations with respect to time

The active power supplied by the DFIG stator and BESS at different wind speed is tabled in table II. 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 additional amount of power needed to the grid. During rated wind speed the BESS will be in the floating mode.

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TABLE II: 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

The reactive power of grid is shown in figure 14. 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.

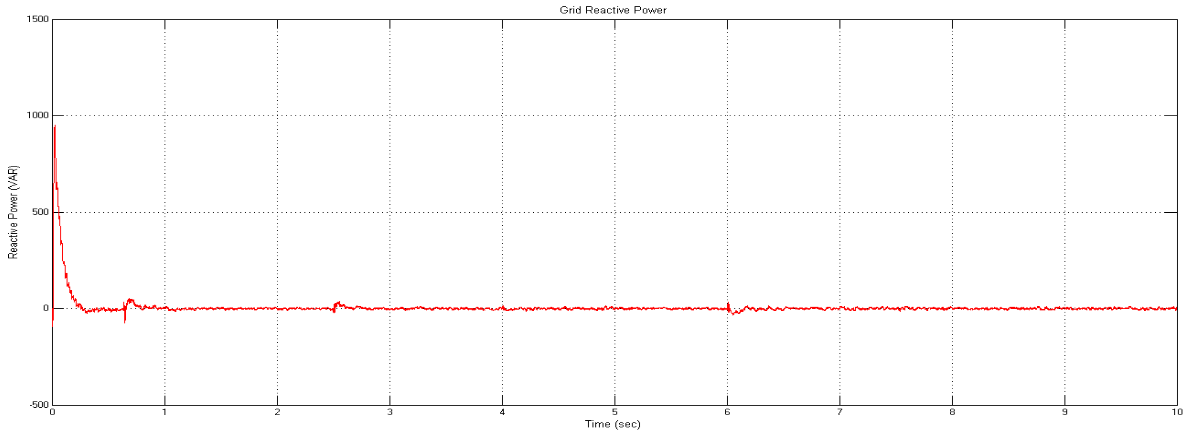

Fig.14. Grid reactive power

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 15. The comparison of settling time for BESS active power using PI and Fuzzy PI controller is shown in the table III.

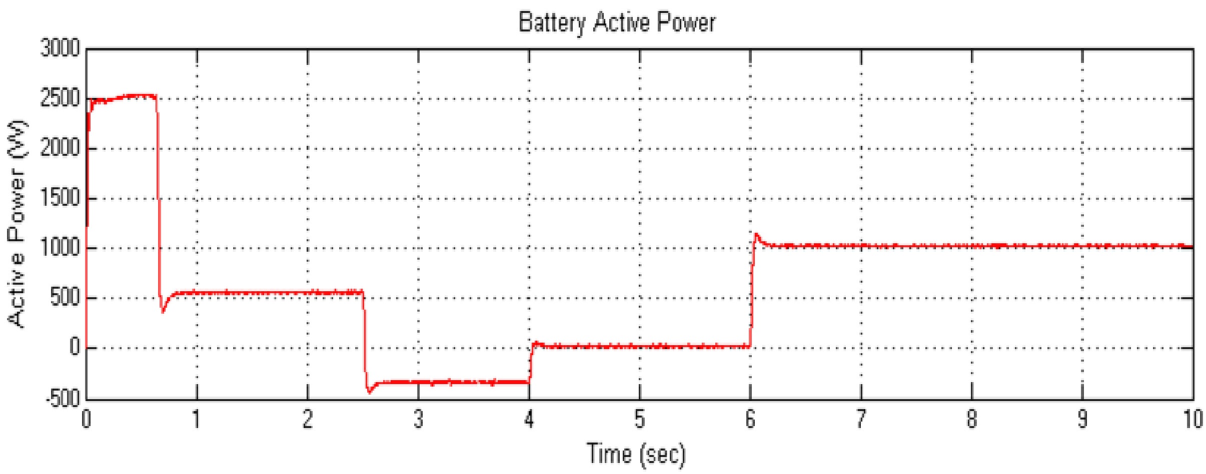

Fig.15. BESS power using using Fuzzy PI controller

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TABLE III: 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

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 16. The comparison of settling time for grid active power using PI and Fuzzy PI controller is shown in the table IV

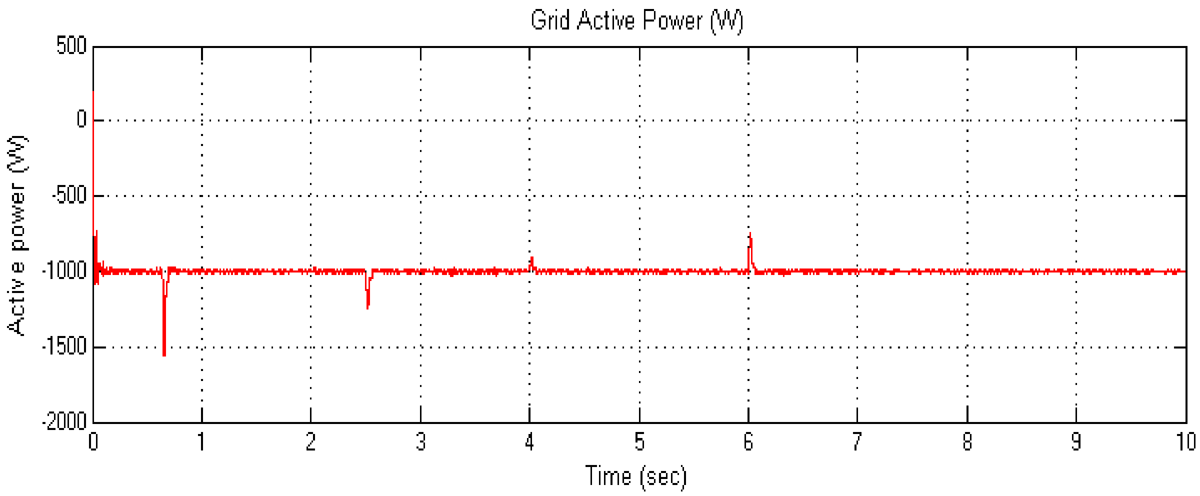

Fig.16. Grid power using using Fuzzy PI controller

TABLE IV: 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 V: 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

V. CONCLUSION

The work presented in this thesis is committed to control and grid-synchronization of the doubly-fed induction generator. A DFIG d-q steady state model is developed to study the real and reactive power control in stator-voltage and stator-flux oriented frame. The simulation results show that the active power of grid is by using GSC and is independent of varying wind speed. The machine torque is obtained as negative this shows that the DFIG is operating as generator. On varying with wind speed the output power of the BESS is varied. Thus the grid power is varying with wind speed. The BESS in the rotor side will helps to overcome these problems. During transient conditions that is when the wind speed is varying the settling time and peak overshoot is high for PI controllers. This problem can be reduced by Fuzzy-PI controller. The simulation was done in MATLAB/Simulink

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Sudheesh S received B.tech degree in Electrical & Electronics Engineering from Younus College of Engineering and Technology, Kollam, Kerala in the year 2011. He is currently working towards M.tech degree in Power systems from M.G.University. His areas of interest are Wind energy and its applications, Induction machines, Power system control & advanced relaying etc.

Daina Shaji received B.tech degree in Electrical & Electronics Engineering from Rajiv Gandhi Institute Of Technology, Kottayam, kerala in the year 2011. She is currently working towards M.tech degree in Power systems from M.G.University. Her areas of interest are Wind energy, Power quality, Control and grid connectivity, Power system control, Power electronics & advanced relaying etc

Jaison Cherian received B.tech degree in Electrical& Electronics Engineering from Cochin University of Science and Technology in the year 2010. He received M.Tech degree in Industrial Drives and Control from Rajiv Gandhi Institute of Technology, Kottayam in the year 2012. Currently he is working as Assistant Professor in Electrical department, Saintgits College of Engineering, Kerala. His area of interest are Vector control of AC machines, Adaptive control of electric drives, Speed control of BLDC motors, Control and grid connectivity of DFIG etc