International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Application of Unified Power Flow Controller in DFIG Based Wind Turbine

Sushabhan Biswas[1]

[1]JIS College of Engineering, Department of Electrical Engineering, Kalyani, Nadia, India

Abstract: ***The power quality is affected by the wind power injection into an electric grid. The performance of the wind turbine and thereby power quality are determined on the basis of measurements and the norms followed according to the guideline specified in International Electro-technical Commission standard, IEC-61400. The measurements of power quality are the active power, reactive power, voltage sag, flicker, harmonics and electrical behavior of switching operations and these are measured according to national/international guidelines. Unified Power Flow Controller (UPFC) is used to control the power flow in the transmission systems by controlling the impedance, voltage magnitude and phase angle. This controller offers advantages in terms of static and dynamic operation of the power system. A Unified Power Flow Controller (UPFC) is an electrical device for providing fast-sensation on high-voltage electricity transmission networks. This paper clearly shows the power quality issues which are improved using the Unified Power Flow Controller (UPFC), the fault protection issues are also discussed. The STATCOM and SSSC control scheme for the grid connected wind energy generation system for mitigating power quality issues is simulated using MATLAB/SIMULINK environment, and a DFIG is also used to study the response of the system during grid disturbances.***

Keywords: Power quality, Doubly Fed Induction Generator (DFIG), Unified Power Flow Controller (UPFC), Grid connected DFIG system, Matlab Simulink**.**

1. Introduction

Presently, the wind power attracted much attention as a promising renewable energy resource to constitute an important role in the modern power systems. Wind power solves the energy crisis problem in a certain extent, but the large scale wind power dive into power system has brought a series of technical problems, one of the problems is that the impaction on the protection configuration can't neglect. 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. So, if there is any fault in the subsystems there will be disturbances, disruptions and the other effects, which decrease the power quality in the system. In the proposed Simulink model of wind farm we have introduced-

Unified Power Flow Controller (UPFC) mode, when the shunt and series converters are interconnected through the DC bus. When the disconnect switches between the DC buses of the shunt and series converter are opened, two additional modes are available i.e. Shunt converter operating as a Static Synchronous Compensator(STATCOM)controlling voltage and Series converter operating as a Static Synchronous Series Capacitor (SSSC) controlling injected voltage, while keeping injected voltage in quadrature with current. Unified Power Flow Controller (UPFC) are being used extensively in power systems because of their ability to provide flexible power flow control . The main motivation for choosing SVC in wind farms is its ability to provide bus bar system voltage support either by supplying and/or absorbing reactive power into the system. As a main stream configuration for large wind turbines, DFIG wind turbines are required to remain grid connected during grid faults so that they can contribute to the stability of the power transmission system. This raises problems in terms of generator/converter protection and control. In the case of grid faults, the controllability of the DFIG variable speed wind turbine embraces both the wind turbine control for preventing over-speeding of the wind turbine and the control and protection of the power converter during and after grid faults.

2. DFIG Based Wind Turbine

A doubly fed induction generator is basically a standard, wound rotor induction generator with its stator windings directly connected to the grid and its rotor windings connected to the grid and its rotor windings connected to the grid through a converter. The AC to DC and DC to AC Converter is divided into two parts: the rotor side converter and the grid side converter. Force commutated power electronic devices are used in these voltage source converters to synthesize an AC Voltage from a DC source. A capacitor connected on the DC side acts as the DC voltage source. The grid side converter is connected to the grid by using a coupling inductor. The three phase rotor winding is connected to the rotor side converter by slip rings and brushes and the three phase stator windings are directly connected to the grid. The power of the wind turbine, the DC voltage and the reactive power or the grid terminal voltage are controlled by the pitch angle command and the voltage command signals V_r and V_{gc} generated by the control system for the rotor and grid side converters respectively.

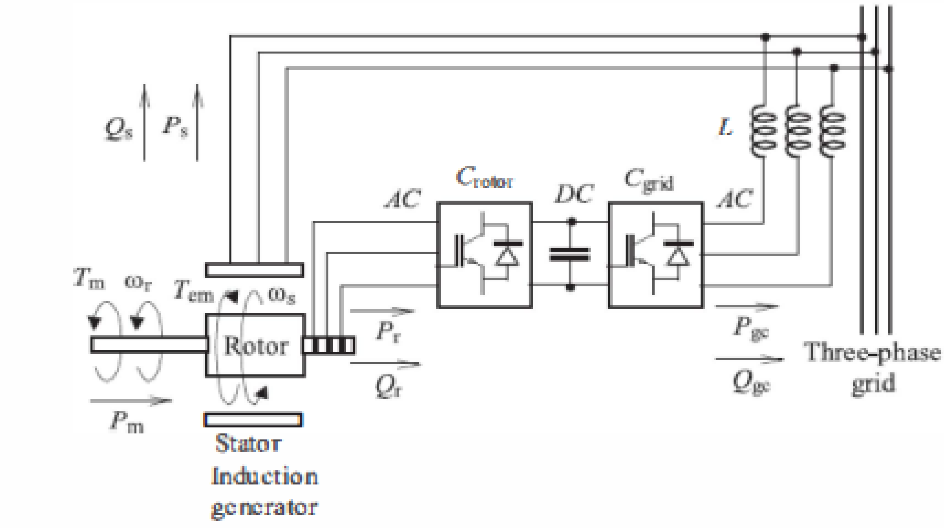

Figure 1: Power flow in DFIG

Figure 1 shows the flow of power in a Doubly Fed Induction Generator. The absolute value of slip is generally much lower than 1 and accordingly the electrical power output of the rotor P_r is only a fraction of the real power output of the stator P_s. W_s is positive and constant for a constant frequency grid voltage and also the electromagnetic torque Tm is positive for power generation, so the sign of P_r is a function of the slip sign. P_r is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). P_r is transmitted to DC bus capacitor and tries to set up the DC voltage for super synchronous speed operation . P_r is taken out of the DC bus capacitor and tries to reduce the DC bus voltage for sub synchronous speed operation . The DC voltage is kept constant by generating or absorbing the grid electrical power P_{gc} from the grid side converter. For a lossless AC/DC/AC converter P_{gc} is equal to P_r in steady state and the wind turbine speed is determined by the absorbed or generated power P_r by the rotor side converter. The voltage measured at the grid terminals can be controlled by controlling the grid side converter DC bus voltage of the capacitor can be regulated and by controlling the rotor side converter. The phase sequence of the AC voltage generated by the rotor side converter is positive for sub synchronous speed and negative for super synchronous speed. The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip. The reactive power or the voltage at the grid terminals can be controlled by the capability of the rotor and grid side converter of generating or absorbing reactive power. The rotor side converter is used to control the wind turbine output power and the voltage (reactive power) measured at the grid terminals. The voltage regulation of the DC bus capacitor is done by using the grid side converter. The rotor power converter as a vulnerable part of the DFIG power converter, which has a restricted over-current limit, needs special attention especially during faults in the grid. When faults occur and cause voltage dips, subsequently the current flowing through the power converter may be very high (over-current). During this situation, it is common to block the converter to avoid any risk of damage, and then to disconnect the generator from the grid. Motivated by the reason above, this report provides a study of the dynamics of the grid connected wind turbine with DFIG. In steady-state at fixed turbine speed with a lossless DFIG system, the mechanical power from the aerodynamic system is balanced by the DFIG power. Pm = Ps + Pr. It follows that

$Pr = Pm - Ps = Tm\omega r - Tm\omega s = -Tm((\omega s - \omega r)/\ \omega s) * \omega s = -s\ Tm\omega s = -sPs$

where s is defined as the slip of the generator.

3. Power Quality Issues

Power quality problem is any power problem manifested in voltage, current, or frequency deviation that results in failure or malfunctioning of customer equipment. Power quality is a two-pronged issue, with electronic equipment playing both villain and victim. The causes and consequences of power quality problems can be traced to a specific type of electrical disturbance. In most of industry, more than 90% of the electric motor with inverter driven application .Poor power quality causes trouble in receptacle/transmission equipment and electronic equipment malfunctions / Failure. Power quality is a common problem for both electric power suppliers and users. It is not easy to identify whether the cause of poor power supply quality is at the supplier's system or the user's system. Voltage fluctuations are changes or swings in the steady-state voltage above or below the designated input range for a piece of equipment. Fluctuations include both sags and swells and it causes large equipment start-up or shut down; sudden change in load.

4. Fault Protection Issues

The rotor power converter as a vulnerable part of the DFIG power converter, which has a restricted over-current limit, needs special attention especially during faults in the grid. When faults occur and cause voltage dips, subsequently the current flowing through the power converter may be very high (over-current). During this situation, it is common to block the converter to avoid any risk of damage, and then to disconnect the generator from the grid. Motivated by the reason above, this paper provides a study of the dynamics of the grid connected wind turbine with DFIG. The paper starts with development of a wind turbine model with DFIG in

Matlab Simulink, followed by simulations of the model during grid disturbance. In the simulation, the ability of the DFIG to recover terminal voltage after grid disturbance is presented. The response of the DFIG to faults and subsequent action of the over-current protection is described. Two different operation modes, i.e. sub-synchronous and super-synchronous operation, are treated separately. The results from the two operation modes are then evaluated. The inclusion of the saturation effect in the generator to provide better prediction of current magnitude is included as well.

5. Operating Principal of UPFC

Line outage, congestion, cascading line tripping, power system stability loss are the major issues where capability and utilization of FACTS are noticed. Representative of the last generation of FACTS devices is the Unified Power Flow Controller (UPFC). The UPFC is a device which can control simultaneously all three parameters of line power flow (line impedance, voltage and phase angle). Such "new" FACTS device combines together the features of two "old" FACTS devices: the Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC).

The shunt inverter is used for voltage regulation at the point of connection injecting an opportune reactive power flow into the line and to balance the real power flow exchanged between the series inverter and the transmission line. The series inverter can be used to control the real and reactive line power flow inserting an opportune voltage with controllable magnitude and phase in series with the transmission line.

The series inverter is controlled to inject a symmetrical three phase voltage system of controllable magnitude and phase angle in series with the line to control active and reactive power flows on the transmission line. So, this inverter will exchange active and reactive power with the line. The reactive power is electronically provided by the series inverter, and the active power is transmitted to the dc terminals. The shunt inverter is operated in such a way as to demand this dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor Vdc constant. So, the net real power absorbed from the line by the UPFC is equal only to the losses of the two inverters and their transformers. The remaining capacity of the shunt inverter can be used to exchange reactive power with the line so to provide a voltage regulation at the connection point.

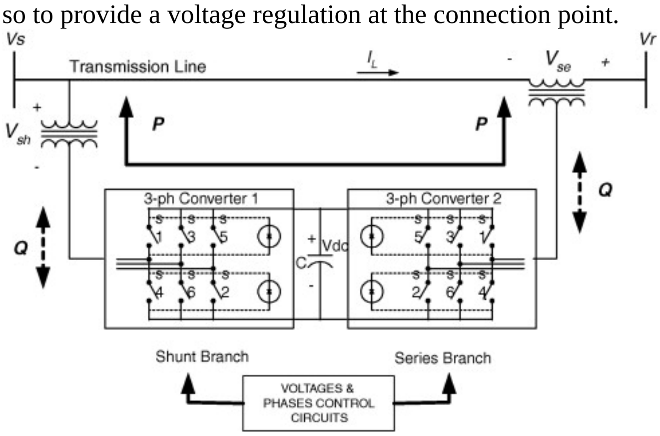

Figure 2: UPFC Link in Transmission Line

6. Proposed Model

A Unified Power Flow Controller (UPFC) is used to control the power flow in a 120 kV /25 kV transmission systems. The system connected in a loop configuration consists essentially of three buses (B575, B25, B120) interconnected through transmission line (L1) and two transformer banks. The model of DFIG based 9MW wind farm with UPFC is designed using MATLAB/ SIMULINK is shown in Figure 2.

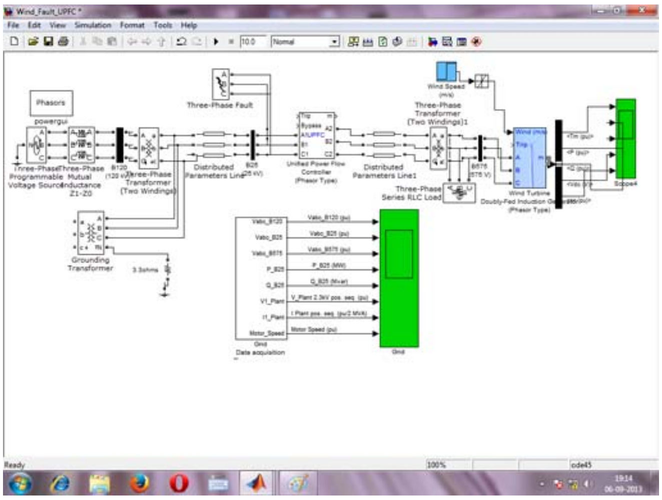

Figure 3: DFIG based wind energy conversion system with UPFC

The UPFC located at the right end of the 30-km line L1 between the 120 kV buses B25 and B575 is used to control the active and reactive powers flowing through bus B25, while controlling voltage at bus B575. The UPFC consists of two 100-MVA, three-level, 48-pulse GTO-based converters, one connected in shunt at bus B25 and one connected in series between wind B575 and B25. The shunt and series converters can exchange power through a DC bus.

This pair of converters can be operated in three modes:

Unified Power Flow Controller (UPFC) mode, when the shunt and series converters are interconnected through the DC bus. When the disconnect switches between the DC buses of the shunt and series converter are opened, two additional modes are available.

Shunt converter operating as a Static Synchronous Compensator (STATCOM) controlling voltage at bus B1. Series converter operating as a Static Synchronous Series Capacitor (SSSC) controlling injected voltage, while keeping injected voltage in quadrature with current.

7. Simulation Results

Initially started simulation wind speed is set at 12 m/s, then at t = 10s, wind speed increases suddenly at 16 m/s. Start simulation and observe the signals on the "Wind Turbine" scope monitoring the wind turbine voltage, current, generated active and Reactive powers, DC bus voltage and turbine speed.

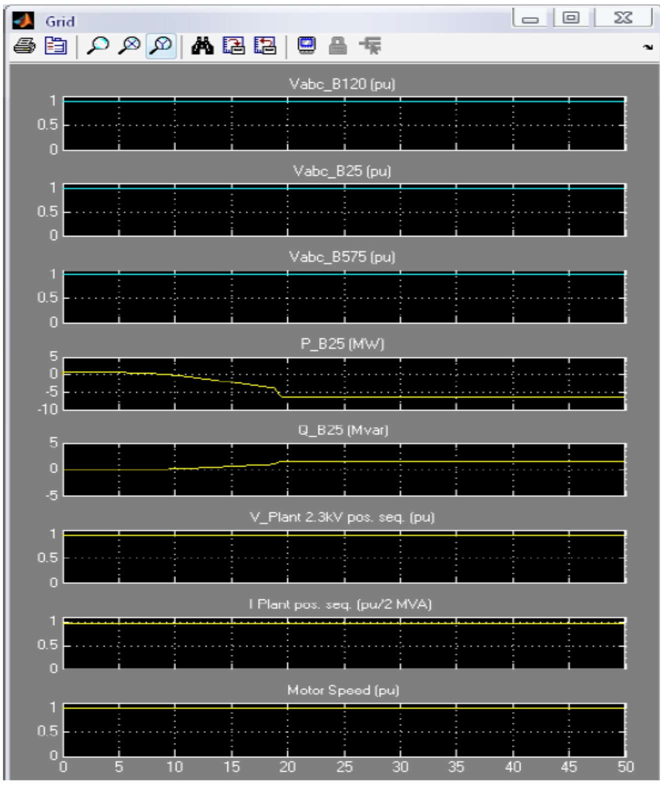

Figure 4: Grid characteristics with change in speed

Now open the "Fault" block menu and select "Phase A Fault". Check that the fault is programmed to apply a 9-cycle single-phase to ground fault at t = 10s. We observed that when the wind turbine is in "Voltage regulation" mode, the positive-sequence voltage at wind-turbine terminals (B575) drops to 0.8 pu during the fault, which is above the under voltage protection threshold (0.75 pu for a t > 0.1 s). The wind farm therefore stays in service.

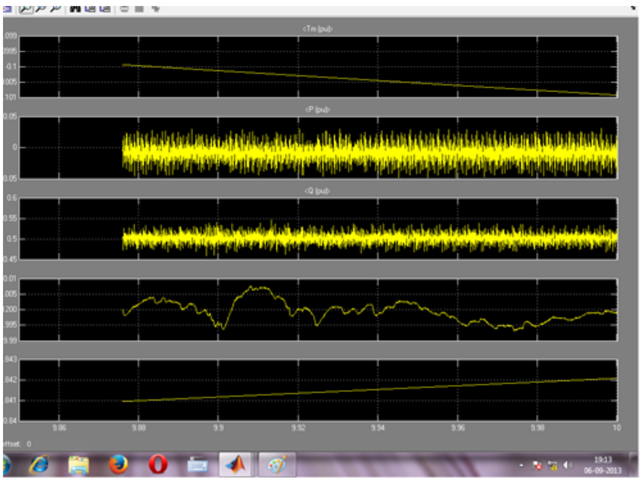

Figure 5: Fault tolerance at time of fault

The voltage (Vabc_25) and current (Iabc_25) at bus B25 without UPFC controller and with UPFC controller are shown in Figure 6 and Figure 7 respectively.

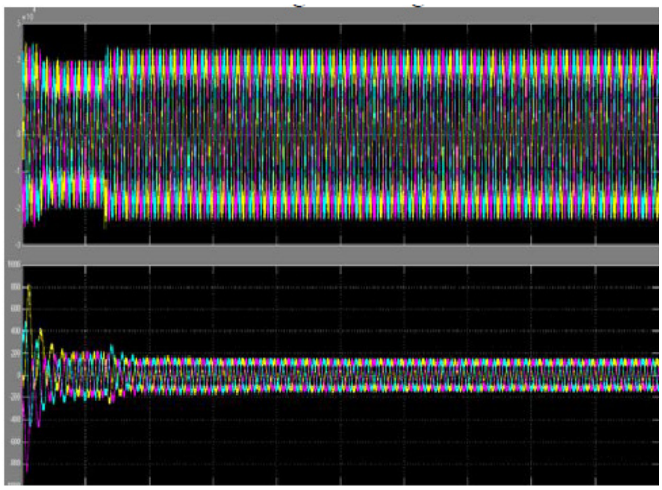

Figure 6: The voltage, current at bus B25 without UPFC

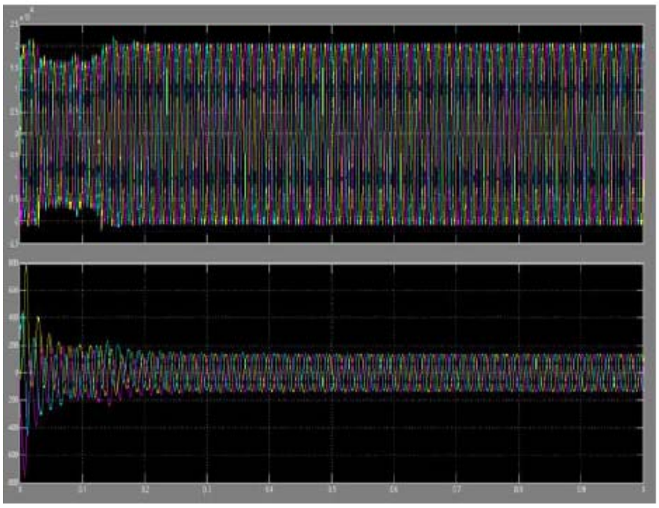

Figure 7: The voltage, current at bus B25 with UPFC

8. Conclusion

This paper presents the grid connected wind energy system for power quality improvement by using UPFC. The power quality problems, its consequences and their mitigation techniques are presented here. In this proposed scheme to eliminate the harmonic content of the load current the UPFC-based control system is used. So that power quality is maintained at the point of common coupling. Therefore, to control the power from one end to another end, this concept of power flow control and voltage injection is applied. Modeling the system and studying the results have given an indication that UPFC are very useful when it comes to organize and maintain power system. The UPFC is a device which can control simultaneously all three parameters of line power flow (line impedance, voltage and phase angle). The UPFC controller mitigates the harmonic distortion that caused by the nonlinear load where all values of THD for voltage and current at all AC buses are decreased to values within allowable limits of IEEE standard. Wind power generation with DFIG provides better performance for terminal voltage recovery after fault clearance owing to its ability to control reactive power. However DFIG is sensitive to severe voltage dips that result in an excessive stator and rotor current, which leads to the rotor converter being blocked. The shaft oscillation caused by the fault should be considered when examining the dynamic response of the DFIG. Special attention should be paid to the blocking that occurs when the DFIG operates at far below synchronous speed. Since, in this case, the abrupt change in the rotor speed has more serious impacts on the electrical response of the system. As regards the saturation effect during fault, it can be seen in the simulation that the peak value of the stator and rotor current in the model with saturation is higher than in the model without saturation. Therefore it is important to take the saturation effect into account, especially when designing a protection setting. However, the prediction of the current magnitude in the model with saturation is characterized by the saturation curve of the generator.

9. Future Scope

The scope of this work can be extended by using other FACTS devices in the system and comparing the power quality with the proposed scheme. Also, a harmonic reduction system can be implemented in the proposed system to reduce the effects of the harmonics in the overall performance of the system.

References

[1] S. Rajesh Rajan, “Power Quality Improvement in Grid connected Wind Energy System using UPQC”, International Journal of Research in Engineering & Technology (IJRET), Vol.1, Issue.1, pp. 13-20, June 2013.
[2] Jin Yang, John E. Fletcher and John O’Reilly,“A Series-Dynamic-Resistor-Based Converter Protection Scheme for Doubly Fed Induction Generator During Various Fault Conditions”, IEEE Transactions On Energy Conversion, Vol.25, No.2, pp. 422-432, June 2010.
[3] Vibhor Gupta, “Study and Effects of UPFC and its Control System for Power Flow Control and Voltage Injection in a Power System”, International Journal of Engineering Science and Technology, Vol.2, No. 7, 2010.
[4] Gyugyi. L. “Unified power flow controller concept for flexible AC Transmission system”, IEE Proceedings-C vol-139, no.4,pp 323-331 July 1992.
[5] Richard Gagnon, Gilbert Sybille, Serge Bernard, Daniel Paré, Silvano Casoria, Christian Larose “Modeling and Real-Time Simulation of a Doubly-Fed Induction Generator Driven by a Wind Turbine” Presented at the International Conference on Power Systems Transients (IPST’05) in Montreal, Canada on June 19-23, 2005 Paper No. IPST05-162.
[6] V. Amarnath Reddy, P. Harshavardhan Reddy, M. Sudheer babu, “Power Quality Improvement in Wind Energy System by using STATCOM on Integration to the Grid”, International Journal of Modern Engineering Research (IJMER), Vol.2, Issue.5, pp. 3637-3640, Sep-Oct 2012.
[7] Sharad W. Mohod, Mohan V. Aware, “Power Quality Issues and its Improvement in Wind Energy Generation Interface to Grid System”, International Journal of Electrical & Instrumentation Engineering, Vol.1, No.2, pp. 116-122, August 2011.
[8] J. G. Slootweg and W. L. Kling, Wind power in power systems, John Wiley and Sons Ltd., 2005.
[9] Morales and J.C. Maun: “Power quality responsibilities by grid impedance assessment at a wind power production”, CIRED, Barcelona, Spain, 12-15 May 2003.
[10] S. W. Mohod and M. V. Aware,” Power quality issues & its mitigation technique in wind energy conversion,” in Proc. of IEEE Int. Conf. Quality Power & Harmonic, Wollongong, Australia, 2008.
[11] Dr. Rakesh Saxena and Sonali Barod, “Analysis of power Quality in power Supplies”, International Journal of Scientific & Engineering Research Volume 3, Issue 8, August-2012.
[12] Power Quality issues standards and guide lines‖, IEEE, Vol-32, May,96.
[13] N. G. Hingorani and L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems, New York: IEEE, 2000.
[14] A.P. Jayam and B.H. Chowdhury, “Improving the dynamic performance of wind farms with STATCOM”, IEEE, 2009.
[15] Daad-Saoud Z., “Application of STATCOMs to Wind Farms,” IEE Proc. Gener. Transm.Distrib.Vol.145, No.5, pp.511-517, 1998.
[16] F. Wang, “Design of SSSC Damping Controller to Improve Power System Oscillation Stability, “0-7803-5546-6/99/$10.00 © 1999 IEEE.

Author Profile

Sushabhan Biswas received the B.Tech degree in Electrical Engineering from JIS College of Engineering in 2011. His M. Tech final thesis titled “Comparative study of fault tolerance & power quality issues in DFIG (Doubly Fed Induction Generator) system” has been already submitted in May,2014 at JIS College of Engineering. He has published two (2) research papers in ICONCE-2014 (International Conference on Non-conventional Energy) during Jan,2014. His research topics are renewable energy studies, economic load dispatch and power quality issues in power system.