HARMONIC REDUCTION AND FREQUENCY CONTROL OF DFIG BASED WIND ENERGY CONVERSION SYSTEM

P.GAYATHRI[1], C.SANTHANA LAKSHMI[2]

[1]M.E. Scholar, Department of EEE, Sona College of Technology, Salem-636 005, Tamilnadu, India.
[2] Assistant Professor, Department of EEE, Sona College of Technology, Salem, Tamilnadu, India.

Abstract- As the power consumption increases globally, the fuel usage also increases which pollutes the environment, and this motivates the use of renewable energy resources. Wind energy system is most widely used everywhere which meets the power demand. The proposed system uses the DFIG for Wind energy conversion system with Harmonics reduction and frequency control. In DFIG, the stator is directly connected to the grid as two back to back connected Voltage Source Converters (VSCs) are placed between the rotor and the grid. Nonlinear loads are connected at PCC as the proposed DFIG works as an active filter in addition to the active power generation similar to normal DFIG. Harmonics generated by the nonlinear load connected at the PCC distort the PCC voltage. These nonlinear load harmonic currents are mitigated by GSC control, so that the stator and grid currents are harmonic free. RSC is controlled for achieving MPPT and also for making unity power factor at the stator side by using voltage oriented reference frame. Synchronous reference frame (SRF) control method is used for extracting the fundamental component of load currents for the GSC control. And also, the frequency is monitored and controlled by using PLL. This proposed system is evaluated using the MATLAB Simulink software.

I. INTRODUCTION

Variable speed wind turbines is snug with a DFIG connected to the electric grid. Nowadaystotal automatic control of both active and reactive power output are increasingly gaining in its importance. Active and reactive DFIG control system are divided into two control sub-systems. They are two semiconductor power converters, one on the rotor part and one on the grid part. Both converter systems hire the DFIG active and reactive power vector control. The rotor current vector consist of two components one controlling the magnetic flux and the another controlling the generator electromagnetic moment.

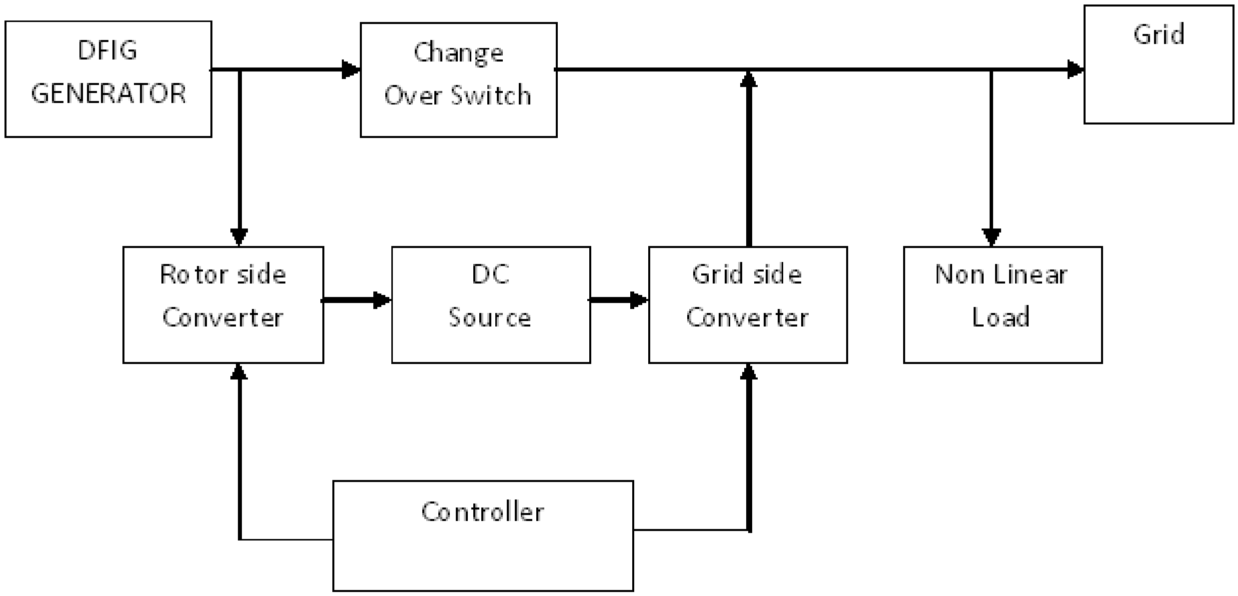
Mechanical power obtained from the wind turbine is converted into electric power by the DFIG and imparted to the grid through the generator stator and rotor. In this it is necessary to make up for the losses in stator and rotor copper coils (iron losses, as well as the ones caused by friction and ventilation have not been considered in this project). The wind turbine power distribution between the DFIG stator and rotor depends on the wind turbine control system active power reference. The DFIG can operate in both the super-synchronous and the sub-synchronous operation modes, and the DFIG can impart power to the grid or take power from it with increased losses in the generator copper coils.

II. SYSTEM CONFIGURATION AND OPERATING PRINCIPLE

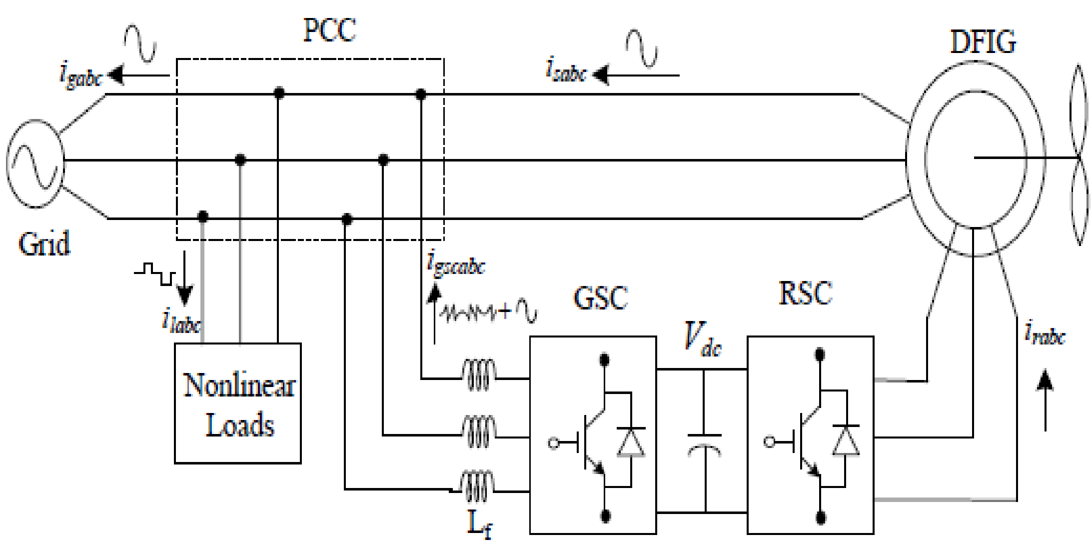
Fig. 1 shows a schematic diagram of proposed DFIG based WECS with integrated active filter capabilities. In DFIG, the stator is directly connected to the grid as shown in Fig. 1. Two back to back connected Voltage Source Converters (VSCs) are placed between the rotor and the grid. Nonlinear loads are connected at PCC as shown in Fig. 1. The proposed DFIG works as an active filter in addition to the active power generation similar to normal DFIG. Harmonics generated by the nonlinear load connected at the PCC distort the PCC voltage. These nonlinear load harmonic currents are mitigated by GSC control, so that the stator and grid currents are harmonic free. RSC is controlled for achieving MPPT and also for making unity power factor at the stator side by using voltage oriented reference frame. Synchronous reference frame (SRF) control method is used for extracting the fundamental component of load currents for the GSC control.

III. DESIGN OF DFIG BASED WECS

Selection of ratings of VSCs and DC link voltage is very much important for the successful operation of WECS. The ratings of DFIG and DC machine used in this experimental system are given in Appendix. In this section, detailed design of VSCs and DC link voltage is discussed for the experimental system used in the laboratory.



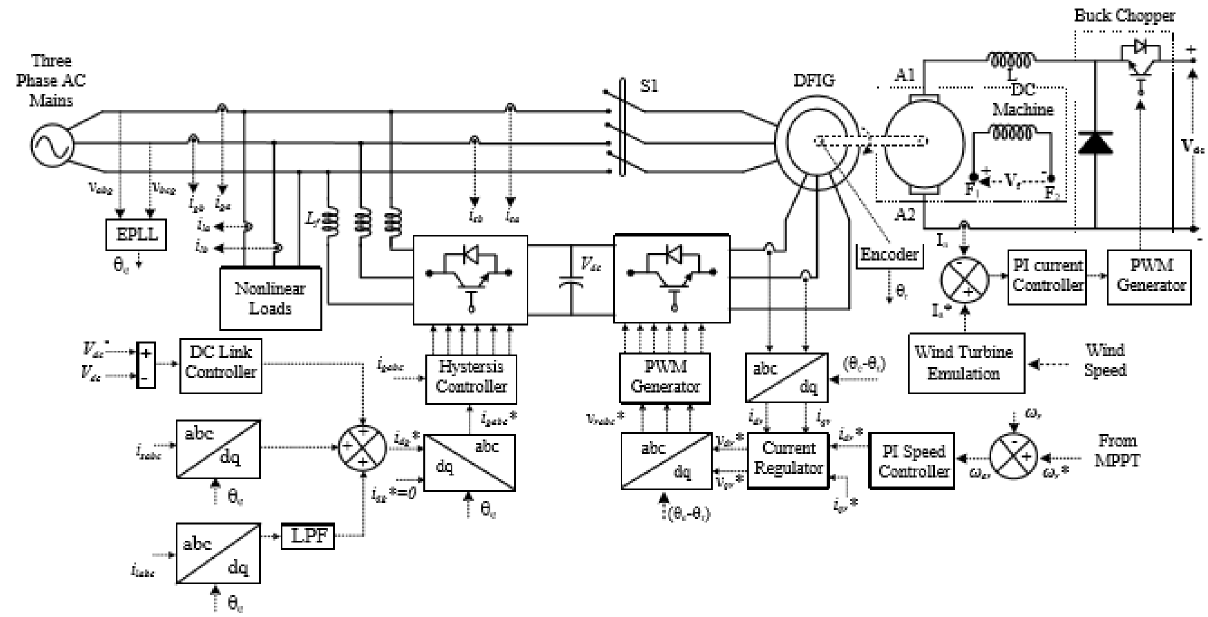
The DFIG draws a lagging volt-ampere reactive (VAR) for its excitation to build the rated air gap voltage. It is calculated from the machine parameters that the lagging VAR of 2.And when concerned to the USC rating the kVAR is needed when it is running as a motor. The operating speed of DFIG ranges from 0.7 p.u to 1.3 p.u. thus the maximum slip (smax) is 0.3. to make unity power factor at the stator side, reactive power of 600 VAR (Smax* Qs = 0.3*2 kVAR) is needed from the rotor side (Qrmax). The maximum rotor active power is (Smax* P). The power rating of the DFIG is 5 kW. So the maximum rotor active power (Prmax) is 1.5kW (0.3*5 kW=1.5 kW). So the rating of the VSC used as RSC, Thus kVA rating of RSC, Srated is calculated as 1.615 kVA.



IV. SYSTEM CONTROL

Control algorithms for both GSC and RSC are presented in this section. Complete control schematic is given in Fig. 2. The control algorithm for emulating wind turbine characteristics using DC machine and Type A chopper.

The main purpose of RSC is to extract maximum power with independent control of active and reactive powers. Here, the RSC is controlled in voltage oriented reference frame. So the active and reactive powers are controlled by controlling direct and quadrature axis rotor currents (idr and iqr) respectively. Direct axis reference rotor current is selected such that maximum power is extracted for a particular wind speed. This can be achieved by running the DFIG at a rotor speed for a particular wind speed. So the outer loop is selected as a speed controller for achieving direct axis reference rotor current.



As seen in Exercise 2, a three-phase wound-rotor induction machine can be setup as a doubly-fed induction motor. In this case, the machine operates like a synchronous motor whose synchronous speed (i.e., the speed at which the motor shaft rotates) can be varied by adjusting the frequency of the ac currents fed into the rotor windings. The same wound-rotor induction machine setup can also serve as a doubly-fed induction generator. In this case, mechanical power at the machine shaft is converted into electrical power supplied to the ac power network via both the stator and rotor windings. Furthermore, the machine operates like a synchronous generator whose synchronous speed (i.e., the speed at which the generator shaft must rotate to generate power at the ac power network frequency) can be varied by adjusting the frequency of the ac currents fed into the rotor windings. The remainder of this exercise discussion deals with the operation of three-phase wound-rotor induction machines used as doubly-fed induction generators. In a conventional three-phase synchronous generator, when an external source of mechanical power (i.e., a prime mover) makes the rotor of the generator rotate, the static magnetic field created by the dc current fed into the generator rotor winding rotates at the same speed as the rotor. As a result, a continually changing magnetic flux passes through the stator windings as the rotor magnetic field rotates, inducing an alternating voltage across the stator windings. Mechanical power applied to the generator shaft by the prime mover is thus converted to electrical power that is available at the stator windings. In conventional (singly-fed) induction generators, the relationship between the frequency of the ac voltages induced across the stator windings of thegenerator and the rotor speed is expressed using the following equation.

A. ALGORITHM FOR THE DESIGN OF PI CONTROLLER

The following steps are considered for the design of PI controller.

- Read the open loop transfer function of the given higher ordersystem.
- Form the closed loop transfer function.
- Obtain the step response of closed loop system.
- Check the response for the required specifications.
- If the specifications are not met, get a reduced order model and design a controller for the reduced order model.
- Obtain the initial values of the parameter Kp and Ki by pole zero Cancellation method.
- Cascade the controller with reduced order model and get the closed loop response with the initial values of the controller parameters.
- Find the optimum values for the controller parameters which satisfy the required specifications.
- By applying the optimum values, cascade this controller with the original system.
- Obtain the closed loop step response of the system with the controller.
- If the specifications are met give exit command else tune the parameters of the controller till they meet the required specifications.

For designing the PI controller, the values of controller parameters Kp and Ki are obtained through existing tuning method. The GA is employed to obtain the optimized values of Kp and Ki to meet out the designs specifications.

V. EXPERIMENTAL IMPLEMENTATION AND OPERATING SEQUENCE

A prototype of the DFIG based WECS with integrated active filter capabilities is developed using DSP (dSPACE DS1103) in the laboratory. A photograph of prototype is shown in Fig. 3. In this experimental system, DFIG is coupled with a DC machine. Wind turbine characteristics are emulated using Type A chopper and a DC machine. The DC machine flux is made constant by keeping the field voltage constant. So the torque of the machine is controlled by controlling the armature current. The torque of the DC machine is selected from the wind turbine characteristics for a particular wind speed and the rotor speed. The armature current is calculated from the demanded torque using flux constant (kΦ). The duty ratio of the chopper is obtained from the current controller. Initially the stator of the DFIG is kept isolated from the grid using switch S1 and the DC machine runs at constant speed by giving fixed duty ratio to the chopper. The GSC is controlled for maintaining the voltage at the DC link. Initially this GSC works like a simple active filter for supplying the reactive power and harmonics of the local nonlinear loads. Now this RSC is made on for making the voltage of the DFIG same as the grid voltage by adjusting the reactive component of rotor current (iqr). An active power component of rotor current (idr) is made zero for making sure that the stator voltage and the grid voltage are in same phase. Now the switch S1 is made on. The control of DC machine is changed from fixed duty ratio mode to wind turbine mode. Still as there is no active power flow from DFIG to grid, the speed of the machine ramps to

V. RESULTS AND DISCUSSION

Both simulated and experimental results are presented in this section for validating steady state and dynamic performances of this proposed DFIG with integrated active filter capabilities. In this section, the working of this proposed GSC is presented as an active filter even when the wind turbine is in shut down condition. The power that is coming into the PCC through GSC is considered as positive in this paper. A. Steady State Performance of DFIG Based WECS with Integrated Active Filter Capabilities The simulated performance of this proposed DFIG is presented at a 10.6 m/sec wind speed as shown in Fig. 4. As the proposed DFIG is operating at MPPT, the reference speed of the DFIG is selected as 1750 rpm. The load currents are observed to be nonlinear in nature. The GSC is supplying required harmonics currents to the load for making grid currents (igabc) and stator currents (isabc) balanced and sinusoidal. Fig. 4 also presents the stator power (Ps), GSC power (Pgsc), load power (Pl) and grid power (Pg). At above synchronous speed, the power flow is from the GSC to PCC, so the GSC power is shown as positive. Total power produced by the DFIG is the sum of stator power (Ps) and GSC power (Pgsc). After feeding power to the load (Pl), the remaining power is fed to the grid (Pg). Figs. 5 (a-d) show harmonic spectra and waveforms of grid current (iga), load current (ila), stator current (isa) and grid voltage (vga) respectively. From these harmonic spectra, one can understand that grid current and stator current THDs are less than 5% as per IEEE-519 standard [35] limits given in Table-I. Fig. 6 shows test results by performing tests on the developed prototype at a fixed wind speed of 10.6 m/sec. These test results are observed similar to simulated results. Fig. 7 shows simulated results of GSC working as an active filter even when the wind turbine is in stall condition. Here, stator currents are zero as there is no power production from the DFIG.

The load power is supplied from the grid. So the grid power (Pg) is observed to be negative. Now this GSC supplies harmonics currents and reactive power. So the reactive power taken from the grid (Qg) is observed to be zero. Grid currents are observed to be balanced and sinusoidal even

VI. CONCLUSION

The GSC control algorithm of proposed DFIG has been modified for supplying the harmonics and reactive power of the local loads. In this proposed DFIG, the reactive power for the induction machine has been supplied from the RSC and the load reactive power has been supplied from the GSC. The decoupled control of both active and reactive powers has been achieved by RSC control. The proposed DFIG has also been verified at wind turbine stalling condition for compensating harmonics and reactive power of local loads. This proposed DFIG based WECS with an integrated active filter has been simulated using MATLAB/ Simulink environment and simulated results are verified with test results of developed prototype of this WECS. Steady state performance of proposed DFIG has been demonstrated for a wind speed. Dynamic performance of this proposed GSC control algorithm has also been verified for the variation in the wind speeds and for local nonlinear load.

VII. REFERENCES

[1] RajibDatta and U.T Ranganathan, (2002) "Variable speed wind power generation using DFIG – A comparison with alternative schemes", IEEE Transaction on energy conversion, Vol. 17, no. 3

[2] Wenzhong Gao, Ziping Wu, Jianhui Wang, (2003) "A review of inverter and frequency control technologies for variable speed wind turbines", IEEE Transactions on energy conversion,

[3] Edward Muljadi, (2007) "Effect of Variable Speed Wind Turbine Generator on stability of a weak grid". IEEE Transaction on energy conversion,

[4] S.S. Murthi, Bhim Singh, (2007) "A comparative study of fixed speed and variable speed wind energy system conversion system feeding the grid", IEEE Transaction on energy conversion,

[5] R. Pena, J.C. Clare, (2008) "DFIG using back to back PWM converter and its application of variable speed wind energy generation", IEEE Transaction on energy conversation,

[6] HenaPolinder, Frank F.A Vander Pijl, GertJandeVilder and Peter J. Tauner (2009) "Comparison of direct drive and Geared Generator concept for wind turbines", IEEE Transaction on energy conversion,

[7] Huang Ya- Feng, Yan Gan- Gui, Chao- Yan, Mu Gang, Zhang Cheng- Xin, (2010) "minimizing and Utilization of reactive power capability of DFIG system for wind turbines", IEEE Transaction on energy conversation,

[8] Abdullah Asuhaimi B. MondZin, Mahmoud Persaran H. A, (2012) "An overview on DFIG generators controls and contributions to wind based electrival generation", IEEE Transaction on energy conversion,

[9] Donald S. Zinger, Edward Mujadi, (2014) "Annualized wind energy improvement using variable speed", IEEE Transaction for Industrial Applications,

[10] Omer Goksu, Remus Teodorescu Fellow, Claus LethBak, Florin Lov, Philip Carnekjaer, (2014) "Instability of wind turbine converters during current injection to low voltage Grid faults and PLC frequency Based Stability solution", IEEE Transaction on Power Systems,

[11] N. Kiran Kumar, IES Naidu, (2014) "Load frequency control for a multi area power system involving wind", IEEE Transaction on Power Systems