An Extensive Survey on Active and Reactive Power Control of a DFIG for Variable Speed Wind Energy Conversion

Ankit Sharma[1], Prof. Manish Prajapati[2]

[1]Mtech. Scholar, [2]Research Guide

Scope College of Engineering Bhopal

Abstract- Wind power plays a vital role for electrical power transmission network compared to other renewable sources. Wind turbines extract wind power from air flow to produce mechanical power. Induction Generators connected to wind turbines convert mechanical power into electrical power. Wind power is clean, renewable, produces no green house emissions, available plentiful, widely distributed and uses little land with almost zero environmental problems. Wind farms are broadly classified as on-shore and off-shore wind turbines. Wind power significantly varies and inconsistent from year to year, therefore wind power is used in conjunction with the other electric power sources to meet the requirements of grid and for reliable supply of electric power. The doubly-fed induction generator (DFIG) concept, uses a variable speed controlled wind turbine. The smaller rating of the power converters makes this concept attractive from an economical point of view. This work presents an extensive literature survey on active power and reactive power control for wind turbine based on DFIG.

Keywords- Wind energy conversion, DFIG, Active power, Reactive power, Power control.

I. INTRODUCTION

In recent years, the environmental pollution has become a major concern in people daily life and a possible energy crisis has led people to develop new technologies for generating clean and renewable energy. Wind power along with solar energy, hydropower and tidal energy are possible solutions for an environmentally-friendly energy production. Wind Energy Conversion System (WECS) is the overall system for converting wind energy into useful mechanical energy that can be used to power an electrical generator for generating electricity. The WECS basically consists of three types of components: aerodynamics, mechanical, and electrical as shown in Figure 1.1.

a. Wind Turbine Generator

The major components of a wind turbine-generator system are shown in Figure.1.2. The wind turbine (WT) is composed of three blades, the rotor hub and the nacelle located immediately behind the rotor hub which houses the gearbox, generator and other components.

The drive train system consists of three blades, a low-speed shaft, a gearbox, a high-speed shaft and a generator. The low-speed shaft connects the low-speed shaft to a two or three-stage gearbox, followed by a high-speed shaft connected to the generator [3].

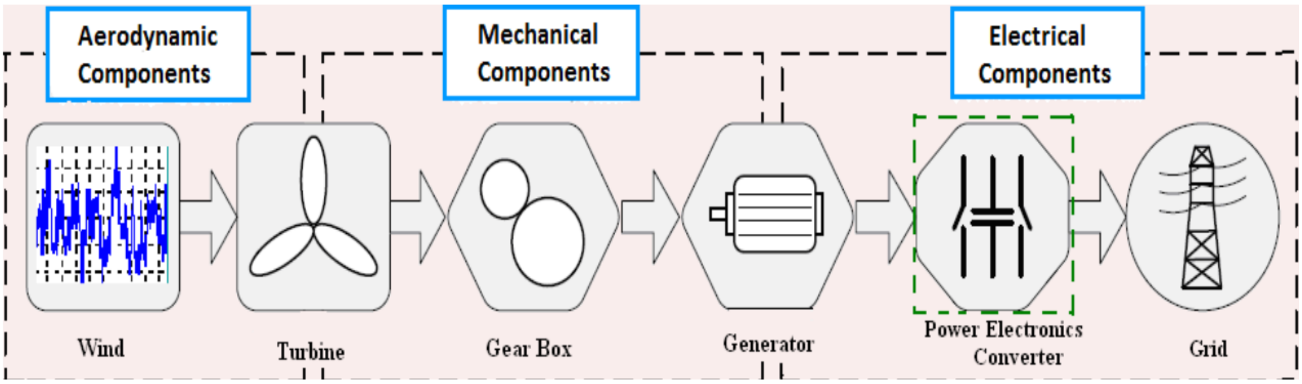

Figure 1.1 Block diagram of WECS connected to grid.

The process of how the wind turbine system generates electrical power will be briefly summarized as follows: 1) the wind strikes the wind turbine blades, causes them to spin and further makes the low-speed shaft rotate, 2) the rotating low-speed shaft transfers the kinetic energy to the gearbox, which has the function of stepping up the rotational speed and rotating the high-speed shaft, 3) the high-speed shaft causes the generator to spin at high speed which is close to the rated speed of the generator, 4) the rotating generator converts the mechanical power to electrical power.

Usually, the output voltages of the generator are low, and hence there will be the need for a transformer to step up the generator output voltage for the purpose of directly connecting to the grid.

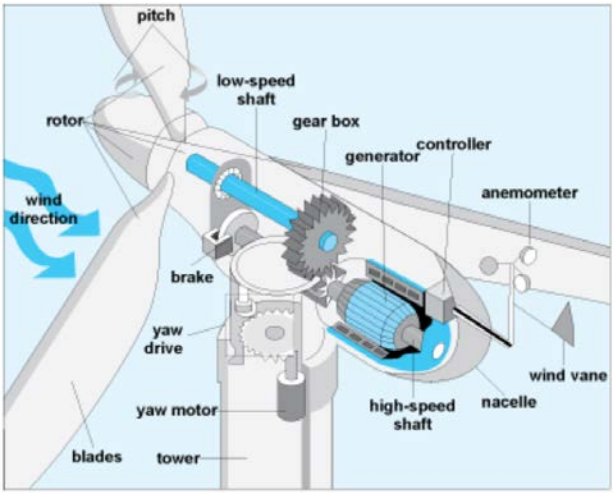

Figure 1.2 Component of a wind turbine generator system.

Other components of a wind turbine-generator system are wind vane, cooling fan and different sensors. These sensors include the anemometer, speed or position sensors as well as voltage and current sensors. The wind vane is used to measure the wind directions and then decide the operation of the yaw control system. Electric cooling fans are used to cool the gearbox, generator, power converters and the on-board controllers.

b. Control of Wind Turbine System

With the increase in wind turbine size and power, its control system plays a major role to operate it in safe region and also to improve energy conversion efficiency and output power quality.

Energy capture: The wind turbine is operated to extract the maximum amount of wind energy considering the safety limits like rated power, rated speed.

Power quality: Conditioning the generated power with grid interconnection standards.

The various control techniques used in wind turbines are pitch control, yaw control and stall control. But in the modern variable speed-variable pitch wind turbines, pitch control is the most popular control scheme [7]. In this control scheme, the horizontal axis wind turbine blades are rotated around its tower to orient the turbine blades in upwind or down wind direction.

II. DOUBLY FED INDUCTION GENERATOR

The term „Doubly Fed" refers to the fact that the voltage on the stator is applied from the grid and the voltage on the rotor is induced by the power converter. This system allows a variable-speed operation over a large, but restricted, range [9]. The converter compensates the difference between the mechanical and electrical frequencies by injecting a rotor current with a variable frequency [9]. Hence, the operation and behavior of the DFIG is governed by the power converter and its controllers.

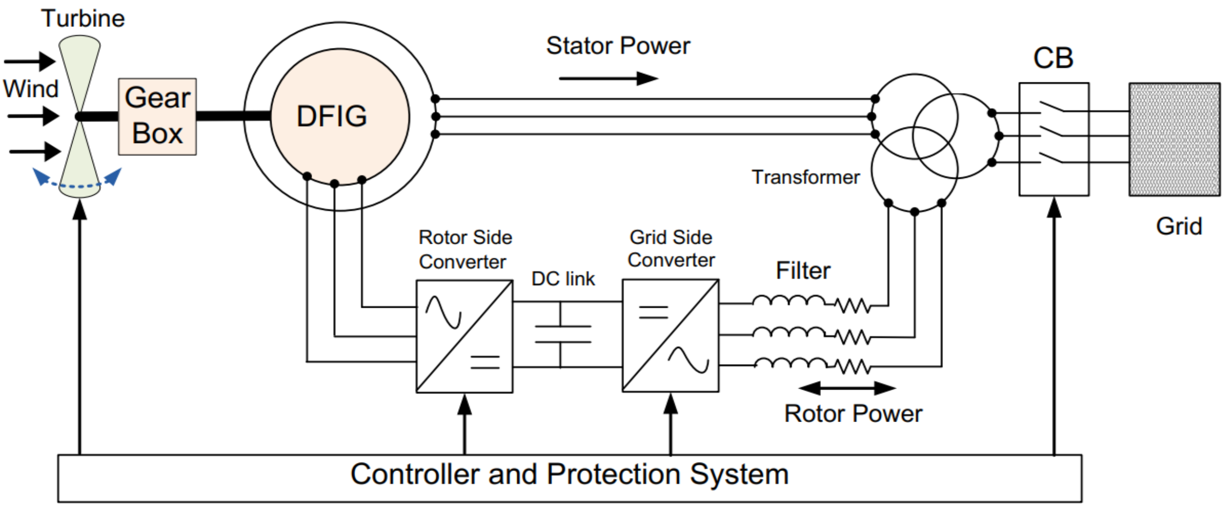

Figure 2.1 Components and protection system.

The DFIG-based WECS basically consists of generator, wind turbine with drive train system, RSC, GSC, DC-link capacitor, pitch controller, coupling transformer, and protection system as shown in Figure 2.1. The DFIG is a wound-rotor induction generator with the stator terminals connected directly to the grid and the rotor terminals to the mains via a partially rated variable frequency ac/dc/ac converter consists of a RSC and a GSC connected back-to-back by a DC-link capacitor. The rotor current is controlled by RSC to vary the electro-magnetic torque and machine excitation. Since the power converter operates in bi-directional power mode, the DFIG can be operated either in sub-synchronous or in super-synchronous operational modes.

The highest level is the WECS optimization; wherein the speed of the wind turbine is set in such a way that optimum wind power can be captured. This control level is mechanical system control. The lower level control being the electrical system control, i.e. torque and reactive power control. The mechanical control system acts slower compared to the electrical control system.

III. LITERATURE REVIEW

SR. NO.	TITLE	AUTHOR	YEAR	APPROACH
1	Active and reactive power control of a DFIG for variable speed wind energy conversion,	F. Mazouz, S. Belkacem, Y. Harbouche, R. Abdessemed and S. Ouchen,	2017	A vector control of a doubly fed induction generator (DFIG) for variable speed wind power generation
2	Simulation and Control of WECS with Permanent Magnet Synchronous Generator (PMSG)	P. Kumar, R. Kumar, A. Verma and M. C. Kala,	2016	Permanent magnet synchronous generator (PMSG) to accomplish the optimal power flow and maximum power transfer
3	The controlling of the DFIG based on variable speed wind turbine modeling and simulation,"	J. Bhukya and V. Mahajan,	2016	The power outputs control and DC-link voltage regulation of the Doubly Fed Induction Generator (DFIG) for the variable speed Wind Energy Conversion System
4	Active and reactive power control of a grid connected speed sensor less DFIG based wind energy conversion system	S. Datta, J. P. Mishra and A. K. Roy,	2015	A new phase locked loop (PLL) based slip speed estimator using rotor current is reported
5	Voltage control and maximum power tracking of DFIG based wind power generator,	I. John and B. Jayanand,	2015	The offshore wind farms have also been continuing its growth rapidly due to much better wind conditions like onshore wind farm
6	Control of the doubly Fed Induction Generator in WECS	B. Farid, A. Rachide and B. M. Lokmane,	2014	A new power control of a variable speed wind energy conversion system based on a doubly Fed Induction Generator (DFIG)
7	Research on control strategy of DFIG rotor side converter,	Zhaoyang Su, Ping Wang and Pengxian Song,	2014	Analyzes the mathematical model of DFIG in synchronous rotating axis. Vector control equations of DFIG

F. Mazouz, S. Belkacem, Y. Harbouche, R. Abdessemed and S. Ouchen, [1] in this work, reported a vector control of a doubly fed induction generator (DFIG) for variable speed wind power generation. The model is developed based on the dual powered generator for the control of the active and reactive powers. Several studies are carried out to test their operation under different wind conditions. The results have shown good performances of the wind energy converter system operate under wind variations with indirect vector control strategies.

P. Kumar, R. Kumar, A. Verma and M. C. Kala, [2] This exploration discussed the detailed electrical model of gearless variable speed wind energy conversion system (WECS) with permanent magnet synchronous generator (PMSG) to accomplish the optimal power flow and maximum power transfer to the distribution grid. PMSG based WECS system has reduce the hardware complexity of speed regulation and their control so it's more reliable and more efficient than doubly fed induction generator (DFIG) based WECS model. Here all the generating machines, power control devices and turbine models are designed in MATLAB/Simulink tool by their detailed equations. The control algorithm of power converter are support on PWM techniques which is used to confine the maximum power form the wind turbine and also control the active and reactive power flow into the distribution grid to improve the power quality. This exploration presents to study the performance of simple and detailed PMSG based WECS to grid connected load or also discusses their performances.

J. Bhukya and V. Mahajan, [3] This research work presents the power outputs control and DC-link voltage regulation of the Doubly Fed Induction Generator (DFIG) for the variable speed Wind Energy Conversion System (WECS). The DFIG control structure consists of the two four quadrant IGBT PWM converters are connected in AC-DC-AC in order to control the power outputs of the DFIG. The dynamic behavior of DFIG is modeled in the Stator Flux Orientation (SFO) related to the Rotor Side Converter (RSC) and Grid Side Converter (GSC) control strategies. The RSC controls the power flow (the active and reactive power) from the stator of the DFIG to the grid by controlling the rotor currents of the DFIG. The GSC ensures the regulation of the DC-link voltage to the desired value by controlling the grid currents. In this work, is realized with a conventional PI controller based on SFO vector control, which gives the super-synchronous operation of the DFIG. This control strategy not only improves the efficiency but also maintains almost unity power factor to the grid. The reported control scheme is simulated and investigated for variations in wind speed and under small disturbance. The effectiveness of the reported method is verified by developing the simulation model of 1.5 MW in MATLAB-SIMULINK-2013.

S. Datta, J. P. Mishra and A. K. Roy,[4] This research work presents the performance study of a speed sensor-less control of grid connected DFIG based variable speed Wind Energy Conversion System (WECS). A new phase locked loop (PLL) based slip speed estimator using rotor current is reported for speed sensor-less stator field oriented vector control operation of rotor side converter (RSC) to ensure decoupled control of stator active and reactive power while maximizing the power generation at unity power factor under varying wind speed. The estimated slip speed is used for back emf compensation of rotor current controllers. Simulation has been carried out in MATLAB/Simulink environment and results show satisfactory operation of the reported speed sensor-less DFIG based variable speed WECS.

I. John and B. Jayanand,[5] Renewable energy systems become more present in the energy market and wind power has already proven it's potential. The offshore wind farms have also been continuing its growth rapidly due to much better wind conditions like onshore wind farms. The studied system here is a variable speed wind generation system based on Doubly Fed Induction Generator (DFIG). In this topology, stator side converter and rotor side converter is used to implement the DFIG control to achieve wind power conversion. Here, a maximum power control strategy is incorporated with the DFIG, whereby the produced power serves as the active power reference for the DFIG. Stator flux oriented vector control is applied to decouple the control of active and reactive power generated by the DFIG based wind turbine. A DC/DC boost converter is used for DFIG system to DC grid connection. This system represents transferring offshore wind power to the terrestrial ac grid through the High Voltage DC (HVDC) network. The details of the control strategy and system simulation results in Simulink are presented in the work.

B. Farid, A. Rachide and B. M. Lokmane, [6] The major part of the existing research works concerning variable speed wind turbines control is not only to capture the maximum power from the wind but, also, to improve the quality of power and to converge the system for operating at unity power factor. This research proposes a new power control of a variable speed wind energy conversion system based on a doubly Fed Induction Generator (DFIG) using space vector modulation to achieve control of active and reactive powers exchanged between the stator of the DFIG and the grid to ensure a Maximum Power Point Tracking (MPPT) of a wind energy conversion system and to reduce significantly Powers and Torque ripples. The SVM control is applied to rotor side converter for active and reactive power control and voltage regulation of wind turbine. This new approach is validated by modeling using Matlab-Simulink software and simulation results can prove the excellent performance of this control as improving power quality and stability of wind turbine.

Zhaoyang Su, Ping Wang and Pengxian Song, [7] Doubly fed induction generator (DFIG) is widely used in wind energy conversion system (WECS). This exploration analyzes the mathematical model of DFIG in synchronous rotating axis. Vector control equations of DFIG are studied under the stator flux oriented control method. A double closed-loops schematic diagram of stator flux oriented vector control method is designed. WECS can run at variable-speed constant-frequency state. Power factor of DFIG stator is adjustable. Active power and reactive power can be controlled independently. To validate the reported control strategy, a case study of a typical 5MW DFIG-based wind energy conversion system is carried out by simulation in PSIM. Finally, the validity of the reported method is further verified by means of laboratory experiments with a DFIG system. Simulation and experimental results prove that the reported control strategy is effective.

IV. PROBLEM STATEMENT

WECS is a nonlinear system which consists a large number of nonlinear terms. Selection of significant terms and estimation of parameters from this large set of generator speed terms and output power terms is important . When the wind speed is less than the rated value, angle of attack is kept at the optimal value which captures the maximum power. When the wind speed exceeds 15m/sec, passive stall is employed. Air turbulence acts on the surface of the blade in the opposite direction of wind, which reduces the lift force on the turbine blades. This causes the reduced power capture. Passive stall is employed in small turbines. No sensors or actuators are used and therefore passive stall is cost effective and robust.

For above rated speed, in active stall, the adjustable blades are made to turn into the wind direction, which results in reduced power capture. The power capture can be increased and maintained at rated value by adjusting the angle of attack. A power/frequency characteristic, or droop characteristic controls the slope of active power production. This control shall be adjusted according to demands. Due to the current penetration level of Wind Power in the grid WPP must provide the reactive power exchange with the grid. The given range defines for each operation set point the minimal amount of reactive power (lagging or leading) in respect to produced active power.

V. CONCLUSION

This shows a broad review on Wind Energy Conversion system in light of DFIG active and reactive power control. More specifically, the related previous studies and researches on the modelling, the control strategies, and the state of the art converter topologies applied in DFIG-based wind turbine-generator systems are presented in this exploration. Wind power age utilizes either settled speed or variable speed turbines which can be ordered into four noteworthy types. The principle contrasts betwee n these wind turbine types are the ways how the aerodynamic efficiency of the rotor would be limited for different wind speed conditions. These days, DFIGs are most ordinarily utilized as a part of the wind turbine industry for expansive wind turbines. With a society direction towards a future atmosphere disaster the demand for breakthrough inventions in green energy production has increased rapidly during the last periods.

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