Review Paper on DFIG Wind Turbine Technology

Ashutosh Tripathi[1], Ravi Kumar Rajalwal[2]

REC, Bhopal

Abstract – The Doubly Fed Induction Generator (DFIG) based wind turbine with variable speed variable-pitch control scheme is the most popular wind power generator in the wind power industry. This machine can be operated either in grid connected or standalone mode. The paper offers discussion of RSC and GSC control scheme of wind turbine for cumulative modernization of wind turbine technology through literature survey of wind turbine configuration, mainly of double fed induction generator (DIFG).This paper gives proper understanding of control schemes, characteristics and limitation of DIFG.

Keywords: ,DIFG,.

I. INTRODUCTION

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, particularly in the wind energy production, new grid codes have been released, stipulating particular requirements concerning grid support during steady state operation and grid faults. However, most of the renewable energy generation systems are based on other generation principles and use modern control hardware such as power electronic devices like DFIG. By contrast, the control of a non renewable power plant with synchronous generator is quite slow. The dynamic behaviour during and instantly after fault clearing is dominated by the inertial reaction of the synchronous generator, which result in transients and affected by the excitation system. The conventional concept of synchronous generator is directly connected to the power system via a power transformer and the control of terminal voltage is by the field excitation. The rotor windings of the DFIG-based wind turbines are connected with the use of two back-to-back converters, while the stator windings are connected directly to the network via a power transformer. The control of terminal voltage by the DFIG is performed by the two back-to back converters. The grid side converter and rotor side converter can inject reactive power. The study presented in this paper compares the performance and behaviour of both systems in order to better understand the positive and negative effect on the stability.

This paper objective is literature survey of wind turbines technology and different method of its power control technology mainly DFIG through control schemes of admission type and different configurations of converter schemes with improvement in power generation process. In the paper, fixed speed wind turbine and variable speed wind turbine are compared with its characteristics, drawbacks and this is derived that variable speed wind turbine compensates most of the shortcomings of previous wind turbine and improves the dynamic performance [1-3]. Variable speed wind turbine power converter, configurations, working modes, techniques model and their characteristics are discussed. The main control schemes discussed are RSC and GSC. The control scheme performance evaluation of and compatibility are focused with the back to back converters.

II. CONCEPT OF A WIND TURBINE GENRATOR SYSTEM

Generally speaking, wind power generation uses either variable speed or fixed speed turbines which can be characterised into four major types. The main changes between these wind turbine types are the ways how the aerodynamic efficiency of the rotor would be imperfect for different wind speed conditions. These four types are briefly described below [4]:

1. *Fixed Speed Wind Turbines (WT Type A)*

An asynchronous squirrel-cage induction generator (SCIG) directly connected to the grid via a transformer dealing with type ‘A’ wind turbine. The so-called “fix speed WT” comes from the point that the rotational speed of the wind turbine cannot be automatically controlled and will only differ by the wind speed. 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 subsequently there is no reactive power regulator. Besides, this type of wind turbine transfers the wind variations to mechanical instabilities and further converts these into electrical power oscillations due to the fact that there are no speed or torque control loops. These electrical power oscillations can lead to an effect in the case of a weak grid.

2. *Partial Variable Speed Wind Turbine with Variable Rotor Resistance (WT Type B)*

A wound rotor induction generator (WRIG) directly connected to the grid deals with this type of wind turbine. The controlled resistances are connected in series with the rotor phase windings of the generator. In this way, the total rotor resistances can be regulated, and thus the slip and the output power can be controlled. Due to the limitation of the serial resistance sizes, the variable speed range is usually small, typically 0-10%.above synchronous speed [4].

3. *Variable Speed Wind Turbine with Partial Scale Power Converter (WT Type C)*

This arrangement, known as the doubly-fed induction generator (DFIG) concept uses a variable speed controlled wind turbine. The stator phase windings of the doublyfed 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. 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 eye-catching from a cost-effective sight. Besides, this type of wind turbine can also achieve the desired reactive power compensation.

4. *Variable Speed Wind Turbine with Full Scale Power Converter (WT Type D)*

This structure usually uses a permanent magnet synchronous generator (PMSG) and a full-scale power converter. The stator phase windings are connected to the grid through a full-scale power converter. Some of this type of wind turbines adopt a gearless concept, which means that instead of connecting a gearbox to the generator, a direct driven multi-pole generator is used without a gearbox[5].

The control schemes for a wind turbine-generator system include the pitch angle control, MPPT control, and the DFIG control. In which DFIG control is discussed in this review paper[6-9].

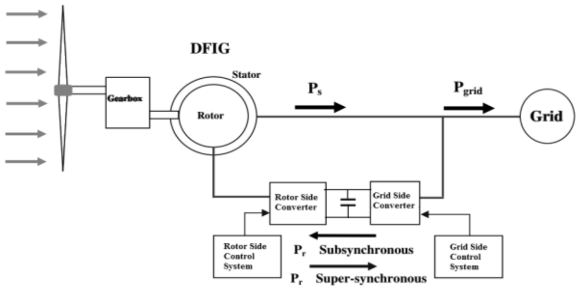

Figure 1: DFIG baised Wind Turbine Genrator System

III. DEVELOPED TECHNOLOGY ON VARIABLE SPEED WIND TURBINE

The main goal is to maximize the wind energy at different speeds of wind, which can be obtained by adjusting the turbine speed by maintaining optimal tip speed ratioλ_{otp} is maintained constant. For achieving optimal tip speed each power curve has maximum power point with the given wind speed. For obtaining maximum available energy from the wind at different speed of wind, the turbine speed must be adjusted to ensure its operation at all the MPPs. The trajectory of MPPs represents a power curve. Now the control mechanism/schemes ensure the adjustment in speed of turbine so as to maximize power extraction. This is concept VSWT set up [8-9]. A full capacity and reduced capacity configuration is proposed for variable speed wind turbine. The reduced capacity configuration consists of processing of slip power of wound rotor induction machine. If the rotor resistance is connected to slip terminals, slip power got wasted and machine attains only about 10% of speed variation near to synchronous speed operating range whereas if slip power is feedback to the grid after processing through back to back converters (Kramer technique) then 30% of speed variation can be achieved within operating range[10].

The back to back converters are directly connected from WRIM to grid in full capacity. This needs converter switches to survive rated voltage so configuration cost is high. The doubly fed induction machine can be worked in generating mode in both super-synchronous and sub-synchronous modes[11]. The SCIG controlled over a range of super-synchronous and sub-synchronous speeds, with the novel secondary

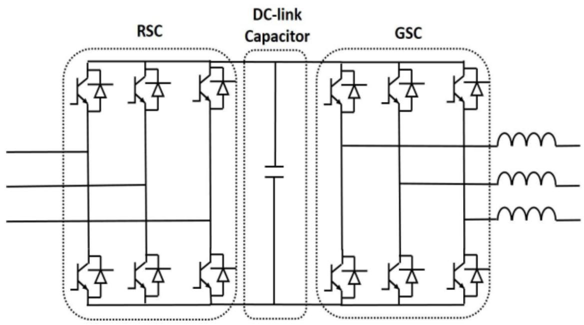

Figure 2: Power converter of the DFIG

EMF signal generator, shows considerable benefit over sub-synchronous systems which is based on the Kramer technique. This does not have the stability problems normally associated with doubly fed machines. The steady-state analysis of a wound-rotor induction generator operated at varying shaft speeds in the super-synchronous and sub-synchronous regions, by control of both the direction and magnitude of slip power is studied. The Kramer technique provides better performance as compared to rotor resistance method in reduced capacity, but is cost of firing circuits and converter switches is accounted more. The rated gearbox ratios, speed settings, and machine and converter ratings were described for VSWT based DFIG and this rating and data is considered as orientation for developing wind turbine installation for higher power wind farms [10]. With the Kramer technique based DFIG WTs or wound rotor configuration, decoupled active and reactive power control of the generator could be achieved, with more efficient energy production, improved power quality and improved dynamic performance. The concept of a variable speed wind turbine (VSWT) driving

DFIG has received increasing attention because of its noticeable advantages over other Wind Turbine Generating systems. DFIG-based WT are more popular on account of their favourable cost/performance attribute resulting primarily from the need for a much smaller converter rating compared to the machine rating. DFIGs are widely used in modern WTs due to their power control capability; variable speed operation, low converter cost, and reduced power loss and these characteristics are compared to fixed speed induction generators and fully rated converter systems. The converter design and control technique using an ac/dc/ac converter in the rotor circuit of DFIM is a standard drive option for high power applications involving a limited speed range [12-13].

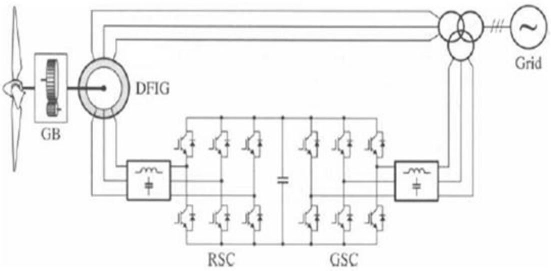

Figure 3: Variable speed with reduced capacity configuration

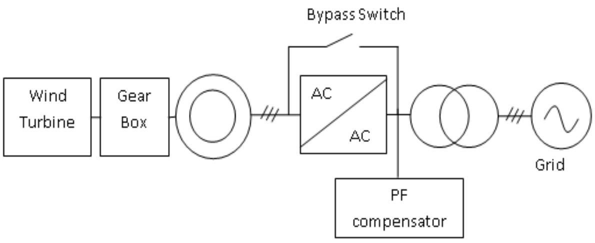

Figure 4: Variable speed with full capacity configuration

The rotor side power (30% of rated) is handled by power converter only. The control system and power circuits required for a rectifier are studied, and closed loop regulation through d.c. link voltage for four quadrant operation in order to control power feedback to the supply with desired power factor is achieved [14]. In detailed design of the DFIG using back-to-back PWM voltage source converters in the rotor circuit is validated experimentally by considering a grid connected system [15]. Also it was found DFIGs and a four-quadrant ac-to-ac converter connected to the rotor windings increases the transient stability margin of the electrical grids, when compared with the case where the fixed speed wind systems with cage generators are used [16].

IV. CONTROL SCHEMES OF DFIG WIND TURBINE

DFIGs are controlled using decouples the rotor currents into active power (or torque) and reactive power (or flux) components, which are either stator flux oriented (SFO) [17-19], or stator voltage oriented / voltage oriented control (VOC) [17-20] as shown in the figure below

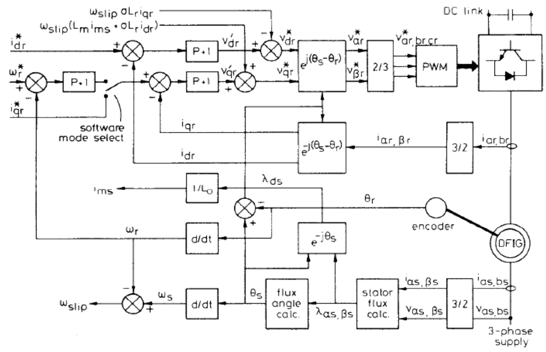

Figure 5. Stator flux oriented control scheme

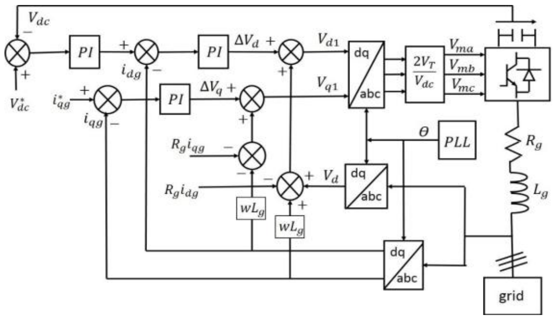

Figure 6:Grid side VSC control scheme

The DFIG control is completed by control of the variable frequency converter, which includes RSC control and GSC control. The objective of the RSC is to allow for decoupled controlling the active and reactive power. This facilitates high flexibility which enables the turbine to capture maximum energy from wind and to provide reactive power support to the grid.

The RSC control structure involves of inner loop and outer loop in which the inner loop regulates the d-axis and q-axis rotor components, i.e. I_{dr} and I_{qr} , independently and the outer loop regulates the stator real power and reactive power autonomously. The stator voltage orientation (SVO) control principle for a DFIG is described in [31], where the q-axis of the rotating reference frame is aligned to the stator voltage i.e. $V_{ds} = 0$ and $V_{qs} = V_s$. the stator side flux can be controlled using PI controller. In this study, the q-axis flux is regulated to zero$(\psi_{qs} = 0)$ and $(\psi_{ds} = \psi_s)$ for the de-coupled control of real and reactive power [21].

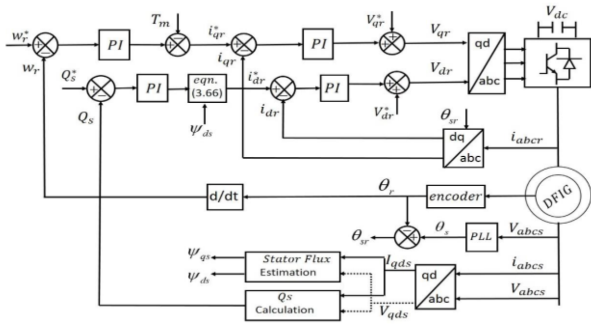

Figure 7:Block diagram of RSC control system

The control mechanism of GSC which controls the voltage across the capacitor and reactive power exchange between the converter and grid is V_{dc} reached by controlling the current. Now, DC voltage dynamics in DC-link is given by

$$CpV_{dc} = \frac{3}{4}\left(M_{qr}I_{qr} + M_{dr}I_{dr}\right) + \frac{3}{4}\left(M_{df}I_{df} + M_{qf}I_{qf}\right)$$

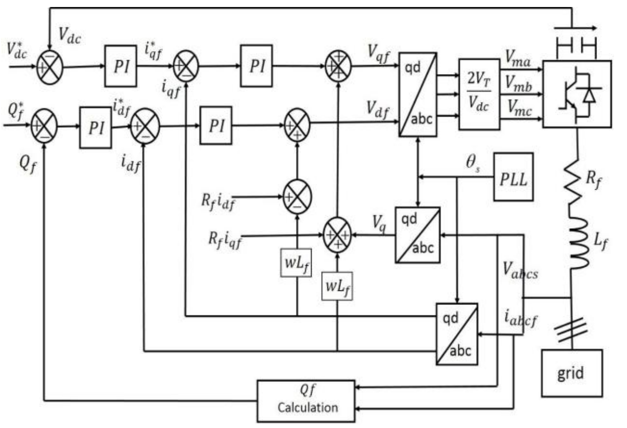

Figure 8:Block diagram of GSC control system

In the above mentioned controller the RSC and GSC controllers can designed separately and then combined together. This procedure is only valid when the controlled variables are independent of each other, i.e. they should be mutually decoupled[7,13,17].

V. CONCLUSION

The control strategies discussed above can be implemented effectively but needs appropriate tuning parameters to achieve decoupling. It often happens that if one current loop parameter varies, than the other loop output also varies and proper tuning is not achieved. In other words it is time consuming task to define proper tuning parameters. This problem occurs frequently in SFO control scheme. The PI controllers help in proper tracking of reference parameter which is generated according to the loading bus conditions. Also in fault/abnormal conditions or during wind speed variation, the output should be in stability limits.

REFERENCES

[1] R. Datta and V. T. Ranganathan, "Variable-speed wind power generation using doubly fed wound rotor induction – a comparison with alternative schemes," *IEEE Trans. Energy Conversion*, vol. 17, no. 3, pp. 414-421, Sept. 2002.

[2] V. Akhmatov, "Analysis of dynamic behavior of electric power systems with large amount of wind power," Ph.D. thesis, Technical University of Denmark, Kgs. Lyngby, Denmark, Apr. 2003.

[3] B. Wu, Y. Lang, N. Zargari, S. Kouro, "Power Conversion and Control of Wind Energy System", John Wiley 2011, pp 15-16.

[4] Bijaya Pokharel, "Modeling, Control and Analysis of a Doubly Fed Induction Generator Based Wind Turbine System with Voltage Regulation", Tennessee Technological University, Master thesis, December 2011.

[5] F. Iov, M. Ciobotaru and F. Blaabjerg, "Power Electronics Control of Wind Energy in Distributed Power Systems", *11th International Conference on Optimization of Electrical and Electronic Equipment*, Brasov, pp. XXIX - XLIV, May 2008.

[6] Jianzhong Zhang, Ming Cheng, Zhe Chen and Xiaofan Fu, "Pitch Angle Control for Variable Speed Wind Turbines", *2008 Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies*, pp. 2691-2696, April 2008

[7] R. Pena, J. C. Clare and G. M. Asher, "Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed windenergy generation," *IEE Proceedings Electric Power Applications*, Vol. 143, No. 3, pp. 231-241, May 1996

[8] Wei Qiao, Wei Zhou, José M. Aller, and Ronald G. Harley, "Wind Speed Estimation Based Sensorless Output Maximization Control for a Wind Turbine Driving a DFIG", *IEEE Transactions on Power Electronics*, Vol. 23, No. 3, pp. 1156-1169, May 2008

[9] 68. Eftichios Koutroulis and Kostas Kalaitzakis, "Design of a Maximum Power Tracking System for Wind-Energy-Conversion Applications", *IEEE Transactions on Industrial Electronics*, Vol. 53, No. 2, pp. 486-494, April 2006.

[10] T.S. Jayader,"Windmills stage a comeback", *IEEE Spectrum*, 13, pp. 45-49, 1976.

[11] I. Cardici, M. Ermis, "Double-output induction generator operating at subsynchronous and supersynchronous speed: steady state performance optimisation and wind-energy recovery", *IEE proc. B*,139, (5), pp. 429-442, 1992.

[12] S. Engelhardt, I. Erlich, C. Feltes, J. Kretschmann, F. Shewarega, "Reactive Power Capability of Wind Turbines Based on Doubly Fed Induction Generator," *IEEE Trans. on Energy Conversion*, vol. 26, no. 1, pp. 364-372, March 2011.

[13] S. Muller, M. Deicke and R.W. de Doncker, "Doubly fed induction generator systems for wind turbines," *IEEE, Industry Applications Magazine*, vol. 8, iss. 3, pp. 26-33, May/June 2002.

[14] S.R. Jones, K. Jones, "Control strategy for sinusoidal supply side convertors', TEE Colloquium on *Developments in real time control for induction motor drives*, Digest 1993/024, February 1993.

[15] R. Pena, J. C. Clare, and G. M. Asher, "Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed wind-energy generation," *IEE Proc. Elect. Power Appl.*, vol. 143, no. 3, pp. 231-241, 1996.

[16] M. V. A. Nunes, J. A. P. Lopes, H. H. Zurn, U. H. Bezerra, R. G. Almeida, "Influence of the variable-speed wind generators in transient stability margin of the conventional generators integrated in electrical grids," *IEEE Trans. Energy Conversion*, vol. 19, no. 4, pp. 692-701, Dec. 2004.

[17] S. Muller, M. Deicke and R.W. de Doncker, "Doubly fed induction generator systems for wind turbines," *IEEE, Industry Applications Magazine*, vol. 8, iss. 3, pp. 26-33, May/June 2002.

[18] W. Leonard, "Control of Electrical Drives", Springer, New York, 2001.

[19] A. Petersson, T. Thiringer, L. Harnefors, and T. Petru, "Modeling and experimental verification of grid interaction of a DFIG wind turbine," *IEEE Trans. Energy Conversion*, vol. 20, no. 4, pp. 878–886, Dec. 2005.

[20] L. Xu, D. Zhi, and B. Williams, "Predictive current control of doubly fed induction generators," *IEEE Trans. Industrial. Electronics,* vol. 56, no. 10, pp. 4143–4153, Oct. 2009.

[21] Xie Zhen, Zhang Xing, Yang Shuying, Li Qin and Zhai Wenfeng, "Study on Control Strategy of Maximum Power Capture For DFIG in Wind Turbine System", *2010 2nd IEEE International Symposium on Power Electronics Distributed Generation Systems*, pp. 110-115, June 2010.