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**A Review of Modern Controlling Technologies in Doubly Fed Induction
Generators(DFIG)**

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Abstract

Doubly fed induction generators (DFIG) based wind turbine is an emerging technology, which is applicable for fixed speed generator system. The DFIG system consists of a Wound Rotor Induction Generator (WRIG) with the stator windings directly connected to the constant frequency three-phase grid and with the rotor windings connected to grid through a bidirectional back-to-back IGBT based voltage source converter. This system allows a variable speed operation over a large range. This paper provides a comprehensive review the basic features and normal operation of DFIG systems for wind power applications and different aspects including their variable-speed feature, control systems, and application issues.

Keywords: Controllers, Grid side converter, Rotor, Wind power, Wind turbine

Introduction

Wind power is the most reliable and developed renewable energy source. The share of wind power with respect to total installed power capacity is increasing worldwide. Recently there has been a growing amount of interest in wind energy conversion systems (WECS). Among various other techniques of wind power generation, the doubly fed induction generator (DFIG) has been popular because of its higher energy transfer capability, low investment and flexible control. DFIG based wind turbines currently dominate the wind energy market due to their four-quadrant active/reactive power control, variable speed operation, low converter cost, and reduced power loss compared to other solutions[1].

Wind turbines (WTs) 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. There are several reasons for using variable-speed operation of wind turbines; among those are possibilities to reduce stresses of the mechanical structure, acoustic noise reduction and the possibility to control active and reactive power. Most of the major wind turbine manufactures are developing new larger wind turbines in the 3-to-5-MW range. These large wind turbines are all based on variable-speed operation with pitch control using a direct-driven synchronous generator (without gear-box) or a doubly-fed induction generator (DFIG).

DFIG is different from the conventional induction generator in a way that it employs a series voltage-source converter to feed the wound rotor. The feedback converters consist of Rotor side converter (RSC) and Grid side converter (GSC). The control capabilities of these converters give DFIG an additional advantage of flexible control and stability over other induction generators. Today doubly-fed induction generators are commonly used by the wind turbine industry for larger wind turbines [2].

DFIG

A doubly-fed induction generator (DFIG) was developed for a wind power system with a wide variation of wind speed. It consists of stator and rotor. The stator of the DFIG is directly connected to the power grid while its rotor needs to be connected to the power grid through an ac-ac power converter. The DFIG can supply the constant frequency power to the grid without reference to wind speed variation, and can control the power factor at the connection point [3].

The stator windings of DFIGs are directly connected to the grids, and rotor windings are connected to the grids through back-to-back power electronic converters. The back-to-back converter consists of two converters, i.e., rotor side converter (RSC) and grid side converter (GSC) that are connected "back-to-back." Between the two converters a dc-link capacitor is placed, as energy storage, in order to keep the voltage variations in the dc-link voltage small.

The characteristics of DFIG are high efficiency, flexible control and low investment. The stator of DFIG is directly connected to the power grid while the rotor is connected to the power grid through a back-to-back converter, which only takes about 20%–30% of the DFIG rated capacity for the reason that the converter only supplies the exciting current of the DFIG. The back-to-back converter consists of three parts: rotor side converter (RSC), grid side converter (GSC), and dc link capacitor. The controllers of the converter have significant effect on the stability of grid-connected DFIG [4].

The wound rotor doubly fed electric machine is the only electric machine that can be operated with rated torque to twice synchronous speed for a given frequency of excitation (7,200 rpm with one pole-pair doubly fed machine when both stator and rotor are fed with 60 Hz versus 3,600 rpm for otherwise similar singly fed electric machine). In high power applications two or three pole-pair machines are common. Higher speed with rated torque means that doubly fed machines have lower cost per kW, higher efficiency, and higher power density.

The working of DFIG is based on the principle of induction generator. It has multiphase wound rotor and a multiphase slip ring assembly with brushes for accessing rotor winding. The rotor windings are connected to the grid via slip rings and a back to back voltage source converter that controls both the rotor and grid currents (hence acting as a control system). By adjusting the converter's parameters it is possible to control the active and reactive power fed to the grid independently of the generators turning speed, giving it a distinct advantage over other conventional power generators. Fig.1 shows a schematic representation of a DFIG setup:

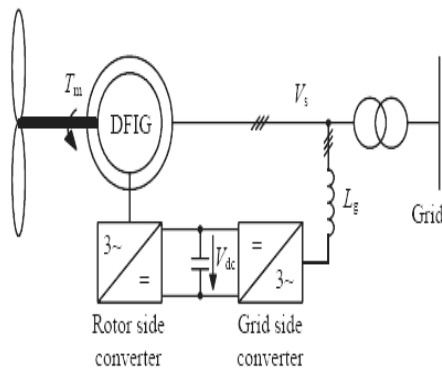


Fig 1. Wind turbine driven DFIG

The doubly fed generator rotors are typically wound with 2 to 3 times the number of turns of the stator. This means that the rotor voltages will be higher

and currents respectively lower. Thus in the typical $\pm 30\%$ operational speed range around the synchronous speed, the rated current of the converter is accordingly lower which leads to a lower cost of the converter. The drawback is that controlled operation outside the operational speed range is impossible because of the higher than rated rotor voltage. Further, the voltage transients due to the grid disturbances (three- and two-phase voltage dips, especially) will also be magnified. In order to prevent high rotor voltages - and high currents resulting from these voltages - from destroying the IGBTs and diodes of the converter, a protection circuit (called crowbar) is used. The crowbar will short-circuit the rotor windings through a small resistance when excessive

The wind turbine and the doubly-fed induction generator system

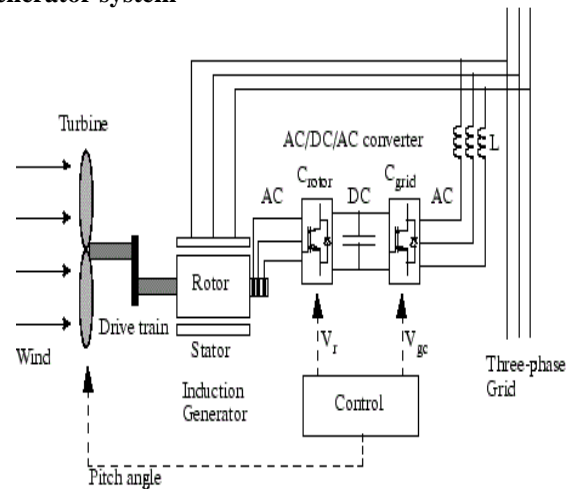


Fig 2: Operating Principle of the Wind Turbine Doubly-Fed Induction Generator

The power flow, illustrated in the figure, is used to describe the operating principle.

Let

- P_m Mechanical power captured by the wind turbine and transmitted to the rotor
- P_s Stator electrical power output
- P_r Rotor electrical power output
- P_{gc} C_{grid} electrical power output
- Q_s Stator reactive power output
- Q_r Rotor reactive power output
- Q_{gc} C_{grid} reactive power output
- T_m Mechanical torque applied to rotor

- T_{em} Electromagnetic torque applied to the rotor by the generator
- ω_r Rotational speed of rotor
- ω_s Rotational speed of the magnetic flux in the air-gap of the generator, this speed is named synchronous speed. It is proportional to the frequency of the grid voltage and to the number of generator poles.
- J Combined rotor and wind turbine inertia coefficient

The mechanical power and the stator electric power output are computed as follows:

$$P_m = T_m \omega_r$$

$$P_s = T_{em} \omega_s$$

(2)
For a lossless generator the mechanical equation is:

$$J \frac{d\omega_r}{dt} = T_m - T_{em}$$

(3)
In steady-state at fixed speed for a lossless generator $T_m = T_{em}$ and $P_m = P_s + P_r$.
It follows that:

$$P_r = P_m - P_s = T_m \omega_r - T_{em} \omega_s = -T_m \frac{\omega_s - \omega_r}{\omega_s} \omega_s = -s T_m \omega_s = -s P_s$$

(4)
Where s is defined as the slip of the generator: $s = (\omega_s - \omega_r) / \omega_s$.

Controllers

A Controller is a device introduced in the system to modify the error signal and to produce a control signal. The controllers may be electrical, electronic, hydraulic or pneumatic, depending on the nature of the signal and system. Only electronic controllers are presented in the section.

PI controller: The conventional PI controllers, because of their simple structures, are still the most commonly used control techniques in power systems, as can be seen in the control of the WTs equipped with DFIGs [5],[6]. Unfortunately, tuning the PI controllers is tedious and it might be difficult to tune the PI gains properly due to the nonlinearity and the high complexity of the system.

PI controllers are used in the rotor side converter to improve the transient performance. The controllers dynamically change values according to the different wind speeds to increase DFIG transient performance in a global operating range [7].

Hysteresis controller: Hysteresis current controller scheme is based on a feedback loop, generally with two-level comparators. The switching commands are issued whenever the error limit exceeds a specified tolerance band " $\pm h$." Unlike the predictive controllers, the hysteresis controller has the advantage of peak current limiting capacity apart from other merits such as extremely good dynamic performance, simplicity in implementation and independence from load parameter variations. The disadvantage with this hysteresis method is that the converter switching frequency is highly dependent on the ac voltage and varies with it [8].

Fuzzy Logic controller: The fuzzy logic approach provides the design of a non-linear, model free controller and hence, can be used for the coordinated control of RSC and GSC in the DFIG system. The Mamdani type fuzzy logic controller may not be able to provide superior control over a wide range of operation. Instead, a Takagi-Sugeno (TS) type fuzzy controller can provide a wide range of control gain variation by utilizing both linear and non-linear rules in the consequent expression of the fuzzy rule base [9].

Phase Locked Loop controller: A phase-locked loop or phase lock loop (PLL) is a controller that generates an output signal whose phase is related to the phase of an input signal. While there are several differing types, it is easy to initially visualize as an electronic circuit consisting of a variable frequency oscillator and a phase detector. The oscillator generates a periodic signal. The phase detector compares the phase of that signal with the phase of the input periodic signal and adjusts the oscillator to keep the phases matched. Bringing the output signal back toward the input signal for comparison is called a feedback loop since the output is 'fed back' toward the input forming a loop [10].

Neural Network Controller: In recent years artificial neural networks (ANNs) have gained a wide attention in control applications. It is the ability of the artificial neural networks to model nonlinear systems that can be the most readily exploited in the synthesis of nonlinear controllers. Artificial neural networks have been used to formulate a variety of control strategies [11].

There are two basic design approaches:

- Direct inverse control – it uses a neural inverse model of the process as a controller.
- Indirect design – the controller uses a neural network to predict the process output [12].

Control System

As mentioned above, there are two back to back converters hence we need to control these two converter sides. Primarily, these controllers are known as RSC and GSC controllers. For controlling the aerodynamic power beyond certain point, pitch angle controller is used.

Rotor-Side Converter: The rotor side converter is used to control the wind turbine output power and the voltage or reactive power measured at the grid terminals. The power is controlled in order to follow a pre-defined power speed characteristic (tracking characteristic) [13]. The control system using PI controller is shown in Fig. 3.

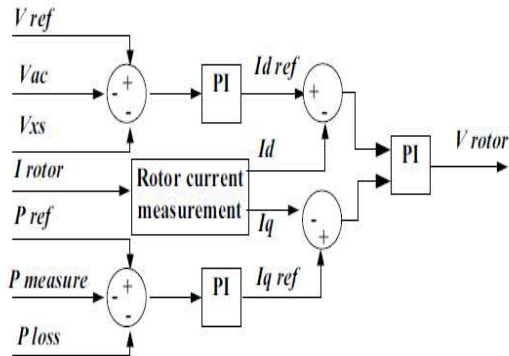


Fig. 3 The scheme of the rotor-side converter control system
We control the electromagnetic torque into the current regulator on the d-axis to compare the difference between the q-axis from var regulator (Q). Current regulator was transformed into voltage on the d-q axis, after its conversion between Cartesian to polar and polar to Cartesian. Then convert voltage control by dq0 to abc transformation to use in controlling.

Grid-Side Converter: The grid side converter is used to regulate the DC bus capacitor voltage. The control system using PI controller is shown in Fig. 4. The grid-side converter control fed dc voltage regulator from difference between V_{dc} and V_{dc} reference, and transfer into the d-q axis current or the current regulator by PI controller. Then, using PI controller, transfer the regulator again into the d-q axis voltage with the electrical equation of Park's transformation. It converts not unlike the rotor-side converter into using the DFIG controlled. The PI controller is controlled at the optimum point for the DFIG systems [14].

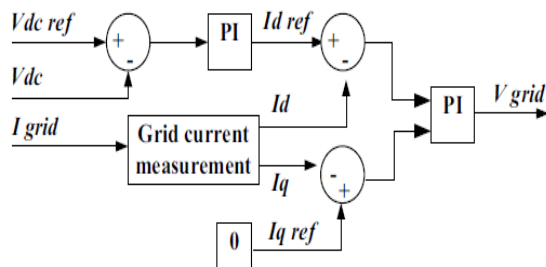


Fig. 4 The scheme of the grid-side converter control system

The pitch angle: The pitch angle is kept constant at zero degree until the speed reaches the maximum point speed of the tracking characteristic. Beyond this point the pitch angle is proportional to the speed deviation from this point speed. For electromagnetic transients in power systems, the pitch angle control is less interest. The wind speed should be selected such that the rotational speed is less than this maximum point speed [14]. The control system using PI controller is shown in Fig. 5.

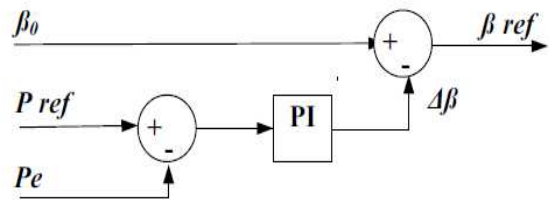


Fig. 5 The scheme of the pitch angle control system

Control Techniques for DFIG

Scalar control Technique

The sinusoidal pulse-width modulation (SPWM) technique is widely used in variable speed drive of induction machine, for scalar control where the stator voltage and frequency can be controlled with minimum online computational requirement. In addition, this technique is easy to implement. However, this algorithm has the following drawbacks. This technique is unable to fully utilize the available DC bus supply voltage to the VSI. This technique gives more total harmonic distortion (THD), this algorithm does not smooth the progress of future development of vector control implementation of ac drive. These drawbacks lead to development of a sophisticated PWM algorithm which is Space Vector Modulation (SVM). This algorithm gives 15% more voltage output compare to the sinusoidal PWM algorithm, thereby increasing the DC bus utilization. Furthermore, it minimizes the THD as well as loss due to minimize number of commutations in the inverter [15].

Vector Control Technique: Vector control, also called field-oriented control (FOC), is a variable frequency drive (VFD) control method which controls DFIG and three-phase AC electric motor output by means of two controllable VFD inverter output variables such as voltage magnitude and frequency. FOC is a control technique used in AC synchronous and induction motor applications also that was originally developed for high-performance motor applications which can operate smoothly over the full speed range, can generate full torque at zero speed, and is capable of fast acceleration

and deceleration but that is becoming increasingly attractive for lower performance applications as well due to FOC's motor size, cost and power consumption reduction superiority. Not only is FOC very common in induction motor control applications due to its traditional superiority in high-performance applications, but the expectation is that it will eventually nearly universally displace single-variable scalar volts-per-Hertz (V/f) control [16].

Direct Torque Control: The Direct Torque Control (DTC) method is basically a performance enhanced scalar control method. The main features of DTC are direct control of flux and torque by the selection of optimum inverter switching vector, indirect control of stator current and voltages, approximately sinusoidal stator flux and stator currents and high dynamic performance even at standstill. The advantages of DTC are minimal torque response time, absence of coordinate transformations which are required in most of vector controlled drive implementation and absence of separate voltage modulation block which is required in vector controlled drives. The disadvantages of DTC are inherent torque and stator flux ripple and requirement for flux and torque estimators implying the consequent parameters identification [17].

Conclusion

A DFIG based wind turbine has an ability to generate maximum power with varying and adjustable speed, ability to control active and reactive power by the integration of electronic power converters, low power rating of cost converter components. The DFIG system applied to wind power generation has gained considerable academic attention and industrial application during the past 10 years. DFIG is the most competitive option in terms of balance between the technical performance and economic costs.

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References

- [1] Mishra, S., Mishra, Y., Fangxing Li, Dong, Z. Y., Eriksen, P. B., Ackermann, T., Abildgaard, H., Smith, P., Winter W. and Rodriguez Garcia, J. M., (2005). System operation with high wind penetration. *IEEE Power Energy Mag*, **3(6)**: 65–74.
- [2] Viorica Spoiala, Helga Silaghi and Dragoş Spoiala, (2008). Control of Doubly-Fed Induction Generator System for Wind Turbines. *Journal of Computer Science and Control Systems*, **1(1)**: 213-218.
- [3] Ji-Heon Lee, Jong-Kyou Jeong, Byung-Moon Han, Nam-Sup Choi and Han-Ju Cha, (2010). DFIG Wind Power System with a DDPWM Controlled Matrix Converter. *Journal of Electrical Engineering & Technology*, **5(2)**: 299-306.
- [4] Yufei Tang, Ping Ju, Haibo He, Chuan Qin and Feng Wu, (2013). Optimized Control of DFIG-Based Wind Generation Using Sensitivity Analysis and Particle Swarm Optimization. *IEEE*, **4(1)**: 509 - 520.
- [5] Jouko Niiranen, (2008). About the active and reactive power measurements in unsymmetrical voltage dip ride-through testing. *Wind Energy*, **11(1)**:121–131.
- [6] Morren, J. and De Haan, S. W. H., (2005). Ridethrough of wind turbines with doubly-fed induction generator during voltage dip. *IEEE Trans. Energy Conversion*, **20 (2)**: 435-441.
- [7] Tang, T. and Xu, L., (1995). A flexible active reactive power control strategy for a variable speed constant frequency generating system," *IEEE Trans. Power Electronics*, **10(4)**: 472-477.
- [8] Baohua Dong, Sohrab Asgarpour and Wei Qiao, (2010). ANN-Based Adaptive PI Control for Wind Turbine with Doubly Fed Induction Generator. North American Power Symposium (NAPS).
- [9] Srinivas Bhaskar Karanki, Nagesh Geddada, Mahesh K. Mishra, and Kalyan Kumar, B.,(2013). A Modified Three-Phase Four-Wire UPQC Topology with Reduced DC-Link Voltage Rating. *IEEE transactions on industrial electronics*, **60(9)**: 3555 – 3566.
- [10] Ying, H., (1998). Constructing non-linear variable gain controllers via the Takagi-Sugeno fuzzy control, *IEEE Trans. Fuzzy Syst*, **6(2)**: 226-235.
- [11] Vemula Lohith Kumar, (2013). Simulation of Integer N Frequency Synthesizer. *International Journal of Engineering Trends and Technology*, **4(6)**: 2662-2665.
- [12] Levin, A. U. and Narendra K. S., (1993). Control of Nonlinear Dynamical Systems Using Neural Networks: Controllability and Stabilization. *IEEE Transactions on Neural Networks*, **4**: 192-206.
- [13] Branstetter, P. and Skotnica, M., (2000). Application of artificial neural network for speed control of asynchronous motor with

- vector control. Proceedings of International Conference of Kosice, EPE-PEMC 2000, pp. 6-157- 6-159.
- [14] Parminder Singh, Gagandeep Sharma and Sushil Prasher, (2013). Power Control of DFIG Using Back to Back Converters (PWM Technique). *International Journal of Engineering and Innovative Technology*, **3(3)**: 196 – 200.
- [15] Tapia Arantxa, Gerardo Tapia, Xabier Ostolaza, J. and Jose Ramón Saenz, (2003). Modeling and Control of a Wind Turbine Driven Doubly Fed Induction Generator. *IEEE Transactions on energy conversion*, **18(2)**: 194 - 204.
- [16] Youcef Bekakra and Djilani Ben Attous, (2012). Comparison Study between SVM and PWM Inverter in Sliding Mode Control of Active and Reactive Power Control of a DFIG for Variable Speed Wind Energy. *International Journal Of Renewable Energy Research*, **2(3)**: 471-477.
- [17] Bose and Bimal K., (2009). The Past, Present, and Future of Power Electronics. *Industrial Electronics Magazine, IEEE*, **3 (2)**:7 - 11, 14.
- [18] Yerra Sreenivasa Rao and Jaya Laxmi A., (2012). Direct torque control of doubly fed induction generator based wind turbine under voltage dips. *International Journal of Advances in Engineering & Technology*, **3(2)**: 711-720.