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Generation of Wind Power using Doubly Fed Induction Generator

Gargi Mishra**, Ramit Mohan, Kartik Kapoor, Kartikey Kumar
Department of Electrical and Electronics, Bharati Vidyapeeth College of Engineering,
New Delhi, India

Abstract

Due to independent controlling mechanism for the active and reactive power, doubly fed induction generator (DFIG) is still culled by the wind turbine companies. The control strategies are continuously advancing to manage the grid codes (i.e. reactive power compensation, low voltage ride-through operation). This paper focuses on the control strategies using combined reactive power compensation for power converters to maintain the optimized lifetime distribution under normal grid conditions. An advanced demagnetizing control is also discussed which maintains the minimum thermal stress of the rotor-side converter in case of the short-term grid fault. A modularized control strategy of the DFIG system under unbalanced and distorted grid voltage is also presented, which discusses the control targets of the smooth active and reactive power and balanced sinusoidal current of the rotor-side as well as the grid-side converter. In this paper, the limitations of control strategy implementation for wind turbines are also discussed.

Keywords: *Doubly-fed induction motor, reactive power, low voltage ride-through unbalanced distorted*

****Author for Correspondence*** E-mail: gargi.mishra1983@gmail.com

INTRODUCTION

Doubly Fed Electrical Generators (DFEG), are capable of operating at multiple speeds i.e. above and below the synchronous speed. This technology is used at large scale due to variable speed of wind turbines (WT). When a quick strong rush of wind strikes on wind turbine, the turbine blades try to accelerate but a synchronous generator cannot accelerate because it is connected to the grid [1–3]. The variable speed of WT causes varying frequency at output, thus output of generator is first converted to DC, and then it is again converted to AC of desired frequency with the help of an inverter. This system is useful in household applications and farming requirements. To cope up with the requirements of new grid code, several DFIG models have been proposed in literature [4–5]. DFIG technology is used for extraction of maximum energy from wind. Induction generator is the principle component of DFIG with many phase wound rotors and various slip rings with carbon brushes. DFIG suffers from many problems related to their efficiency, cost and size. The converter controls the rotor currents and active and reactive power is fed to the grid from stator independent of the rotating speed of generator. It relies on the two main principles of controlling, axis current vector control and direct torque control (DTC) [6]. The doubly fed generator rotors are wound with 2 to 3 times the number of turns of the stator, that is, the operational speed is about 30% of the synchronous speed and this refers to a reduced cost of the rated current converter [7–9]. Therefore, the voltage is distributed by the transfer of the AC power to the grid. A doubly fed induction machine has various controls like conventional induction machine or generator in power wind technology. The lower cost of the converter is the advantage over other variable speed solutions because of the portion in mechanical power about 25–30% is fed to the grid through the converter, remaining is fed to grid directly from the stator. The configuration of the DFIG system is shown in Figure 1.

WIND POWER GENERATION THROUGH DFIG

Electricity generation through wind turbines uses wind power to operate an electrical generator. The wind cuts through the blades producing a force which rotates the shaft in the container, which goes into the gear box. This box provides the rise in speed of rotation for the generator. Magnetic field is used to transmute the rotational energy into electrical energy. The output power is then passed to transformer which transforms the electricity of 700 V to approximately 33 kV [10]. The wind power generated by turbines can be given by Eq. (1):

$$P = 0.5\, C_p A \mu V^3 \qquad (1)$$

Where, C_p is coefficient of power, μ is density of air in kg/m^3 and V is velocity of wind in m/sec.

Fixed speed wind turbine squirrel-cage induction generators (FSWT-SCIG) are used to develop the wind power as they are more common [11]. This system, when connected with low powered grids, encounters two major problems, voltage flickering and low voltage ride through (LVRT) [12]. This wind energy system is usually installed in remote and rural areas as these areas generally have weak grids with unbalanced voltage (over/under-voltage) conditions [13, 14]. One more disadvantage is that capacitors are needed at stator terminals reactive power considerations [15]. In this system, delivery of rated power depends on the wind speed. If speed of wind varies from rated speed, generator speed also varies by 1% of its rated value [16]. If the connected grid is weak, voltage instability is caused due to over-speeding of wind turbines [17]. In the event of occurrence of such crisis, utilities disconnect the wind turbines immediately from the grid. Tripping of some wind turbines in the wind farm makes the power system considerably unstable [12]. The concept of variable speed wind turbine (VSWD) was introduced which can cope with the specified limitations. In case of variable speed systems, the wound rotor induction machine of same rating can improve the energy abduction [11]. The wind energy conversion system is shown in Figure 2.

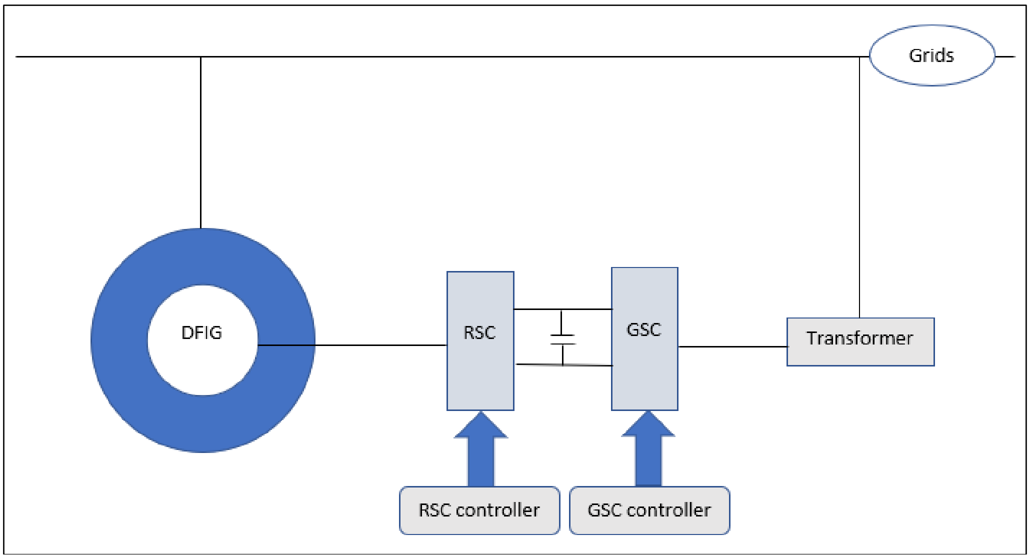

Fig. 1: *DFIG Configuration.*

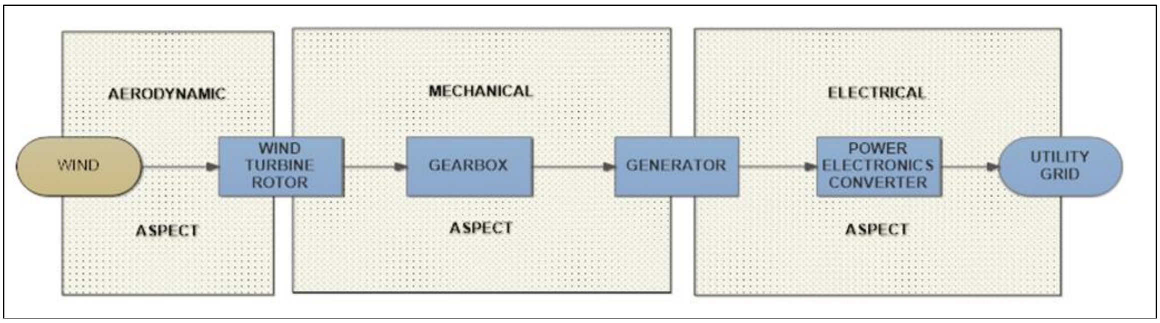

Fig. 2: *Wind Energy Conversion System.*

Table 1: *Percentage of the Wind Potential Utilization (State-Wise) [18].*

Sr. No.	**State**	**Wind Power Installation**	**Total Wind Power Potential at 100 m Above Ground Level**	**% of Wind Power Potential Utilized**
1	Andhra Pradesh	1431.45	44229	3.24
2	Gujarat	3648.61	84431	4.68
3	Karnataka	2869.15	55857	5.14
4	Kerala	43.5	1700	2.56
5	Madhya Pradesh	2141.1	10484	20.42
6	Maharashtra	4653.83	45394	10.25
7	Rajasthan	3993.95	18770	21.28
8	Tamil Nadu	7613.86	33800	22.53
9	Telangana	77.7	4244	1.83
10	Others	4.3	3342	0.13
	Total	**26777.45**	**302251**	**8.86 %**

In the late 50 s and early 60 s in India, the attention towards the windmills was shown. The state wise percentage of the wind potential utilization in India is shown in Table 1.

Nonlinear Variable Speed Variable Pitch Wind Turbine System

The main position of the controller in the WT (Wind Turbine) is to increase the output of energy level at varying wind speed [19]. The major classification of wind turbines is fixed speed wind turbine (FSWT) and variable speed wind turbine (VSWT) [20, 21]. A combination of linear and nonlinear controllers is utilized for variable speed variable pitch wind turbine (VSVPWT) systems. The controllers in WTs are tested for below and above rated wind speed for different step and vertical wind speed profiles. The production of the controllers is examined with nonlinear fatigue, aerodynamics, structures and turbulence. The mechanical power (P_{mech}) that the wind turbine produces while working is given by:

$$P_{mech} = T_t \omega_t \tag{2}$$

$$T_t = (1/2)\rho A R^3 \frac{C_p(\lambda,\beta)}{\lambda^3} \omega_t^2 \tag{3}$$

Where, T_t, A, $C_p(\lambda,\beta)$ and $\rho$are the turbine aerodynamic torque, rotor swept area, power coefficient for a variable pitch wind turbine and air density respectively. Here, the tip speed ratio is:

$$\lambda = R\omega_t/\theta \tag{4}$$

Where, R and θ stand for turbine rotor radius and wind speed respectively. Using blade element momentum theory, the pitch angle dynamics can be derived as 19,22]:

$$\beta = K_1(\omega_t - \omega_r)(1 - \frac{\beta}{K_2}) \tag{5}$$

Wind turbine is a device which converts the kinetic energy of the wind in to electrical energy. Simulation complexity of the wind turbine purely depends on the type of control objective. The important parameters related to a wind turbine are the rotor shaft torsion, rotor shaft friction, rotor inertia and electromagnetic torque [20, 23, 24]. The turbine rotor position can be expressed by δ and the dynamic model of variable pitch variable speed wind turbine can be written as:

$$\delta = \omega_t \tag{6}$$

$$\omega_t = \frac{1}{j}[-K_r\,\delta - B_r\omega_t + T_t - T_e] \tag{7}$$

$$\beta = K_1(\omega_t - \omega_r)(1 - \frac{\beta}{K_2}) \tag{8}$$

Here, K_1 and K_2 are integration constant and the gain reduction constant respectively. Gain reduction constant which reduces the pitch rate at high pitch angles. These parameters are not known precisely which introduces uncertainty in the nonlinear wind turbine dynamics [23, 25].

Comparison of Control Schemes

In literature, three major control schemes are available, which are vector control (VC), Stator flux oriented (SFO) and Voltage oriented control (VOC). From earlier studies we can infer that DFIG is controlled by VC in which both the reactive and real powers are adjusted separately either by SFO or VOC [26–29]. VC is applied on rotor current decoupling which can be either SFO or VOC and is helpful in controlling the DFIG system. VC is used by most widely used models which is based on SFO keeping the amplitude and frequency of the stator or grid voltages consistent, i.e., the voltage of the stator is ideal in the control designs and the characteristics of magnetizing current is not accountable [30–32]. If the above conditions are satisfied, a system can achieve a good response during the normal conditions but the same results are not achieved if the system experiences some AC voltage disturbance. The VC which is based on SVO or VOC is known as "Grid flux-oriented control" [24]. When the VC mode based on the PI controllers in a reference frame on any one of the SFO or VOC frames is used for operating DFIG and because of their performance under standard conditions has been discussed by Zhiand Xu [33], the independent control of real and reactive power helped us to come to a conclusion that the performance of DFIG is highly efficient in usual grid conditions when the system is joined with PI controllers [34, 35]. For developing the mechanisms of wind power extraction in DFIG, the SFO frame is utilized [22,36]; and in the work of Morren and De Haan, we can see that when the SFO frame is used in DFIG wind turbines, direct power control strategy is applied [37]. When VOC was suggested for the controlling operation, no circumstantial layout of the circuit was given and a constant voltage was presumed [26]. When no decoupling circuit was used, it was seen that inadequate response was achieved and that is the reason VOC control has been used [38]. Detailed explanation on DFIG based wind turbines can be found in the book by Leonhard [26]; these systems typically act as controllers.

The Role of Control Strategies in Wind Turbine

The type of generator is not the only thing which is correlated to the performance of a DFIG but control strategies are also enacted as they are a major factor in deciding the operation of DFIG wind turbine system [8]. There are different types of strategies which have been presented to examine the characteristics of the system during both normal and faulty conditions. Vector control (VC), direct current control, rotor side control and real and reactive power control are miscellaneous strategies for studying the mechanism [13]. For the decoupled controlling of the both real and reactive power draws from the DFIGVC or vector control is used and this process is helpful for unrelated control of torque and excitation current. Some reference models such as GSC transient and steady state models can also be used as frame models for DFIM and these methodologies are then modified into algorithms which can be further helpful in calculating real and reactive power by using the VC strategy. If the correct procedure is followed, the motion of reactive power flow does not depend on the active power and because of the dissimilitude of voltage, current and speed which is originated by the variation in the speed of turbine and that is the reason system limitations are accounted [1]. An analogous method is proposed by Soliman *et al.* which assures of reactive power even in the unbalanced conditions as well as outages [9]. The process in which the PI controller method is compared to the state feedback method which contains the active and reactive power by simulation and it has been discussed by Sethi *et al.*and some integral controllers are accompanied by control loops and are analysed by Manwell *et al.* [19, 22]. Some case studies have been developed on the real and reactive power flow in the wind farms with the help of induction generators by employing DFIG.

LIMITATIONS OF CONTROL STRATEGY IMPLEMENTATION FOR WIND TURBINES

The control methods boost the performance during normal and distorted AC grid conditions. The power quality of turbines declines during extraction of wind power using stator flux oriented frames (SFO) [36, 37]. In direct power control schemes the performance declines due to the variations of parameters which varies in accordance to wind speed, temperature changes, saturation etc. It is difficult to implement in DFIG as electromagnetic torque vibrations are more than VC [39]. Moreover direct power control complicates the AC filter designs. Control schemes like (SFO-VC), main drawback is its unavailability of discrete operations of power electronics converters. Similarly in direct torque control schemes, the performance declines during starting when speed is low [37]. So every control method possesses drawbacks but even after many drawbacks, control methods boost overall performance of turbines in wind power generation.

CONCLUSION

This research paper is focused on study of DFIG and various control strategies implemented in the field of wind power generation. The replacement of usual generators by DFIG system affects the synchronizing torques which deteriorates the power system performance. However DFIG exhibits time tested gear system which withdraws more wind energy. The cost of DFIG is higher than usual fixed speed induction generators. It is preferred due to its ability to control reactive power. Moreover in variable wind states, DFIG control structure provides significant performance. Thus to obtain extraordinary performance, good control strategies must be developed.

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