

## Doubly Fed Induction Generator Based Wind Energy Conversion System: A Review

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### ABSTRACT

*Doubly-Fed Induction Generator (DFIG) based wind turbine has gained attention in present day wind power industry due to its performance. D F I G uses the concept of variable speed, variable pitch and torque to control the variation of wind speed relative to the output. In wind energy conversion system, the stator terminal is connected to the grid while the rotor is connected via a bidirectional converter in which DFIG is employed. However, DFIGs are highly subjected to some system disturbances like grid voltage dip and swell. This call for an efficient control operation of DFIG- based WECS to ensure an improved performance under dynamic conditions. The Direct Torque Control (DTC) otherwise known as scalar control technique is a technique best use in DFIG for wind energy extraction due to its better dynamic response, reduce use of machine parameters and its simplicity in implementation. From the work presented, conclusions will be made on the best configuration for WEC system and the control suitable for suppressing torque and regulating flux ruffle.*

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### INTRODUCTION

Environmental risks, non-sustainable assets depletion is a portion of concern responsible for an expanded interest being taken by the significant power producing countries internationally in the production of a clean, green and pollution-free form of power (Patnaik *et al.*, 2015). Among the many sources and technologies namely; (fossil fuels, nuclear power, renewable energy) use to produce energy, renewable energy sources (solar, wind, water) which are clean and green are the most common sources (Jibril *et al.*, 2019; Alhazmi, 2015). These sources of power system generation have taken the lead in the last few decades due to its less negative effect on environment and low cost of generation (Alhazmi, 2015). Among a number of renewable energy sources for electricity generation, wind energy been among the cleanest renewable energy sources is highly favoured (Sun *et al.*, 2018; Meng *et al.*, 2016). Wind power global installation capacity has reached 318GW in 2013 (Patnaik *et al.*, 2015) and it is expected to reach 720GW by 2020 (Ngamroo, 2017). This rapid integration of wind power as compared to other renewable energy sources has become a critical element in the modern power network (Liao *et al.*, 2017). A wind energy using doubly fed induction generator (DFIG) system has several advantages such as high efficiency, variable speed operation and four quadrant active and reactive power capabilities as compared to squirrel cage induction generator (SCIG), wound rotor induction generator (WRIG) and permanent magnet

synchronous generator (PMSG)(Si & Liu, 2015). In DFIG, the stator is directly connected to grid, while the rotor is connected to grid via a bidirectional converter. This converter controls the active and reactive power between the stator and ac supply (Si & Liu, 2015). Wind power plants possess non-linear dynamics together with uncertainties, thus the rotor position angle and mutual inductance between the stator and rotor have non-linear function in DFIG (Si & Liu, 2015). In WEC system, wind power is transformed into the rotational energy in blades of the turbine where a generator producing electricity is connected to its axis. In order to ensure more economics operation of the WECS economically, it is required to extract as much power as possible from the wind (Abubakar, 2016).

### CONFIGURATION OF GENERATOR IN WECS

Generally, fixed speed and variable speed used in wind turbines are categories into four major types (Rashmi *et al.*, 2015).

- a) Fixed-speed wind turbine with induction generator
- b) Variable-speed wind turbine concept with variable rotor resistance
- c) Variable-speed wind turbine concept with full-scale power converter
- d) Variable-speed wind turbine equipped with Doubly-Fed Induction Generator (DFIG)

The aerodynamic efficiency of the rotor and the different wind speed states are the major

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changes between them (Rashmi *et al.*, 2015).

#### **Fixed-Speed Wind Turbine with Induction Generator**

For fixed-speed WT, squirrel cage induction generator (SCIG) is the common generator type (Rashmi *et al.*, 2015). It operates through a gearbox with minimum ranges of speed connected directly to the grid via transformer (Beainy *et al.*, 2016). The SCIG is known for its robustness and requires light maintenance but has a setback of uncontrolled reactive power consumption (Rashmi *et al.*, 2015).

#### **Variable speed Wind Turbine concept with Variable Resistance**

Wound Rotor Induction Generator (WRIG) is the common of this arrangement. The controlled resistances are serially connected with the rotor phase of the generator. These arrangements ensure a full control and regulation of the rotor resistance, power output and the slip (Rashmi *et al.*, 2015). However, WRIG has a limitation of small variable speed of range 0-10% above synchronous speed due to resistances sizes and its trend is been phase out of the global market (Rashmi *et al.*, 2015).

#### **Variable-Speed Wind Turbine Equipped with Doubly-Fed Induction Generator (DFIG).**

Wind industries are inclined to the use of DFIGs because of it reduce noise level, reduce mechanical stress, small capacity of converter etc (Sun *et al.*, 2018). DFIGs uses the concept of variable-speed to controlled (VSWT). In these control method, power electronics equipment's are used to control the generator. There are a few purposes behind utilizing VSWT among which are control of active and reactive power, reduced noise and mechanical stress (Petersson, 2005). Moreover, VSWT converter rating is about 25-30% in DFIG as compared to 100% of the total nominal power of the generator. It also has a wide range of synchronous speed of 30% (Beainy *et al.*, 2016). The concept connects the wound-rotor phase directly to the grid through the stator and its output is connected to a very sensitive bidirectional converter interfacing the rotor winding phases. This allow operation of variable speed of WTs by decoupling both rotor mechanical and power systems frequencies (Meng *et al.*, 2016).

#### **Variable Speed Concept with Full-Scale Power Converter**

Permanent Magnet Synchronous Generator (PMSG) is associated with this concept of full-

scale converter. It adopts a gearless concept as the rotor is been replace with a permanent magnet. The PM therefore, provide the full excitation instead of the field winding and the converter is used to connect the stator phase winding to the grid (Rashmi *et al.*, 2015). PMSGs have some advantages like: high torque, low noise, no mechanical stress and less maintenance cost (Krim *et al.*, 2017). Another beautiful part of PMSG is the full control of synchronous speed to a range of 0-100% but these generate harmonics and power loss due the present of power electronic converters (Rashmi *et al.*, 2015).

#### **DOUBLY FED INDUCTION GENERATOR (DFIG)**

Doubly-Fed Electric Machines are electrical machine that fed in ac current into the winding of stator and rotor (Hlaing, 2015). The machine operates like a synchronous motor whose speed (speed at which the motor shaft rotates) can be varied by adjusting the frequency of the ac current fed into the rotor winding. In DFIGs, mechanical power at the machine shaft is converted into electrical power supplied to grid via the stator and rotor windings (Lab-volt, 2014). The generator also operates like a synchronous generator whose speed (speed at which the generator shaft must rotate to generate power at grid frequency) can be varied by simply adjusting the frequency of ac current fed into the rotor winding (Hlaing, 2015). DFIG allow the frequency and amplitude of their output voltages to be at constant value in various wind speed variation. This feature makes DFIGs remain connected and synchronised to the grid all time (Hlaing, 2015). Very lately, the use of VSWT system with DFIGs in the grid has attract a global attention due to a number of abilities like four-quadrant active and reactive power capabilities (Patnaik *et al.*, 2015; Meng *et al.*, 2016), adjustable to variable wind speed (Alex, 2015), high efficiency and energy yield (Beainy *et al.*, 2016). Generally, VSWT consist of a gearbox, turbine and DFIG combine together to convert the captured wind energy by the WT through gearbox to electrical energy (Liu *et al.*, 2016). The stator terminal of the DFIG are connected directly to the grid (Beainy *et al.*, 2016; Sun *et al.*, 2018) whereas, the rotor is connected to the grid via back-to-back converter (Patnaik *et al.*, 2015) as highlighted in Figure 1.

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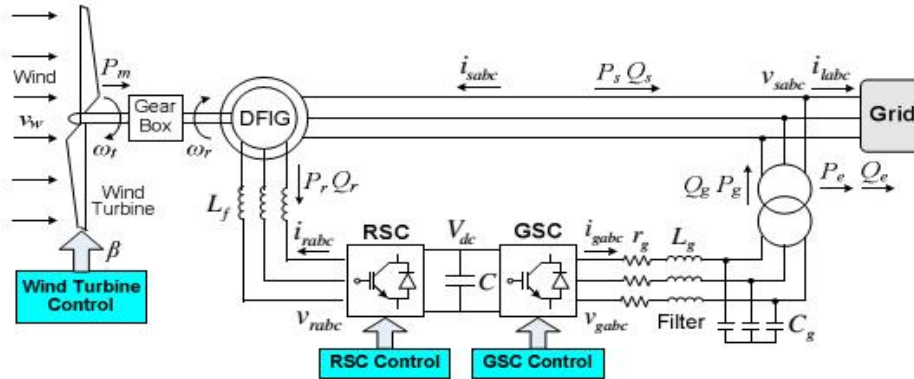


Figure 1: Schematic Representation of a Grid Connected DFIG (Abubakar, 2016)

The basic requirement for a grid mode connection is to maintain a standard frequency at the output relative to the grid. The Grid Side Converter (GSC) control the power of the DFIG at normal or synchronous speed while at super or sub synchronous speed the Rotor Side Converter (RSC) control the output power (Fletcher, 2014).

### Modelling of DFIG

A DFIG is basically a wound rotor induction machine in synchronous reference frame (Bayat and Torun, 2017). The stator winding is connected directly to the grid (Sun *et al.*, 2018) while the rotor is connected to the grid via a power electronic converter (Patnaik *et al.*, 2015). The model equations of DFIG can be expressed from the equations governing induction machine (Bayat and Torun, 2017).

$$V_d = R_s I_d + \frac{d}{dt} \psi_d - \omega_s \phi_q \quad (1)$$

$$V_q = R_s I_q + \frac{d}{dt} \psi_q + \omega_s \phi_d \quad (2)$$

$$V_d = R_r I_d + \frac{d}{dt} \psi_d - \omega_r \phi_q \quad (3)$$

$$V_q = R_r I_q + \frac{d}{dt} \psi_q + \omega_r \phi_d \quad (4)$$

With,

$$\phi_d = X_s I_d + X_m I_q \quad (5)$$

$$\phi_q = X_s I_q + X_m I_d \quad (6)$$

$$\phi_d = X_r I_d + X_m I_q \quad (7)$$

$$\phi_q = X_r I_q + X_m I_d \quad (8)$$

Where,

V: voltage

I: current

R: resistor

$\phi$  : flux linkages

$V_d, V_q$  : d & q component stator voltages

$V_d, V_q$  : d & q components rotor voltages

$I_d, I_q$  : d & q components rotor current

$I_d, I_q$  : d-q component stator current

$\omega_r$  &  $\omega_s$ : rotor and stator speed of the generator.

$X_r, X_s$ , &  $X_m$  : rotor inductance, stator inductance and magnetising inductance respectively.

### Control Strategy of DFIG

DFIG can be controlled using the Direct Torque Control (DTC) or the Direct Power Control (DPC) which has a fundamental basis in either stator-voltage oriented vector control or stator-flux oriented (Nazari, 2012). The details of the control

techniques will be discussed in the following sub-section.

### Direct Torque Control.

The Direct Torque Control (DTC) otherwise known as scalar control technique is a technique

best use in DFIG for wind energy extraction due to its better dynamic response, reduce use of machine parameters and its simplicity in implementation (Nazari, 2012; Trivedi *et al.*, 2015; Song *et al.*, 2018). The torque and flux are taken as two control variables and a switching vector is properly selected to obtain a desired operation (Trivedi *et al.*, 2015). However, DTCs have some limitations of large torque and flux ripple, variable switching frequency which can all be complemented by additional voltage vector (Song *et al.*, 2018). To achieve the

complementation, the output level of the control technique must be increased. Thus, making the stator flux vector space expand which increases the complexity of the system (Song *et al.*, 2018). The DTC classical method utilized voltage vector in motor control which invariably control the applied time thereby making the control torque more accurate hence suppressing the torque and flux ripple (Song *et al.*, 2018). The electromechanical torque is given by

$$T_e = 3n_p I_m [\psi_s i_R] \approx -3n_p \psi_s i_R \quad (9)$$

Where  $T_e$ : electromechanical torque

$n_p$ : number of poles

$\psi_s$ : stator flux

$i_R$ : q-component of rotor current.

The equation (9) describes the stator-flux oriented system. The q component of the rotor current  $i_R$  is used to control the torque because

the stator flux is relatively fixed to the stator voltage. Torque can be difficult to measure as such an open-loop is use to control the torque (Pettersson, 2005).

$$i_R^r = -\frac{T_e^r}{3n \psi_s} \quad (10)$$

where  $T_e^r$ : reference torque

$n_p$ : number of poles

$i_R^r$ : reference current

$\psi_s$ : stator flux

#### Direct Power Control.

Direct Power Control (DPC) otherwise a vector-oriented control (Trivedi, 2015) was design for a three-phase Pulse Width Modulation (PWM) converter (Nazari, 2012). DPC technique is simply based on p-q theory (Trivedi *et al.*, 2015) which select its optimal switching table based on errors occurring between reactive and active powers and their references from the switching state of the

converter. This technique guarantees a better dynamic response (Nazari, 2012). However, DPC suffer an unsatisfied control precision from rotor voltage generated for reactive and active powers particularly at maximum wind capturing (Trivedi *et al.*, 2015; Nazari, 2012). For converters connected to grid, KVL yields equation (11) (Trivedi *et al.*, 2015).

$$V_s = R_s i + L_s \frac{d}{dt} + V_c \quad (11)$$

Where  $V_s$ : grid voltage vector

$i$ : current vector

$V_c$ : converter voltage vector

Also, the grid voltage vector  $V_s$  is denoted by equation (12)

$$V_s = V_m e^{j\omega t} \quad (12)$$

Where  $\omega$ : angular velocity of the grid voltage vector.

$$V_c = \sqrt{\frac{2}{3}} V_d (S_1 + S_2 e^{j\frac{2\pi}{3}} + S_3 e^{j\frac{4\pi}{3}}) \quad (13)$$

Where  $S_1, S_2, S_3$ : switching states of converter

$V_d$ : DC link voltage

$$\begin{aligned} \Delta p &= R (\Delta s) \\ \Delta q &= I_i (\Delta s) \end{aligned} \quad (14)$$

Equation (14) is used to calculate the reactive and active powers.

### Speed Control

The speed is controlled in cascaded form with the current since the current dynamic is set far ahead of the speed dynamic. The mechanical dynamic is expressed by

$$\frac{d}{dt} \omega(t) = \frac{1}{J} (T_t - T_e) - \frac{B}{J} \omega(t) + \frac{1}{J} \zeta \quad (15)$$

Where  $T_e$  : electromechanical torque

$J$  : inertia

$T_t$  : turbine torque.

$\omega_r$  : turbine rotor speed

$B$  : viscous-friction coefficient

$\zeta$  : unmodeled quantities and external disturbances.

Also,  $T_e(t) = K_t i(t)$

### CONCLUSION.

This work has presented a review on different configuration and topologies of induction generators used in wind energy conversion system. The work reviewed that DFIG has gained global attention due to its advantages over PMSG, WRIG and SCIG in terms of variable speed operation, efficiency, reactive power capabilities, four quadrant operation. Although, its efficient performance depends upon the type of control method used. For this reason, the work also reviewed the most common types of control methods used (Direct Torque Control and Direct Power Control), together with their limitation. It is observed that DTC is preferred over DPC as highlighted. Although, it requires the incorporation of a controller such as sliding mode control, second order sliding mode control, model predictive control and other controllers to guarantee efficient control of the system.

### REFERENCE

- Abubakar A. S. (2016). Development of a Model Predictive Control Scheme for Doubly Fed Induction Generator for a grid-connected Wind Turbine System. Phd Seminar. Department of Electrical Engineering. Ahmadu Bello University, Zaria. Unpublished.
- Alex K. Katherine D. Kathy A, (2015). Introduction to DFIG for Wind Power Application. Department of Earth, Atmospheric and Planetary Science (EAPS) MIT, 259-278.
- Alhazmi, (2015). Modelling of Doubly-Fed Induction Generator using MATLAB/SIMULINK. Master's thesis, California state university Los Angeles.
- Bayat M. M and Torun Y. (2017). Modelling and Linearization of DFIG Based Wind Turbine. European Scientific Journal July 2017 /SPECIAL/ edition ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431.
- Beainy, Maatouk, Moubayed and Kaddah, (2016). Comparison of Different Types of Generator for Wind Energy Conversion System Topologies. 2016 3rd International Conference on Renewable Energies for Developing Countries (REDEC) 978-1-5090-1864-2/16
- Fletcher J and Yang J. (2010). Introduction to Doubly-Fed Induction Generator for Wind Power Applications. *University of Strathclyde, Glasgow United Kingdom*
- Hlaing S. (2014). Basic Concepts of Doubly Fed Induction Generator Driven by Wind Energy Conversion System. *International Journal of Scientific Engineering and Technology Research* Vol.03, Issue.15-2014, Pg:3242-3246
- Lab-Volt, (2011). Principles of Doubly-Fed Induction Generators (DFIG). Canada
- Krim, Abbas, Krim and Mimouni, (2017). Classical vector, first-order sliding mode and high-order sliding-mode control for a grid connected variable speed wind energy conversion system: A comparative study. *Wind Engineering* 1–22: DOI: 10.1177/0309524X17723202.
- Jibril, Y., Olarinoye, G. A., Abubakar, A. S., Abdulwahab, I., & Ajayi, O. (2019). Control Methods Used In Wind Energy Conversion System: A Review. *ATBU Journal of Science, Technology and Education*, 7(2), 53-59.
- Liao K, He Z, Xu Y, Cheng G, Dong Z.Y, Wong K.P, (2017). Sliding Mode Based Damping Control of DFIG for Interarea Power Oscillations. *IEEE Transactions on Sustainable Energy*, Vol. 8, No. 1, 2017 258-267. DOI 10.1109/TSTE.2016.2597306
- Liu, Han and Wang, (2017). Second-order sliding mode control for power optimisation of DFIG-based variable speed wind turbine. *IET Renew. Power Gener.*, 2017, Vol. 11



- Iss. 2, pp. 408-418 doi: 10.1049/iet-rpg.2015.0403
- Meng, Yang and Sun, (2016). Guaranteed Performance Control of DFIG Variable-Speed Wind Turbines IEEE transactions on control systems technology. 1-9: DOI: 10.1109/TCST.2016.2524531
- Nazari and Heydari. (2012). Direct Power Control Topologies for DFIG-Based Wind Plants. International Journal of Computer and Electrical Engineering, Vol. 4, No. 4, August 2012
- Ngamroo, (2017). Review of DFIG Wind Turbine Impact on Power System Dynamic Performances. IEEJ TRANSACTIONS. 1-11: DOI:10.1002/tee.22379
- Patnaik, Dash and Mahapatra, (2015). Adaptive terminal sliding mode power control of DFIG based wind energy conversion system for stability enhancement. Int. Trans. Electr. Energ. Syst. 2016; 26:750–782. DOI: 10.1002/etep.2105
- Petersson, (2005). Analysis, Modelling and Control of Doubly-Fed Induction Generator for Wind Turbine. PhD thesis, Chalmers University of Technology Sweden.
- Rashmi, Ramanujan and Purushotham, (2015). Permanent Magnet Synchronous Generator Configuration in Wind Turbines Technological status review, survey and market trends. International Journal of Scientific & Engineering Research, Volume 6, Issue 2, February-2015.
- Si and Liu. (2015). Model predictive control for DFIG-based wind power generation under unbalanced network conditions. Paper presented at the Control Conference (CCC), 2015 34th Chinese.
- Song, Li and Jia. (2018). A Novel Direct Torque Control Method Based on Asymmetric Boundary Layer Sliding Mode Control for PMSM. *Energies* 2018, 11, 657; doi:10.3390/en11030657
- Sun, Han and Zhang, (2018). Maximum Wind Power Tracking of Doubly Fed Wind Turbine System Based on Adaptive Gain Second-Order Sliding Mode. Journal of Control Science and Engineering Volume 2018, Article ID 5342971, 11 pages [doi.org/10.1155/2018/5342971](https://doi.org/10.1155/2018/5342971).
- Trivedi, Jadeja and Bhatt. (2015). A Review on Direct Power Control for Applications to Grid Connected PWM Converters. Engineering, Technology & Applied Science Research Vol. 5, No. 4, 2015, 841-849