International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 04 Issue: 02 | Feb -2020 ISSN: 2582-3930

DOUBLY FED INDUCTION GENERATOR BASED WIND POWER SYSTEMS: A REVIEW

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Abstract - Doubly fed induction generators (DFIG) based wind turbine is an emerging technology, which becomes increasingly popular due to its various advantages over fixed speed generator systems. 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, and so on. This study presents an overview and literature survey over past few decades on the different problems associated due to penetration of WT-DFIG in the power system and control aspects of DFIG.

***Key Words*: DFIG, wind power, stability**

1. INTRODUCTION

Wind power is today's fastest growing renewable energy source. The Global Wind Energy Council (GWEC) [1] and Electrical India magazine [2] reported that worldwide installed capacity of wind power reached 293 GW by the end of 2011. India (14550 MW) is in 5th position for installed capacity. China (44733 MW), US (40180 MW), Germany (27215 MW) and Spain (20676 MW) are advanced than India. Present target of India declare that by the end of 2012, installed capacity will be increased 6000 MW. Variable speed operation is introduced to capture the maximum possible energy available from the wind. Due to enormous advantages over the other types of generator, DFIG is recently most popular trend to use for extracting more wind energy with variable speed constant frequency (VSCF).

World's largest sum of electricity generation contributed by non-renewable sources of fuel such as coal, gas and oil. These fuels emit lots of CO2 other harmful gases to the atmosphere and their residues in the water, which raised global warming issues of earth health problems of human and wild-life issues [3].

Electricity demand growth is strongest in developing countries, where demand will climb by over 4% per year over the projected period, which gets more than triple by 2030. Consequently, the electric energy demand in developing countries will rise global electricity share from 27% in 2000 to 43% in 2030 [4].

So many WECS technologies available classified as: fixed speed and variable speed WECS. Fixed speed employed Squirrel Cage Induction Generator (SCIG) as mechanical to electricity conversion element with soft starter technology simple to construct but may affect steady state stability of power system under unbalanced conditions such as gust in wind, voltage dip in the bus bar voltage, and Need a stiff power grid and not tolerated by weak Grid [5].

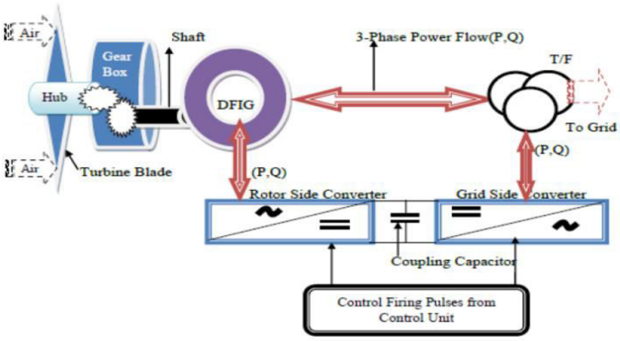

Fig. 1 DFIG with power converter

Variable speed WECS employed mainly two technologies such as SCIG in which Capacitor bank and soft-starter are replaced by a full scale converter. It requires 100% rating of power stability equipment (FACTS for power factor correction) as that of generator rating. It gives still less effective steady state stability measures as constrained by high cost of converter [6-7]. Second technology of variable WECS is Doubly Fed Induction Generator (DFIG) based wind power to electricity conversion element as shown in fig. 1. This technology becomes so much popular and opted by maximum number of countries in the world.

2. Literature Review

Leonhard [8] and P. Vas [9] well explained the vector control techniques used for the independent control of torque and excitation current in the synchronous reference frame. Yamamoto and Motoyushi [10] have shown the technique to decouple control of active and reactive powers of the machine. In this technique used reference frame is fixed to the air-gap flux and rotor side is connected to grid via cycloconverter. The converter design and control techniques are described by Ned Mohan et.al [11]. Pena, Clare and Asher [12] gave the detail design of DFIG using back-to-back PWM voltage source converters in the rotor circuit and also they have validated the system experimentally considering a grid connected system and stand-alone system.

The instantaneous position of the rotor is required with respect to the stator for decoupled control of active and reactive power. In conventional field oriented control schemes, the instantaneous rotor position is estimated by using absolute encoder fitted to the shaft. A high resolution position encoder is more expensive as well as reduces the system reliability. However, in DFIG wind turbine system the encoder mounting is not easy task. The encoder must be mounted in such way that angle between rotor and stator axis can be access directly. The sensor less vector control of the machine. V.T.Ranganathan [13] also implemented a position sensor less algorithm for rotor side field oriented control of the machine.

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Pena [12] used model reference adaptive system (MRAS) to estimate the same. Some techniques are proposed by different researchers to estimate rotor position, rotor currents and torque angle. DFIG based system is dominating in grid connected modern WECS. It has excellent advantages, such as maximum power point tracking (MPPT) capability [12], variable speed constant frequency (VSCF) operation [13] and independently active-reactive power regulation [14]. Since the stator side of DFIG is directly connected to the grid and the rotor side via back-to-back converter, DFIG system is very sensitive to grid faults [15]. Even though if severely symmetrical/asymmetrical fault occurs, the grid voltage dips [15] obviously but wind turbine must have the fault ride through (FRT) [16] capability to continue power supply to grid and return back to normal operation after clearance of the fault.

Therefore, the control strategy must be designed in such way that DFIG can operate not only in normal grid conditions, as well as in faulty grid conditions. There are so many literatures explained FRT with converter protection technology, low voltage ride through [17], voltage-frequency regulations [18], uninterrupted power flow operations under balanced or unbalanced grid faults [19] as well as island operations in the distributed energy generation systems.

However, during this fault it is required to keep the DC-link voltage stable and limit the current fluctuations of the generator side converter (GSC). After removing the fault, GSC operates again in normal conditions. During this operation DC-link voltage fluctuates and so that the rotor current control strategy might be influenced which is undesirable. Again for the high voltage applications the electrolytic capacitor size has to be optimized because of heavy, expensive and unreliability. Some of literature [20]–[22] proposed the improved control strategies [21] such as direct capacitor current control [20] and current injection [22]. But these are not fully sufficient control strategy for desired performance as well as stability.

However, proposed technologies and algorithms are explained in the above literatures so far do not address to all the requirements of VSCF DFIG system. Recently, in order to improve the steady state and transient stability, dynamic performance and power quality of the DFIG system as well as to produce more power output, lots of control strategies have been proposed. Implementation of such control algorithms requires faster real time computations. High-speed digital signal processors (DSP) are recently introduced to overcome such computational burden. DSP based implementation approach has been described in the paper [23]. In this paper [23] the performance of three control strategy namely vector control (VC), direct torque control (DTC) and direct power control (DPC) have been compared. Sliding mode robust control technique has been introduced to reduce the torque fluctuations [24] and maximum power utilization [25], [26] In this strategy parametric uncertainty of the system has been described and also improved vector control strategy has been proposed [27]. Multiple Model Predictive Control algorithms has been suggested [28] for maximum energy extraction from the wind turbine and reduction of drive train torsional torque. Improved hysteresis based current regulator control strategy in vector control has been proposed [29] and compares transient and steady-state performances with the conventional PI based current regulators.

3. EMERGING ISSUES AND THEIR CONTROL MEASURES OF DFIG BASED WECS

The Emerging Issues and their Control of DFIG based WECS are described one by one as follows:

(a) Coordinated control of frequency regulation capability.
A (DFIG)-based WECS not provide frequency response because of the decoupling between the output power and the grid frequency .Power reserve margin also problem for DFIG because of the maximum power point tracking (MPPT) operation. [8] presented a novel frequency regulation by DFIG-based wind turbines to coordinate inertial control, rotor speed control and pitch angle control, under low and high wind speed variations.

(b) Battery Control Operation (BESS)
[9] presented a new based on battery energy storage system (BESS) and tried to reduce the power fluctuations on the grid for uncertain wind conditions and also, compared with an existing control strategies like the maximum power point extraction at unity power factor condition of the DFIG.[10] presented the modified rotor side of DFIG with DC link capacitor is replaced with the BES. The coordinated tuning of the associated controllers using bacterial foraging technique (based on eigen-value) to damp-out power oscillations. Furthermore, an evolutionary iterative particle swarm optimization (PSO) approach for the optimal wind-battery coordination in a power system was proposed in [11], [12].

(c) Stator Current Harmonic Control
[13] proposed a sixth-order resonant circuit to eliminate negative sequence 5th harmonic and positive sequence 7th harmonics currents from fundamental component of stator current. A stator current harmonic control loop is added to the conventional rotor current control loop for harmonic suppression. The affects of voltage harmonics from the grid on the DFIG are also have been discussed in [14]–[17]. Resonant controllers have been widely used in harmonic control and unbalanced control for both DFIG and power converter systems [17]. The use of resonant circuits aims to achieve high bandwidth at certain frequencies and also eliminate current harmonics in the three-phase power converter systems [16]–[20] and the DFIG [17] during grid voltage distortion. In [22]–[24], the resonant controllers are used to keep the current output balanced during a grid voltage imbalance.

(d) Fault Ride Through
A grid fault posed an overload condition to DFIG when it trying to stabilize the wind farm. This would check the fault ride through capability of the DFIG. [26] Proposed the dc-link chopper-controlled braking resistor with the supplementary rotor current (SRC) control of the rotor side converter of the DFIG and series dynamic braking resistor (SDBR) connected to the stator of the DFIG. [27,28] a study focused on stabilizing FSWT without using any FACTS device. A series dynamic braking resistor (SDBR) was used to improve the FRT of large wind farms composed of IGs in [29], while in

[30] the SDBR was connected to the rotor side converter of the DFIG to improve its Fault Ride Through capability.[31]

(e) Regulation of active/reactive power
DFIG is a electromechanical device and is modeled as non-linear system with rotor voltages and blade pitch angle as its inputs, active and reactive powers as its outputs, and aerodynamic and mechanical parameters as its uncertainties. A controller was developed that is capable of maximizing the active power in the maximum power tracking (MPT) mode, regulating the active power in the power regulation (PR) mode for simultaneously adjusting the reactive power to achieve a desired power factor. For MPPT adaptive controls [32] and fuzzy methodologies [33] were proposed despite not knowing the Cp-surface.

(f)Voltage Unbalance Control
[34] Wind energy is often installed in rural, remote areas characterized by weak, unbalanced power transmission grids. Voltage unbalance factor (VUF) is defined as the negative sequence magnitude divided by the positive sequence magnitude. The control topology is fairly standard (based on stator-voltage-oriented *d-q* vector control is used. This orientation can be called grid flux oriented control [35] implemented new rotor current control scheme which consists of a proportional–integral (PI) regulator and a harmonic resonant (R) to suppress 5th and 7th harmonics.

(g) Direct Torque Control
Direct power control (DPC) was based on the principles of direct torque control [36]. The DPC applied to the DFIG power control has been presented in [37]. This strategy calculates the rotor voltage space vector based on stator flux estimated and power errors. An alternative to DPC is power error vector control [38]. This strategy is less complex and obtains results similar to those of direct control of power. A anti-jamming control has been proposed by [39] to improve the controller performance. The predictive control is an alternative control technique that was applied in machine drives and inverters [40]. Some investigations like long-range predictive control [41].

4. RESEARCH GAPS FOUND IN THE LITERATURE

Research gaps found in the above literature are as follows:-

- Need to explore system behavior and control strategies with the simulation models as well as experimentally. Need to enhance the system stability over wide range of rotor speed variations by adding position sensor.
- Need to construct a simulation model to theoretically examining the performance of IG connected to grid not only for voltage fluctuations but also for steady state and transient stability aspects in more fast and efficient manner.
- Need to develop technique measurements of harmonics and to study the effect of harmonics introduced by cyclo converter on the performance of DFIG connected to grid.
- Need to optimize active power requirements of DFIG to enhance the efficiency of the system
- DFIG provide wide control on active, reactive and efficiency but these factors are required to compared on the merge of high cost of power electronics equipment.
- The Dynamic model of DFIG was only limited to theoretical assumptions of sinusoidal mechanical variations, effect on the protection devices were not shown, Need to develop a mathematical model to study nonlinear behavior to predict actual mechanical vibrations and its effect on protection devices.
- Fuzzy logic and neural network based controllers, as well as state-estimation based controllers, could be employed to incorporate the interaction between the various control objectives DFIG -WECS.
- For a variable-speed wind turbine, the control and protection of the converter and generator systems must be included in a model and a detailed model is required.
- For development of wind turbine standard generalized dynamic models to embed in the power system usual numerical tools to be used.
- Robust control is missing as leakage inductance of rotor was neglected in the literature and need to consider the effect of variations in the rotor leakage inductance on the performance of the DFIG under unbalance voltage conditions. Also rebalancing of network voltage after unbalance condition should be explored with control strategy.
- Inappropriate data available and rough observations about load variations cause inaccurate results. Need to develop control strategy to remove uncertainty of compensation capacitance requirements during voltage fluctuations. Need to develop models of DFIG based on variational differential equations.
- To enhance controller response new techniques based on fuzzy or NN need to be implement which gives better
- parametric variation for Robust control.

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