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Performance Analysis of DFIG Wind Turbine

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Abstract: **Wind energy is becoming the most effective renewable energy source mainly because of the growing concerns over carbon emissions and uncertainties in fossil fuel supplies and the government policy impetus. The increasing penetration of wind power in distribution systems may significantly affect VAR compensation and max. Power tracking of the systems, particularly during wind turbine cut-in and cut-off disturbances.**

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.

Keywords: **Wind energy, doubly-fed induction generator- wind turbine, var compensation, ax power tracking characteristics.**

I. INTRODUCTION

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 [1]. According to FatihBirol, Chief Economist, International Energy Agency of the Organization for Economic Cooperation and Development (IEA), world electricity demand is projected to double between 2000 and 2030, growing at an annual rate of 2.4%. This is faster than any other energy demand. Total share of electric energy consumption rises from 18% in 2000 to 22% in 2030. 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[2].In recent years, wind energy has become one of the most economical renewable energy. Hence, wind power could be utilized by mechanically converting it to electrical power using wind turbine ,WT. Various WT concepts have a quick development of wind power. Variable speed operation and direct drive WTs have been the modern developments in the technology of wind energy conversion system, WECS.

Variable-speed operation has many advantages over fixed-speed generation such as increased energy capture, operation at MPPT over a wide range of wind speeds, high power quality, reduced mechanical stresses, aerodynamic noise improved system reliability, and it can provide (10-15) % higher output power and has less mechanical stresses in comparison with the operation at a fixed speed[3][4].

The DFIG wind turbine is a wound-rotor induction generator operated by controlling slip rings or by the power converter interconnected with the grid. There are around thousands of research IEEE activities (Research Publications) on DFIG control aspects during past few decades.

II. DOUBLY - FED INDUCTION GENERATOR (DFIG) WIND TURBINE

The DFIG wind turbine is a wound-rotor induction generator operated by controlling slip rings or by the power converter interconnected with the grid. See Figure1 for the DFIG wind turbine schematic. The AC/DC/AC converter is divided into two components: the rotor-side converter (C_{rotor}) and the grid-side converter (C_{grid}). C_{rotor} and C_{grid} are Voltage-Sourced Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor connected on the DC side acts as the DC voltage source. A coupling inductor L is used to connect C_{grid} to the grid. The three-phase rotor winding is connected to C_{rotor} by slip rings and brushes and the three-phase stator winding is directly connected to the grid. The power captured by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor winding. The control system generates the pitch angle command and the voltage command signals V_r and V_{gc} for C_{rotor} and C_{grid} respectively in order to control the power of the wind turbine, the DC bus voltage and the reactive power or the voltage at the grid[5]

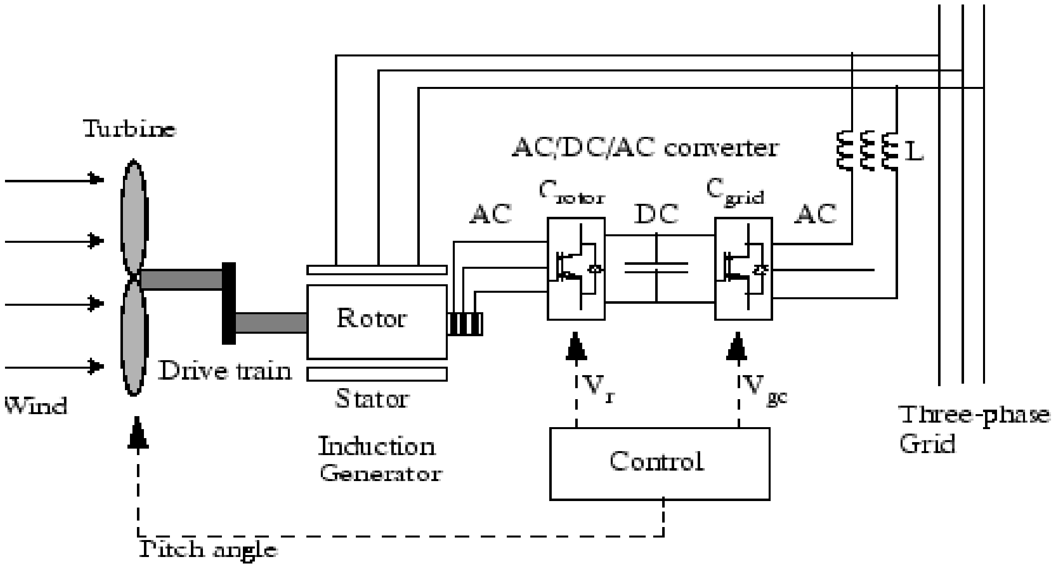

Fig.1: The Doubly-Fed Induction Generator System

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

The Emerging Issues and their Control of DFIG based WECS are shown in the above fig.2 and 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.[6] 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) L:

[7] 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.[8] presented the modified rotor side of DFIG with DC link capacitor is replaced with the BES. The co-ordinate 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 [9][10].

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(c) Stator Current Harmonic Control:

[11] 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 [12]–[13]. Resonant controllers have been widely used in harmonic control and unbalanced control for both DFIG and power converter systems .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 [14] and the DFIG during grid voltage distortion. In [15], 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.

[16] 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. [17] 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[18], while in [19] the SDBR was connected to the rotor side converter of the DFIG to improve its Fault Ride Through capability. A superconducting fault current limiter (SFCL) [20], passive resistance network , and series anti-parellel thyristors connected to the stator side of a grid connected DFIG. [21] Proposed a new control strategy using a dc-chopper inserted into the dc-link circuit of the DFIG and a small value of SDBR connected in series in the stator of the DFIG, the former of which acts as a damping load to suppress the dc-link voltage during a grid fault.

(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 [22], fuzzy methodologies [23] were proposed despite not knowing the Cp-surface. In [24] developed a non-linear controller that simultaneously enables control of the active power in both the MPT and PR modes with aerodynamic and mechanical parameters were known. [25]presented a dynamic model of BDFIG with two machines‘ rotor electromechanically interconnected. The method used to extract maximum power at any given wind speed is to implement maximum power point tracking (MPPT) algorithm based on the various control strategies for the VSR have been discussed in[26].It has been demonstrated in [27] that the proposed BDFIG system can be used for the large off-shore wind energy application with reduced system maintenance cost. [27] proposed a model-based predictive controller for a power control of DFIG and internal mode controller[28] have satisfactory performance when compared with the response of PI, but it is difficult to implement one due to the formulation of a predictive functional controller and the internal mode controller.

Fuzzy based DFIG power control can be realized [23].

(f) Voltage Unbalance Control:

[29] 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 dq vector control is used. This orientation can be called grid flux oriented control[30] 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. The steady-state and transient response of DFIG-based wind power generation system under balanced [31] and unbalanced [32] grid voltage conditions have been well understood. [33] proposed proportional–integral (PI). plus resonant tuned at twice the grid

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frequency current controllers for both grid- and rotor-side converters. For instance, standards IEEE-519–1992 [34] and ER G5/4–1 [35] have, respectively, recommended different practices and requirements for harmonic control in electrical power systems. As indicated in [36] ,the presence of harmonics in the supply system results in torque pulsations and increased copper and iron losses in electrical machines. [37] Presented a feedback/feed forward nonlinear controller for DFIG. The mechanical and electrical parts of the wind turbines are considered separately in most of the current literature: [36,37] considered only the mechanical part, while [38][39] considered only the electrical part, focusing mostly on the DFIGs. [40] Considered both these parts, its controller was designed to maximize wind energy conversion, as opposed to achieving power regulation (i.e., only operate in the MPT mode).

(g) Direct Torque Control:

Direct power control (DPC) was based on the principles of direct torque control. The DPC applied to the DFIG power control has been presented in [41].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 [42]. This strategy is less complex and obtains results similar to those of direct control of power. A anti-jamming control has been proposed by [43] to improve the controller performance.

The predictive control is an alternative control technique that was applied in machine drives and inverters.Some investigations like long-range predictive control general predictive control and model predictive control were applied to the induction motor drives. 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.

The steady-state and transient response of DFIG-based wind power generation system under balanced [43]–[46] and unbalanced [40] grid voltage conditions have been well understood. [41] and [42] proposed proportional–integral (PI) plus resonant tuned at twice the grid frequency current controllers for both grid- and rotor-side converters. For instance, standards IEEE-519–1992 [45] and ER G5/4–1 [66] have, respectively, recommended different practices and requirements for harmonic control in electrical power systems. As indicated in [37] and [38][39], the presence of harmonics in the supply system results in torque pulsations and increased copper and iron losses in electrical machines. [50] presented a feedback/feed forward nonlinear controller for DFIG. The mechanical and electrical parts of the wind turbines are considered separately in most of the current literature.[46] considered only the mechanical part, while [47]considered only the electrical part, focusing mostly on the DFIGs. [48] considered both these parts, its controller was designed to maximize wind energy conversion, as opposed to achieving power regulation (i.e., only operate in the MPT mode),general predictive control and model predictive control were applied to the induction motor drives. principle used in DTC/DPC, have suggested replacing the conventional PI current regulator with a nonlinear predictive current regulator [53].

(h) Dynamic Stability Using FACT Devices:

[54] Proposed a damping controller of the STATCOM is designed by using modal control theory to contribute effective .The analyzed results of stability improvement of power systems using STATCOMs and the damping controller design STATCOMs were presented in [54].System modeling and controller design for fast load voltage regulation and mitigation of voltage flicker using a STATCOM were demonstrated in [53][54]. A new DSTATCOM control algorithm enabling separate control of positive- and negative-sequence currents was proposed in [55]investigated the dynamic performance of a STATCOM and a static synchronous series compensator(SSSC).

(i) MPPT algorithms for a WT with wind speed sensor:

(i).1. Tip Speed Ratio (TSR) technique:

The TSR control method regulates the rotational speed of the generator to maintain an optimal TSR at which power extracted is maximum [56]. The target optimum power extracted from wind turbine can be written as [57]:

$$P_{max} = K_{opt} * \omega_{opt}^3$$

Where, $K_{opt} = 0.5 * A * \left(\frac{r_m}{\lambda_{opt}}\right) * C_{P-max}$

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And, $\omega_{opt} = \frac{\lambda_{opt}}{r_m} * u$

The power for a certain wind speed is maximum at a certain value of rotational speed called optimum rotational speed, ωopt. This optimum rotational speed corresponds to optimum tip speed ratio, λopt. In order to track maximum possible power, the turbine should always operate at λopt. This is achieved by controlling the rotational speed of the WT so that it always rotates at the optimum rotational speed. As shown in Figure 3,for TSR calculation, both the wind speed and turbine speed need to be measured, and the optimal TSR must be given to the controller. The first barrier to implement TSR control is the wind speed measurement, which adds to system cost and presents difficulties in practical implementations. The second barrier is the need to obtain the optimal value of TSR, this value is different from one system to another. This depends on the turbine-generator characteristics results in custom-designed control software tailored for individual wind turbines:

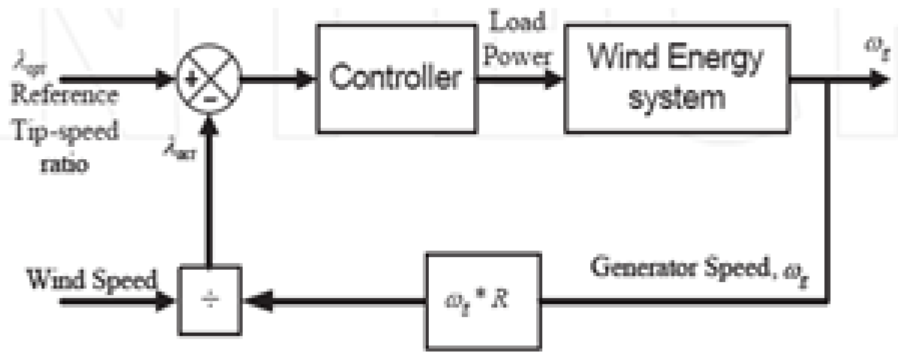

Fig.3 block dig of tip speed ratio control

(i).2. Power Signal Feedback (PSF) control:

In PSF control [56], it is required to have the knowledge of the wind turbine's maximum power curve, and track this curve through its control mechanisms. The maximum power curves need to be obtained via simulations or off-line experiment on individual wind turbines or from the datasheet of WT which makes it difficult to implement with accuracy in practical applications. In this method, reference power is generated using a maximum power data curve or using the mechanical power equation of the wind turbine where wind speed or the rotational speed is used as the input. Figure 4 shows the block diagram of a WECS with PSF controller for maximum power extraction. The PSF control block generates the optimal power command *P*opt which is then applied to the grid side converter control system for maximum power extraction.

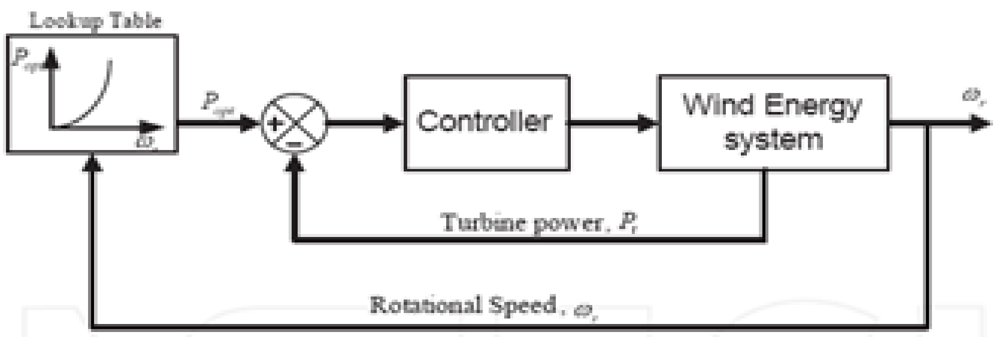

Fig.4 block dig of power signal feedback control

(j) MPPT algorithms for a WT without wind speed sensor:

(j).1. Hill-Climb Searching (HCS):

The HCS [55], control algorithm continuously searches for the peak power of the wind turbine. The maximum power can be extracted from WTG without requiring information about the wind and generator speed.

It can overcome some of the common problems normally associated with the other two methods, TSR and PSF. The tracking algorithm depends on the location of the operating point. According to the changes in power and speed the desired optimum signal has been computed in order to track the point of maximum power.

VI. CONCLUSION

Wind energy is very important non renewable resources of energy. From the above research, it has been shown that with the help of coordinated control of frequency regulation capability method, rotor speed control, pitch angle control can be possible. But with the help of battery control operation, power fluctuation can be reduced. Harmonics currents control can be possible with the help of stator current harmonic control method..Regulation of active and reactive power and hill climb methods are used for maximum power tracking mode.With the help of above methods, maximum power can be achieved.

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