International Journal For Technological Research In Engineering
Volume 3, Issue 7, March-2016 *ISSN (Online): 2347 - 4718*

MODELLING AND SIMULATION OF DOUBLE FEED INDUCTION GENERATOR (DFIG) FOR CONSTANT POWER CONTROL IN WIND POWER PLANT

Krunal Damor[1], Prof.Jignesh Patel[2]
[1]PG Scholar, [2]Assistant Professor, [1,2]Electrical Department, SCET, Saij, Kalol, Gujarat, India

Abstract: Wind turbine generators (WTGs) are usually controlled to generate maximum electrical power from wind under normal wind conditions. With the increasing penetration of wind power into electric power grids, energy storage devices will be required to dynamically match the intermittency of wind energy. To meet the requirements of frequency and active power regulation, energy storage devices will be required to dynamically match the intermittency of wind energy. A novel two-layer constant-power control scheme for a wind farm equipped with doubly-fed induction generator (DFIG) wind turbines. It is connected to the power grid at both stator and rotor terminals. The stator is directly connected to the grid while the rotor is fed through a variable-frequency dc-link-voltage converter, which consists of a rotor-side converter (RSC) and a grid-side .converter .Each DFIG wind turbine is equipped with a super capacitor energy storage system (ESS) and is controlled by the low-layer WTG controllers and coordinated by a high-layer wind-farm supervisory controller (WFSC). The proposed system and control scheme provides a promising solution to help achieve high levels of penetration of wind power into electric power grids.

I. INTRODUCTION

1.1General

Wind energy generation has been noted as the most rapidly growing renewable energy technology. The attention soars towards the sustainable energy sources, in particular the wind energy. This one is considered as the most important and most promising renewable energy sources in terms of development. As wind-power capacity has increased, so has the need for wind power plants to become more active participants in maintaining the operability and power quality of the power grid. As a result, it becomes necessary to require wind power plants to behave as much as possible as conventional power plants .Wind turbine generators (WTG) are usually controlled to generate maximum electrical power from wind under normal wind conditions. However, because of the variations of wind speed, the generated electrical power of a WTG is usually fluctuated. However, it is reasonable to expect that wind power will be capable of becoming a major contributor to the nation's and world's electricity supply over the next three decades. As wind-power capacity has increased, so has the need for wind power plants to become more active participants in maintaining the operability and power quality of the power grid. As a result, it becomes necessary to require wind power plants to behave as much as possible as conventional power plants. In spite of the advantages, wind power has its own shortcomings low energy density requires a large capture unit and its availability varies from time to time. With the development in the present day technologies, research has led to stronger, lighter and more efficient designs of the blades. In recent times, power electronic converters have been widely accepted for the variable speed wind turbine used for the different machines: - wound-rotor induction machines, cage-type induction machines and permanent magnet synchronous machines, different voltage-fed or current-fed converter topologies have been proposed. Usage of doubly-fed induction generator (DFIG) technology allows extracting maximum energy from the winds for low wind speeds by optimizing the turbine speed, while minimizing mechanical stress on the turbine during gusts of wind. However, these studies only focused on control and operation of individual WTGs and did not investigate the issues of WTGs to participate in grid regulation. This project proposes a novel two-layer constant-power control (CPC) scheme for a wind farm equipped with doubly fed induction generator (DFIG) wind turbines, where each WTG is equipped with a super capacitor energy storage system (ESS). The CPC consists of a high-layer wind-farm supervisory controller (WFSC) and multiple low-layer WTG controllers. The high-layer WFSC generates the active-power references for the low-layer WTG controllers of each individual DFIG wind turbine according to the active-power demand from the grid operator. The Doubly-Fed Induction Generator (DFIG) is one of the most frequently deployed large grid-connected wind turbines. Indeed, when compared with the full-scale power converter WT concept, the DFIG offers some advantages, such as reduced inverter and output filter costs due to low rotor- and grid-side power conversion ratings (25%–30%) [1]. However, DFIG-based WTs are very sensitive to grid disturbances, especially to voltage dips. The low-layer WTG controllers then regulate each DFIG wind turbine to generate the desired amount of active power, where the deviations between the available wind energy input and desired active power output are compensated by the ESS. Simulation studies are carried out in MATLAB/SIMULINK Software on a wind farm equipped with 15 DFIG wind turbines to verify the effectiveness of the proposed control scheme.

II. WIND POWER

Wind is abundant almost in any part of the world. Its existence in nature caused by uneven heating on the surface of the earth as well as the earth's rotation means that the wind resources will always be available. The conventional ways of generating electricity using non renewable resources such as coal, natural gas, oil and so on, have great impacts on the environment as it contributes vast quantities of carbon dioxide to the earth's atmosphere which in turn will cause the temperature of the earth's surface to increase, known as the green house effect. Hence, with the advances in science and technology, ways of generating electricity using renewable energy resources such as the wind are developed. Thus, the increasing popularity of green electricity means the demand of electricity produced by using non renewable energy is also increased accordingly.

Features of wind power systems:-

There are some distinctive energy end use features of wind power systems. Most wind power sites are in remote rural, island or marine areas. Energy requirements in such places are distinctive and do not require the high electrical power.

- A power system with mixed quality supplies can be a good match with total energy end use i.e. the supply of cheap variable voltage power for heating and expensive fixed voltage electricity for lights and motors.
- Rural grid systems are likely to be weak (low voltage 33 KV). Interfacing a Wind Energy Conversion System (WECS) in weak grids is difficult and detrimental to the workers' safety.
- There are always periods without wind. Thus, WECS must be linked energy storage or parallel generating system if supplies are to be maintained.

Power from the Wind:-

Kinetic energy from the wind is used to turn the generator inside the wind turbine to produce electricity. There are several factors that contribute to the efficiency of the wind turbine in extracting the power from the wind. Firstly, the wind speed is one of the important factors in determining how much power can be extracted from the wind. This is because the power produced from the wind turbine is a function of the cubed of the wind speed. Thus, if the wind speed doubled, the power produced will be increased by eight times the original power. Then, location of the wind farm plays an important role in order for the wind turbine to extract the most available power form the wind.

The next important factor of the wind turbine is the rotor blade. The rotor blades length of the wind turbine is one of the important aspects of the wind turbine since the power produced from the wind is also proportional to the swept area of the rotor blades i.e. the square of the diameter of the swept area. Hence, by doubling the diameter of the swept area, the power produced will be fourfold increased. It is required for the rotor blades to be strong and light and durable.

As the blade length increases, these qualities of the rotor blades become more elusive. But with the recent advances in fiber glass and carbon-fiber technology, the production of lightweight and strong rotor blades between 20 to 30 meters long is possible. Wind turbines with the size of these rotor blades are capable to produce up to 1 megawatt of power.

The relationship between the power produced by the wind source and the velocity of the wind and the rotor blades swept diameter is shown below.

$$P_{wind} = \frac{\pi}{8} dD^2 v_{wind}^3$$

Thus, in selecting wind turbine available in the market, the best and efficient wind turbine is the one that can make the best use of the available kinetic energy of the wind.

Wind power has the following advantages over the traditional power plants.

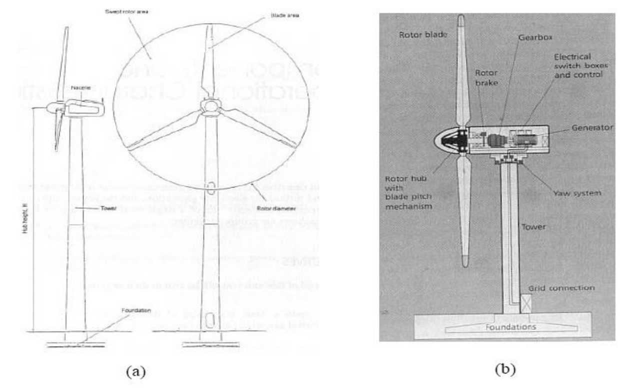
- Improving price competitiveness,
- Modular installation,
- Rapid construction,
- Complementary generation,
- Improved system reliability, and
- Non-polluting.

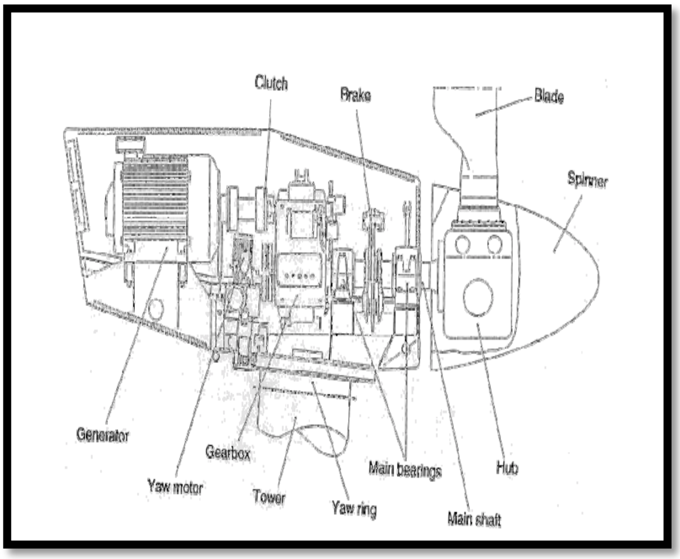
Wind Turbines:-

There are two types of wind turbine in relation to their rotor settings. They are:

- Horizontal-axis rotors, and
- Vertical-axis rotors.

In this report, only the horizontal-axis wind turbine will be discussed since the modelling of the wind driven electric generator is assumed to have the horizontal-axis rotor. The horizontal-axis wind turbine is designed so that the blades rotate in front of the tower with respect to the wind direction i.e. the axis of rotation are parallel to the wind direction. These are generally referred to as upwind rotors. Another type of horizontal axis wind turbine is called downwind rotors which has blades rotating in back of the tower. Nowadays, only the upwind rotors are used in large-scale power generation and in this report, the term .horizontal-axis wind turbine refers to the upwind rotor arrangement. The main components of a wind turbine for electricity generation are the rotor, the transmission system, and the generator, and the yaw and control system. The following figures show the general layout of a typical horizontal-axis wind turbine, different parts of the typical grid-connected wind turbine, and cross-section view of a nacelle of a wind turbine.





(c)

Figs: (a) Main Components of Horizontal-axis Wind Turbine (b) Cross-section of a Typical Grid-connected Wind Turbine (c) Cross-section of a Nacelle in A Grid-connected Wind Turbine

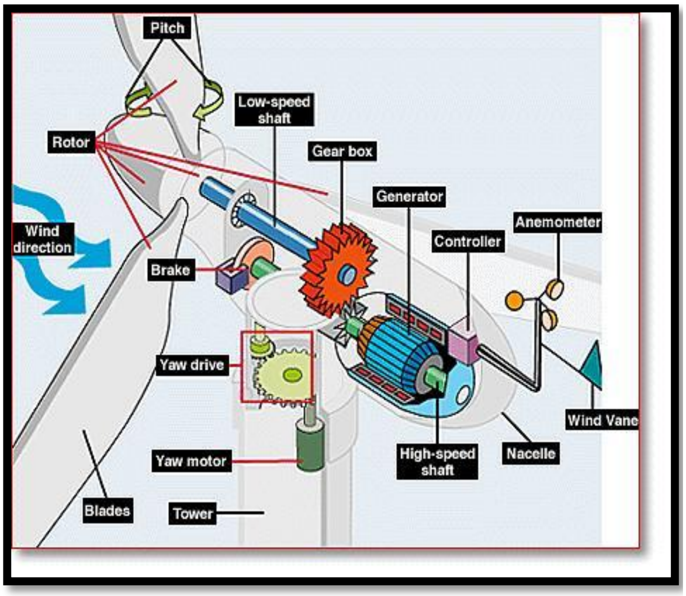


Fig-The main components of a wind turbine can be classified as I) Tower II) Rotor system III) Generator IV) Yaw V) Control system and VI) Braking and transmission system

Induction generator:

An induction generator is a type of electrical generator that is mechanically and electrically similar to a poly phase induction motor. Induction generators produce electrical power when their shaft is rotated faster than the synchronous frequency of the equivalent induction motor. Induction generators are often used in wind turbines and some micro hydro installations due to their ability to produce useful power at varying rotor speeds. Induction generators are mechanically and electrically simpler than other generator types. They are also more rugged, requiring no brushes or commutators. Induction generators are not self-exciting, meaning they require an external supply to produce a rotating magnetic flux. The external supply can be supplied from the electrical grid or from the generator itself, once it starts producing power. The rotating magnetic flux from the stator induces currents in the rotor, which also produces a magnetic field. If the rotor turns slower than the rate of the rotating flux, the machine acts like an induction motor. If the rotor is turned faster, it acts like a generator, producing power at the synchronous frequency.

Why Induction Generator:-

Induction generator is commonly used in the wind turbine electric generation due to its reduced unit cost, brushless rotor construction, ruggedness, and ease of Maintenance. Moreover, induction generators have several characteristics over the synchronous generator. The speed of the asynchronous generator will vary according to the turning force (moment, or torque) applied to it. In real life, the difference between the rotational speed at peak power and at idle is very small approximately 1 percent. This is commonly referred as the generator's slip which is the difference between the synchronous speed of the induction generator and the actual speed of the rotor.

$$\text{slip (s)} = n_s - n$$

This speed difference is a very important variable for the induction machine. The term slip is used because it describes what an observer riding with the stator field sees looking at the rotor which appears to be slipping backward [35]. A more useful form of the slip quantity results when it is expressed on a per unit basis using synchronous speed as the reference. The expression of the slip in per unit is shown below.

$$s = \frac{n_s - n_r}{n_s}$$

A four-pole, 50 Hz generator will run idle at 1500 rpm according to the following formula.

$$n_s = \frac{120 f}{p}$$

If the generator is producing its maximum power, it will be running at 1515 rpm. A useful mechanical property of the generator is that it will increase or decrease its speed slightly if the torque varies and hence will be less tear and wear on the gearbox as well as in the system. This is one of the important reasons to use asynchronous (induction) generator compared to a synchronous generator on a wind turbine.

Induction Machine Analysis

The following figure shows the torque vs speed characteristic of typical squirrel cage induction machine.

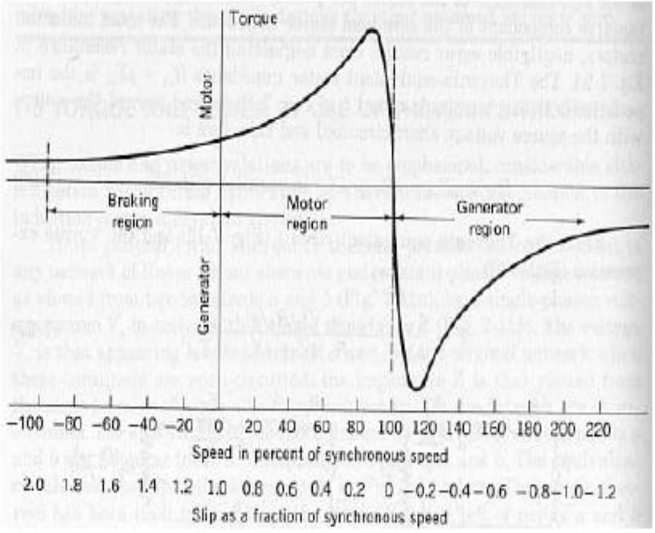


Fig: Torque vs. Speed Characteristics of Squirrel-cage Induction Generator

In the figure, it can be seen that when the induction machine is running at Synchronous speed at the point where the slip is zero i.e. the rotor is spinning at the same speed as the rotating magnetic field of the stator, the torque of the machine is zero. If the induction machine is to be operated as a motor, the machine is to operated just below its synchronous speed. On the other hand, if the induction machine is to be operated as a generator, its stator terminals should be connected to a constant-frequency voltage source and its rotor is driven above synchronous speed (s<0) by a prime mover such as the wind turbine shaft. The source fixes the synchronous speed and supplies the reactive power input required exciting the air gap magnetic field and hence the slip is negative.

The following figure shows the per-phase equivalent circuit of the induction machine.

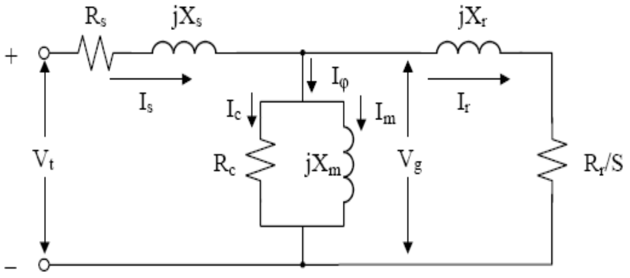


Fig: Per-Phase Equivalent Circuit of An Induction Machine

In this project, star-connected induction machine is evaluated. All the calculations are in per-phase values. Hence, for a star-connected stator:

$$V_{ph} = \frac{V_{line}}{\sqrt{3}} ; I_{ph} = I_{line}$$

In order to analyze the behavior of an induction generator, the operation of an Induction motor must be fully understood. Once, the equivalent circuit parameters have been obtained, the performance of an induction motor is easy to determine. As shown in Fig, the total power Pg transferred across the air gap from the stator is

$$P_{ag} = I_r^2 \frac{R_r}{s}$$

And it is evident from figure 3 that the total rotor loss Prloss is

$$P_{rloss} = I_r^2 R_r$$

Therefore, the internal mechanical power developed by the motor is

$$P_d = P_{ag} - P_{rloss} = I_r^2 \frac{R_r}{s} - I_r^2 R_r = I_r^2 R_r \left(\frac{1}{s} - 1 \right) = I_r^2 R_r \left(\frac{1-s}{s} \right)$$

From the power point of view, the equivalent circuit of figure 3 can be rearranged to the following figure, where the mechanical power per stator phase is equal to the power absorbed by the resistance R2(1-s)/s.

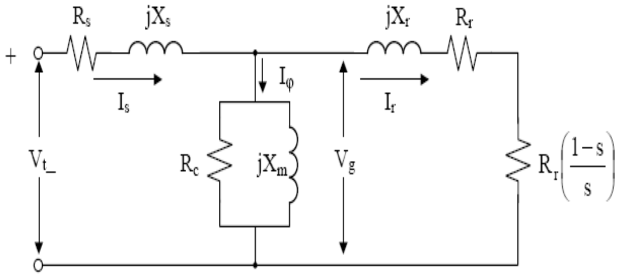


Fig: Alternative Form for Per-Phase Equivalent Circuit

The analysis of an induction motor is also facilitated by using the power flow diagram as shown in the following figure in conjunction with the equivalent circuit.

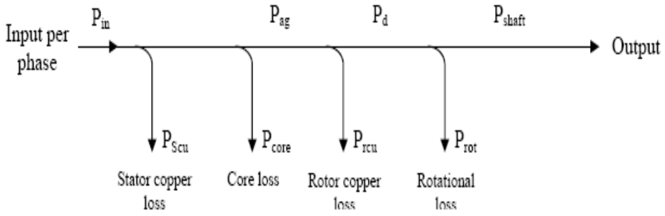


Fig: Power Flow Diagram

Where,

$$P_{ag} = P_{in} - P_{Scu} - P_{core}$$

$$P_d = P_{ag} - P_{core}$$

$$P_{out} = P_{shaft} = P_d - P_{rot}$$

The parameters of an induction generator can be determined by using the no-load test and block rotor test (The steps in calculating the parameters and the test results obtained from a 440V, 4.6A, 2.2kW induction motor).

III. INTRODUCTION OF DFIG

A. DOUBLY-FED ELECTRIC MACHINE

Doubly-fed electric machines are electric motors or electric generators that have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and electrical system. Doubly-fed machines are useful in applications that require varying speed of the machine's shaft for a fixed power system frequency.

B. Classification

Electric machines are either Singly-Fed with one winding set that actively participates in the energy conversion process or Doubly-Fed with two active winding sets. The wound-rotor induction machine and the field-excited synchronous machine are singly-fed machines because only one winding set actively participates in the energy conversion process.

Examples of doubly-fed electric machines are the wound-rotor doubly-fed electric machine, the brushless wound-rotor doubly-fed electric machine, and the brushless doubly-fed induction electric machines.

C. Features of doubly fed machines

The wound-rotor doubly-fed electric machine is the only electric machine that operates with rated torque to twice synchronous speed for a given frequency of excitation (i.e., 7200 rpm @ 60 Hz and one pole-pair versus 3600 rpm for singly-fed electric machines). Higher speed with a given frequency of excitation gives lower cost, higher efficiency, and higher power density. In concept, any electric machine can be converted to a wound-rotor doubly-fed electric motor or generator by changing the rotor assembly to a multiphase wound rotor assembly of equal stator winding set rating. If the rotor winding set can transfer power to the electrical system, the conversion result is a wound-rotor doubly-fed electric motor or generator with twice the speed and power as the original singly-fed electric machine. The resulting dual-ported transformer circuit topology allows very high torque current without core saturation, all by electronically controlling half or less of the total motor power for full variable speed control.

In practice, the classical wound-rotor doubly-fed "induction" electric motor or generator system has known issues of instability, high maintenance and inefficiency of an integral multiphase slip-ring assembly, and discontinuity about synchronous speed where induction ceases to exist. A practical wound-rotor doubly-fed electric machine system that does not rely exclusively on asynchronous (i.e., induction) principles while symmetrically motoring or generating over its entire speed range has never materialized from the electric machine establishment, despite years of research to find an evolutionary brushless, synchronous, and stable control technology.

Consequently, the wound-rotor doubly-fed induction electric machine has been forced into antiquity, except in large installations where efficiency and cost are critical over a limited speed range, such as wind turbines. This may change with recent Brushless Wound-Rotor Doubly-Fed Electric Machine technology development. As do all electromagnetic electric machines, doubly fed machines need torque current to produce the torque. Because there are no permanent magnets in the doubly fed machine, magnetizing current is also needed to produce magnetic flux. Magnetizing current and torque current are orthogonal vectors and do not add directly. Since the magnetizing current is much smaller than the torque current, it is only significant in the efficiency of the machine at very low torque.

Like wound rotor synchronous machines, the magnetic flux can be produced by the stator current, rotor current or by the combination of the both. For example, if all magnetizing current is supplied by the rotor windings, the stator will only have torque current and so unity power factor. At synchronous speed the rotor current has to be DC, as in ordinary synchronous machines. If the shaft speed is above or below synchronous speed, the rotor current must be AC at the slip frequency. Reactive power is used in the rotor winding when it is used to magnetize the machine in non-synchronous operation. Rotor current is also needed to produce torque in addition to magnetization. Thus active power is present in the rotor in addition to reactive power.

Double fed induction GENERATOR (dfig):-

DFIG is an abbreviation for Double Fed Induction Generator, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip ring assembly (see brushless doubly-fed electric machines), but there are problems with efficiency, cost and size. A better alternative is a brushless wound-rotor doubly-fed electric machine.

Principle of a Double Fed Induction Generator connected to a wind turbine

The principle of the DFIG is that rotor windings are connected to the grid via slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents. Thus rotor frequency can freely differ from the grid frequency (50 or 60 Hz). By using the converter to control the rotor currents, it is possible to adjust the active and reactive power fed to the grid from the stator independently of the generator's turning speed. The control principle used is either the two-axis current vector control or direct torque control (DTC). DTC has turned out to have better stability than current vector control especially when high reactive currents are required from the generator.

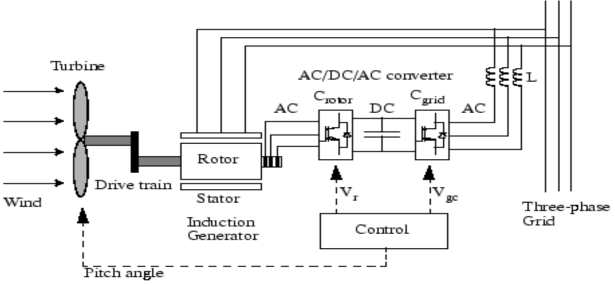


Fig-Operating Principle of the Wind Turbine Doubly-Fed Induction Generator

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 ± 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 currents or voltages are detected. In order to be able to continue the operation as quickly as possible an active crowbar has to be used. The active crowbar can remove the rotor short in a controlled way and thus the rotor side converter can be started only after 20-60 ms from the start of the grid disturbance. Thus it is possible to generate reactive current to the grid during the rest of the voltage dip and in this way help the grid to recover from the fault.

A doubly fed induction machine is a wound-rotor doubly-fed electric machine and has several advantages over a conventional induction machine in wind power applications. First, as the rotor circuit is controlled by a power electronics converter, the induction generator is able to both import and export reactive power. This has important consequences for power system stability and allows the machine to support the grid during severe voltage disturbances (low voltage ride through, LVRT).

Second, the control of the rotor voltages and currents enables the induction machine to remain synchronized with the grid while the wind turbine speed varies. A variable speed wind turbine utilizes the available wind resource more efficiently than a fixed speed wind turbine, especially during light wind conditions. Third, the cost of the converter is low when compared with other variable speed solutions because only a fraction of the mechanical power, typically 25-30 %, is fed to the grid through the converter, the rest being fed to grid directly from the stator. The efficiency of the DFIG is very good for the same reason.

System Model:

The electrical model for the system is developed using dynamic phasors or complex space vectors in the anachronously rotating – reference frame. An illustration of the axes conventions the default convention assumed here aligns the -axis with the positive real axis and the -axis with the negative imaginary axis, and the complex vector. In certain instances it is convenient to locate the real and imaginary axes aligned with a particular complex vector, for instance , in which case the axes are designated and respectively, and the real and (negative) imaginary components with respect to the reference are designated and , a respectively.

The following simplifying assumptions are made in the development of the model.

1) The iron losses, mechanical and power converter losses are negligible.

2) The magnetic circuit of the machine can be represented by linear model.

3) The entire mechanical system can be modeled using a lumped inertia parameter referred to the electrical angle and speed of the induction generator.

4) The power converters can be modeled using state-space averaged representation to represent their low frequency dynamics.

5) The wind farm collection network to PCC is electrically stiff. The conventional DFIG T circuit is transformed into an equivalent circuit

The system equivalent circuit models under these assumptions the complete set of nonlinear state equations are

$$\frac{d\underline{\lambda}_s}{dt} = -\underline{\lambda}_s\left(\frac{R_s}{L_s} + j\omega_e\right) + \underline{i}_R R_s + \underline{v}_f + \underline{v}_i$$

$$\frac{d\underline{i}_R}{dt} = \frac{1}{L_L}\Big[-\underline{i}_R\left(R_R + R_s + j\omega_{sl}L_L\right)\dots$$

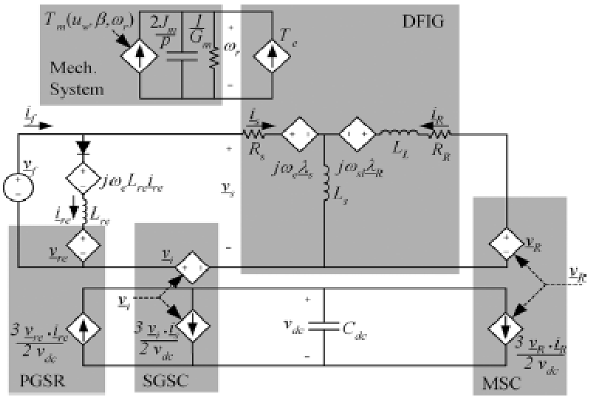
$$+\underline{\lambda}_s\left(\frac{R_s}{L_s} + j\omega_r\right) + \underline{v}_R - \left(\underline{v}_f + \underline{v}_i\right)\Big]$$

$$\frac{d\underline{i}_{re}}{dt} = u(\underline{v}_f - \underline{v}_{re})\left(\frac{\underline{v}_{re} - \underline{v}_f}{L_{re}} - j\omega_e\underline{i}_{re}\right)$$

$$\frac{dv_{dc}}{dt} = \frac{-3}{2v_{dc}C_{dc}}\left[\underline{v}_i \cdot \left(\frac{\underline{\lambda}_s}{L_s} - \underline{i}_R\right) - \underline{v}_{re} \cdot \underline{i}_{re} + \underline{v}_R \cdot \underline{i}_R\right]$$

$$\frac{d\omega_r}{dt} = \frac{p}{2J_m}\left[\frac{3p\ \underline{\lambda}_s \times \underline{i}_R|}{4} + T_m - \frac{2\omega_r}{pG_m}\right]$$

where $u(\cdot)$ is the unit step function.

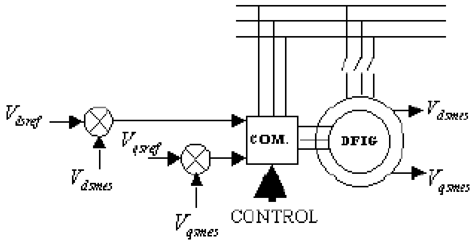


The complex vector dynamic state equations are used form the evaluation of steady state properties and the development of control laws. The dynamic states of the system include the stator flux, , rotor current , rectifier current , dc link voltage, , and rotor speed, . Controllable inputs to the system include the complex voltage vectors for the MSC and SGSC, and respectively.

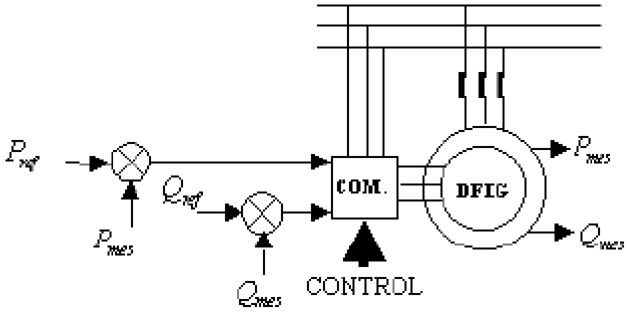
Since the PGSR is a passive network, its conduction state is determined by the state of the diode which conducts when the voltage is greater than. The mechanical power generated at the wind turbine shaft is proportional to the coefficient of performance and the cube of the wind speed. The mechanical torque production due to wind energy capture can be throttled via the blade pitch actuators.

DFIG CONTROL:

When the DFIG is connected to a network, connection must be done in three steps which are presented below the first step is the regulation of the statoric voltages with the network voltages as reference the second step is the stator connection to this network. As the voltages of the two devices are synchronized, this connection can be done without problem. Once this connection is achieved, the third step, which constitutes the topic of this paper, is the power regulation between the stator and the network.



First step



Third step

Fig-Control System of DFIG

IV. MODELLING AND SIMULATION

A. DFIG WIND TURBINE WITH ENERGY STORAGE

Fig. shows the basic configuration of a DFIG wind turbine equipped with a super capacitor-based ESS. The low speed wind turbine drives a high-speed DFIG through a gearbox. The DFIG is a wound-rotor induction machine. It is connected to the power grid at both stator and rotor terminals. The stator is directly connected to the grid while the rotor is fed through a variable-frequency dc-link-voltage converter, which consists of a rotor-side converter (RSC) and a grid-side converter (GSC) and usually has a rating of a fraction (25%– 30%) of the DFIG nominal power. As a consequence, the WTG can operate with the rotational speed in a range of ±25%–30% around the synchronous speed, and its active and reactive powers can be controlled independently. In this work, an ESS consisting of a super capacitor bank and a two-quadrant dc/dc converter is connected to the dc link of the DFIG converters. The ESS serves as either a source or a sink of active power, and therefore, contributes to control the generated active power of the WTG.

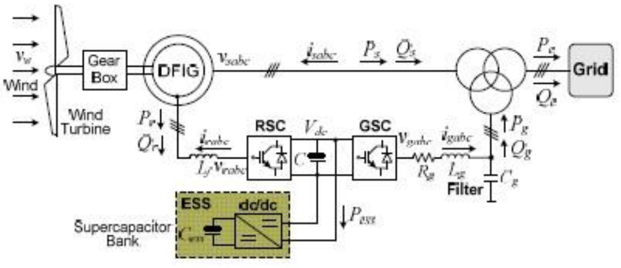


Fig. 1. Configuration of a DFIG wind turbine equipped with a supercapacitor ESS connected to a power grid.

B. WIND FARM MODEL

Fig. shows the configuration of the wind farm used in this work. It consists of 15 DFIG wind turbines of 3.6 MW power capacities each [9]-[10]. The total power capacity of the wind farm is 54 MW. Each DFIG wind turbine is connected to the internal network of the wind farm through a 4.16/34.5-kV voltage step-up transformer.

The high-voltage terminals of all transformers in the wind farm are connected by 34.5-kV power cables to form the internal network of the wind farm. The entire wind farm is connected to the utility power grid through a 34.5/138-kV voltage step-up transformer at the point of common coupling (PCC) to supply active and reactive powers of P and Q, respectively. In this work, the power grid is represented by an infinite source.

Fig 4.2: Simulink model of DFIG wind turbine without any control strategies and energy storage system. Power generated from all the DFIG wind turbine is supply to the transmission line. In the transmission line voltage is 575V. This 575 V is supply to the step up transformer. This transformer is step up to 25 KV. This 25 KV voltage is supply to the 30 KM long transmission line. After transmission line voltage is given to the step up transformer. Between transformer and 30 km transmission line grounding transformer is connected.

Grounding transformer is connected to the three line transmission line for provide a relatively low-impedance path to ground, thereby maintaining the system neutral at or near ground potential. Grounding transformer is also used to limit the magnitude of transient overvoltage when restriking ground faults. It's also providing a source of ground fault current during line-to-ground faults.

After this grounding transformer voltage is supply to the step up transformer. Step up transformer is step up voltage from 25 KV to 125 KV. In this transmission line three phase mutual inductance is connected, this power is then supply to the load side to the transmission line.

Fig 4.2 shows DFIG wind farm without providing any control strategies and energy storage system. So, there are chances of fluctuation in electrical quantities. Fig 5.4 shows wind speed profile of WTG. Wind turbine speeds at all turbines are varying. The variation in wind turbine speed cause fluctuation in electrical quantities.

Fig 4.3 shows DFIG turbine power output. From fig 5.5, there are fluctuations in output of turbine power. So, we can say that without any implement control strategies and energy storage system there are lots of fluctuation in electrical quantities of DFIG wind turbine.

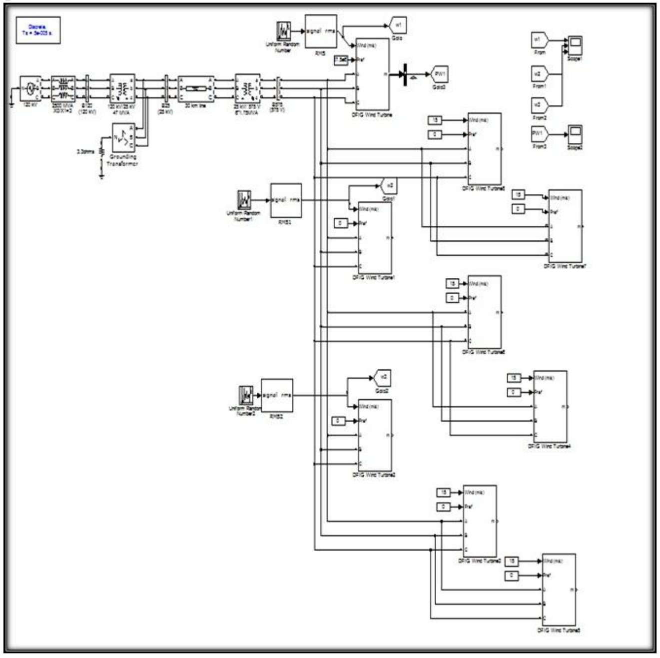


Fig 4.2.: Simulink model of DFIG wind turbine without any control strategies and energy storage system

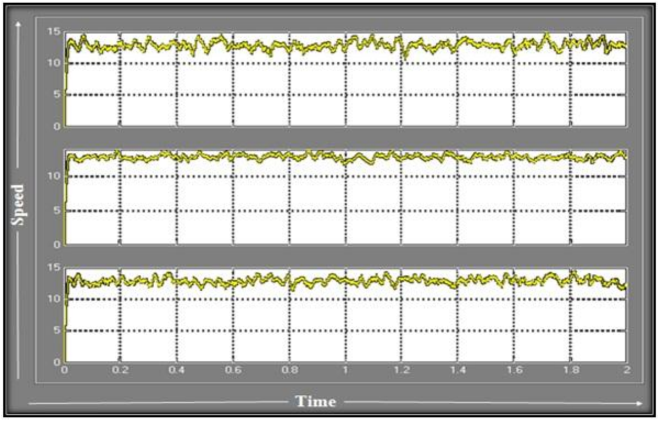


Fig 4.3: wind speeds of turbines

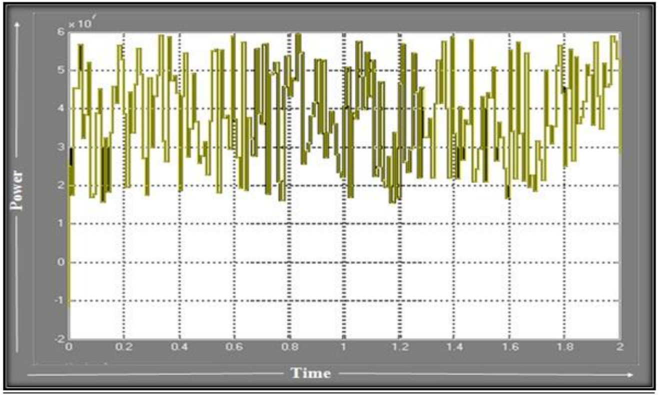


Fig 4.4: DFIG wind turbine power

C. SIMULATION WITH DFIG CONTROL STATEGIES

Grid side converter is connected with inductive load because generator we have used is inductive type so, there are changes in voltage occur due to inductance. Now, grid side converter is connected to the grid via inductive load. Grid side converter is convert grid side voltage from AC to DC voltage. Now, rotor side voltage compare with grid side voltage, there are difference in voltage is produce. This difference is mitigating by energy storage system.

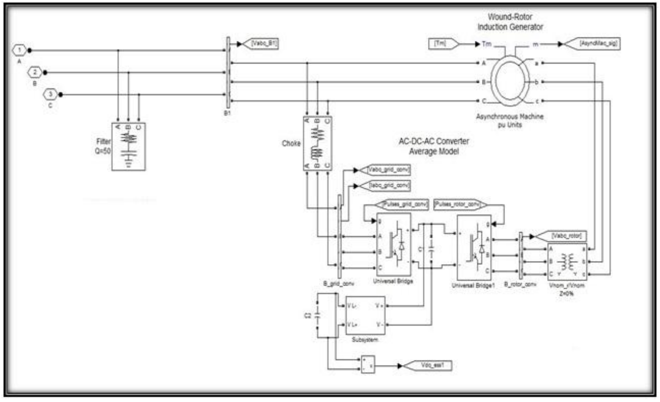


Fig 4.5: Converter control system

In energy storage system capacitor bank is used. With the help of PI controller we can supply voltage to the system if rotor side voltage is less than grid side voltage or absorb voltage from the system if rotor side voltage is more than the grid side voltage. This voltage is supply to the inverter. It's convert DC voltage to the AC voltage. This AC voltage is supply to the transmission line. In transmission line filter is connected to mitigate harmonics present in power.

In the rotor side converter and grid side converter switching operation is done by IGBT / Diode. This switching operation is controlled by wind turbine control. Wind turbine control generates pulses to control switching operation.

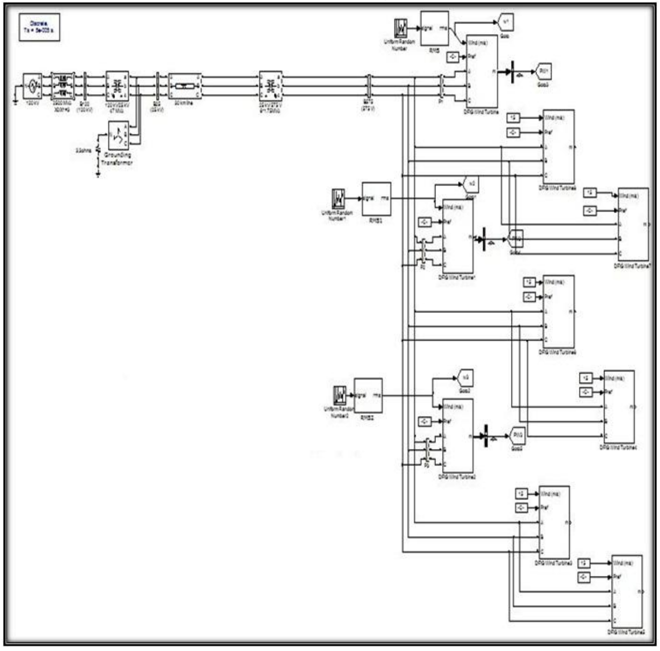


Fig 4.6: Simulink model of DFIG wind turbine with control strategies and energy storage system

D. SIMULATION RESULTS

Simulation studies carried out to verify performance of control strategies under various conditions. There are some results of simulation shown.

WIND SPEED

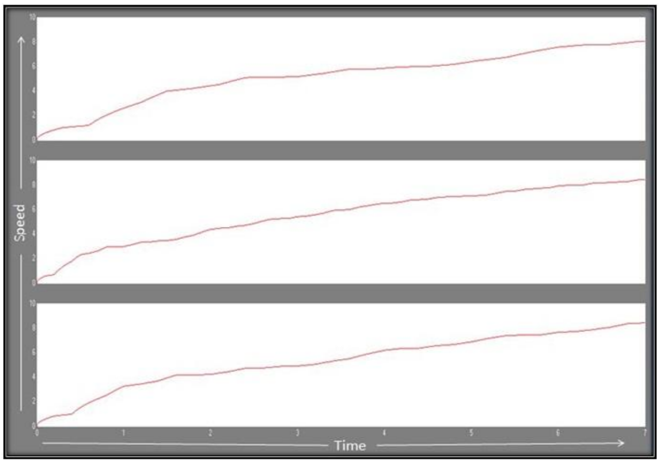


Fig 4.7: Wind speed of wind turbine 1, 2 & 3

Fig 4.7 shows the wind speed profile applied to wind turbine 1, wind turbine 2 and wind turbine 3. The wind speed across wind turbine generator in a range of 4 m/s to 12 m/s. mean value of wind speed across wind generator is 12m/s.

E. VOLTAGE AT ENERGY STORAGE SYSTEM

Voltage across energy storage system is shown in fig 4.8 which indicate voltage between rotor side converter and grid side converter.

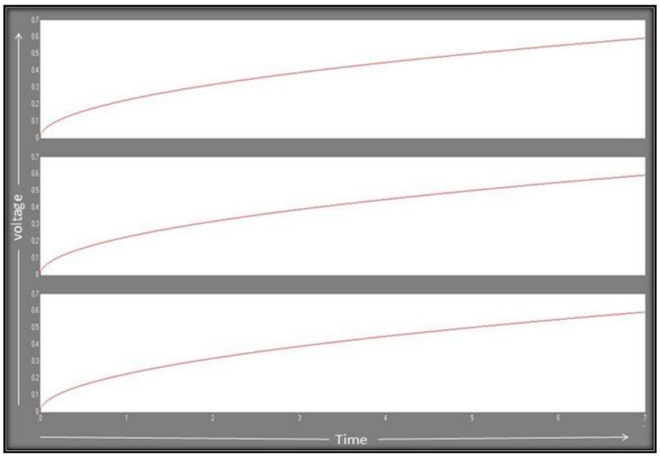


Fig 4.8: Voltage at energy storage system

F. CONSTANT POWER CONTROL DURING VARIABLE WIND SPEE

Fig 4-8, 9 &10 shows active power and reactive power PQ at wind turbine PW, active power at wind turbine and grid side control power Pg. from fig we can see rotor side active power and grid side active power are not actually constant but, with the help of energy storage system we can make power constant and reduce difference between rotor side active power and grid side active power.

Fig 4.9 shows total stator side power and grid side power of all WTG which is 35MW. With the help of proposed control strategies variation in stator side power can be compensated by variation in the grid side power.

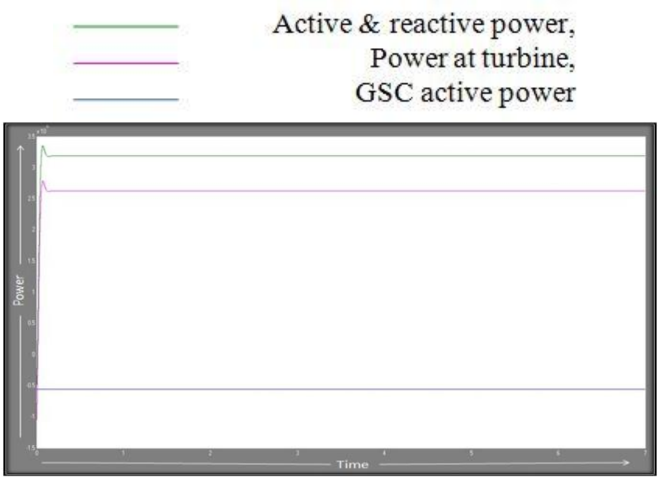


Fig 4.9: Wind Turbine 1 - active & reactive power, power at wind turbine, GSC active power

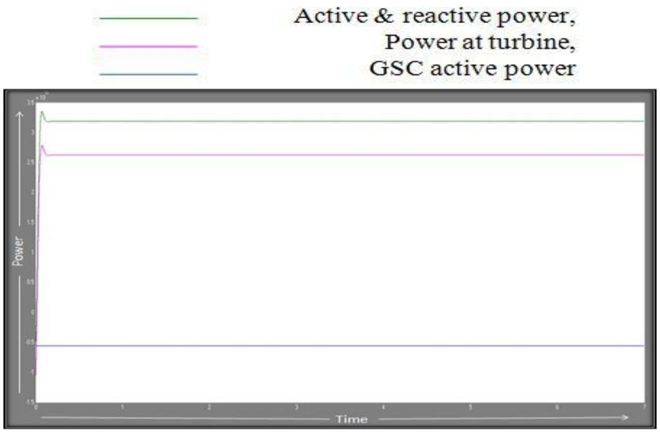


Fig 4.10: Wind Turbine 2 - active & reactive power, power at wind turbine, GSC active power

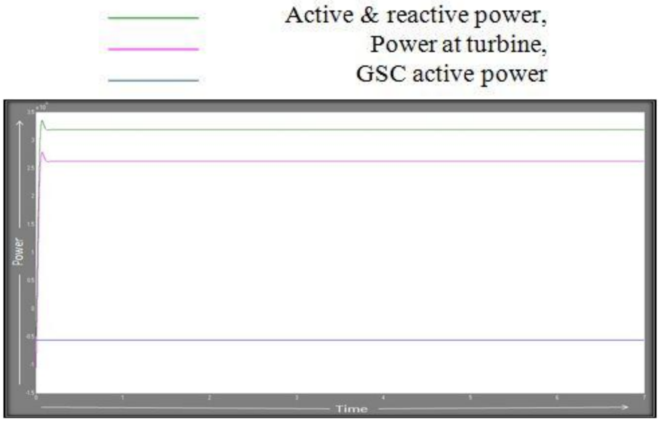


Fig 4.11: Wind Turbine 3 - active & reactive power, power at wind turbine, GSC active power

V. CONCLUSION

With the increasing penetration of wind power, it is necessary to participate of WTG in the grid power supply as well as supply active power for control power flow. We can see from the some output of WTG without any control strategies, there are fluctuations in speed of rotor and output power. After applying the PLL control Strategy and rotor and grid side converter control, we can generate the constant output power at the DFIG generation side. The value of active and reactive power will become constant using DFIG control and the value of D.C voltage at converter control side also become constant.

REFERENCES

[1] Liyan Qu, Wei Qiao,“ Constant Power Control of DFIG Wind Turbines With Supercapacitor Energy Storage”, IEEE TRANSACTIONS ON INDUSTRY APPLICATION, volume:47 Issue:1 ©2011 IEEE.

[2] Marwa Ezzat, Mohamed Benbouzid, S.M. Muyeen and Lennart Harnefors, “Low-Voltage Ride-Through Techniques for DFIG-Based Wind Turbines:State-of-the-Art Review and Future Trends’’,IEEE Harnefors is with ABB, Corporate Research Västerås, Sweden.

[3] Zaijun Wu , Chanxia Zhu and Minqiang Hu “Improved Control Strategy for DFIG Wind Turbines for Low Voltage Ride Through’’, Energies 2013, 6,1181-1197; doi: 10.3390/en6031181, 25 February 2013.

[4] Mr. Subir Datta, Mr. Ksh. Robert Singh, Mr. Subhasish Deb, “Enhancement of Fault Ride through Capability of Doubly Fed Induction Generator Based Wind Energy Conversion System”, International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682 Vol.28, No.28, August 2014.

[5] R. A. Ibrahim, M.S. Hamad, Y.G. Dessouky, B.W. Williams, “A Review on Recent Low Voltage Ride-Through Solutions of Wind Farm for Permanent Magnet Synchronous Generator”, International Journal of Electrical And Electronics Research ISSN 2348-6988 (online) Vol. 3, Issue 2, pp: (256-263), Month: April - June 2015.

[6] Himanshu Verma, Jaimala Gambhir, Sachin Goyal “Energy Storage: A Review”, International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-3, Issue-1, and June 2013.

[7] Guohong Wu, Yutaka Yoshida, Tamotsu Minakawa, “Mitigation of Wind Power Fluctuation by Combined Use of Energy Storages with Different Response Characteristics”, Science Direct ICSGCE 2011: 27–30 September 2011, Chengdu, China.

[8] A.H.M.A.Rahim, S.A. Al-Baiyat, “An Adaptive Neural Network Based Energy Storage Control for Operation Enhancement of a Multi-Generator AC and Wind Power System” Australian Journal of Basic and Applied Sciences, 7(6): 211-222, 2013 ISSN 1991-8178.

[9] S. M. Muyeen, Member, IEEE, Rion Takahashi, Member, IEEE, Toshiaki Murata, and Junji Tamura, Senior Member, IEEE “A Variable Speed Wind Turbine Control Strategy to Meet Wind Farm Grid Code Requirements”, IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 25, NO. 1, FEBRUARY 2010.

[10] Yufei Tang, Student Member, IEEE, Haibo He, Senior Member, IEEE, Jinyu Wen, Member, IEEE, and Ju Liu, Student Member, IEEE, “Power System Stability Control for a Wind Farm Based on Adaptive Dynamic Programming”, IEEE TRANSACTIONS ON SMART GRID, VOL. 6, NO. 1, JANUARY 2015.

[11] Sneha Patil1, D. S. Bankar, “Enhancement of Fault Ride through of DFIG Based Wind Energy Conversion System with the Application of SMES”, International Journal of Emerging Technology and Advanced Engineering, (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4,Issue 5, May 2014)

[12] Heng Nian, Member, IEEE, and Yipeng Song “Direct Power Control of Doubly Fed Induction Generator under Distorted Grid Voltage”, IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 29, NO. 2, FEBRUARY 2014.

[13] Dao Zhou, Student Member, IEEE, Frede Blaabjerg, Fellow, IEEE, Mogens Lau, and Michael Tønnes “Optimized Reactive Power Flow of DFIG Power Converters for Better Reliability Performance Considering Grid Codes”, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 62, NO. 3 MARCH 2015.

WEBSITE

[1] www.mnre.gov.in