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MODELING AND SIMULATION OF ENERGY STORAGE BASED DFIG SYSTEM FOR CONSTANT POWER MANAGEMENT IN WIND POWER PLANT

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Abstract: In the modern times the wind power plant / energy has been one of the most popular renewable energy source. It is also an very useful and sustainable energy source for power generation. 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. In DFIG wind turbine stator and rotor are directly connected to the grid. 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 is help to control power and help to achieving high penetration of wind power in to electrical grid.

I. INRODUCTION

1.1 GENERAL

In the modern times the wind power plant / energy has been one of the most popular renewable energy source. It is also an very useful and sustainable energy source for power generation. So, it is very popular and important renewable energy source after the solar energy. So, due to these kind of various feature the wind power plant become popular and useful for grid integration with continuous power feeding to the grid put for achieving this function it is necessary for us to generate constant power to feed into the grid. . These are several problems are occurred due to which the constant power generation is not possible like wind speed variation, generation of electrical power from wind turbine generation is fluctuated etc. In the recent time wind power plant covers 1 to 2% market of energy source in U.S. From the WTG, we expect that they provide continuous constant power to the grid and increase the role of overall energy market of world that’s why we can expect constant active power to grid, grid frequency regulation etc. As the role and capacity of wind power plant increase, we expect that wind power behave as a conventional power plant. As we discuss about the advantage of wind power plants, it has also some drawbacks like the variation in wind speed according to time. Due to some advancement in technology in latest time these more efficient, lights in weight, strong bladder are design for wind power plant. These are also very useful power electronics converter has been established for different variable speed wind turbines. This type of variable speed wind turbines are used for different machines like wound rotor I.M., squirrel cage type I.M., PMMC type synchronous machine etc. Use of double feed induction generation(DFIG) allows us to utilize maximum energy from the wind. It is use for low wind speed with the help of turbine speed. With the help of DFIG we can minimize the mechanical stress on the wind turbine. we proposed the constant power control mechanism for a wind power plant operated on DFIG with super capacitor storage system. Here for constant power control mechanism these are two controller used Wind farm supervisory controller and Multiple low layer WTG controller. In this system high layer WFSC controller generates active power reference for low layer WTG controllers. The DFIG is very popular and most frequently applicable for large grid connected wind turbines. Compare to other system DFIG provides following advantages of reduce inverter and output filter cost due to the use of low ratings at rotor and grid side power conversion. DFIG based control turbine is very useful against voltage dips in the system. The lower layer WTG controller is easily regulate the DFIG operation to generate required value of active power. In this proposed system the difference between input and output is mitigated by energy storage system.

II. WIND POWER

Wind is available in all over world and it is available or its existence is due to the unrequired heating on the earth surface and also due to the earth’s rotation. The normally methods which is used for electricity generation is using oil, gas, coal etc. But, the main drawback of this system is this system is this type of conventional system of power plant produce pollution in environment. Due to these effects like pollution, temperature increase, greenhouse effect etc. The use and application of renewable energy sources are increased and mainly solar, wind, hydro power. The another best advantages of renewable energy source is that the overall cost of renewable energy sources are decreased day by day due to advancement in the new technologies.

FEATURES OF WIND POWER SYSTEMS:-

These are so many advantages feature of use of wind power system. In most of the wind power plant site location is in rural area, island area and marine areas. The energy equipment in these kind of places are simple and does not require high electrical power.

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- The power system supply cheap variable voltage for heating purpose and expensive higher voltage for motor and lights.
- The rural grid system is very weak up to 33 KV system. The grid integration of wind energy conversion system is very difficult and problem occur for worker of the plant.
- These are some time duration is coming where wind energy is not available. That's storage system is necessary for continuous power supply.

POWER FROM THE WIND:-

The mechanical energy as kinetic energy is provided from the wind to rotate generator and produce electricity. These are so many factor are important for better efficiency and maximum power generation from the wind. The first and very important factor is wind speed to determine the capacity of wind to obtain maximum amount of power. So, the power produced from the wind turbine is equal to the cube of wind speed. So, it will double the value of wind speed than power produce is 8 times to original power. The another important factor for maximum power take from wind turbine is depends upon location of wind farm. Now the another important factor for wind turbine is rotor blade. Because the power extracts from the wind turbine is directly proportional to the swept area of rotor blades. When we will double the diameter of swept area of rotor blades then power produced is 4 times to original power. For these functioning it is important that rotor blades are light in weight strong and reliable in operation. In earlier times when we increase the length of rotor blades them weight is increase. so, due to advancement in technology light weight and strong rotor blades is very useful and conventional to produce power of 1 MW. The relation between power generated and velocity of wind and diameter of rotor blades are given as below:

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

For selection of wind turbine available in market the best and efficient wind turbine is that which is capable of use of kinetic energy of wind.

Wind power plant has the following advantages over the other conventional power plants:

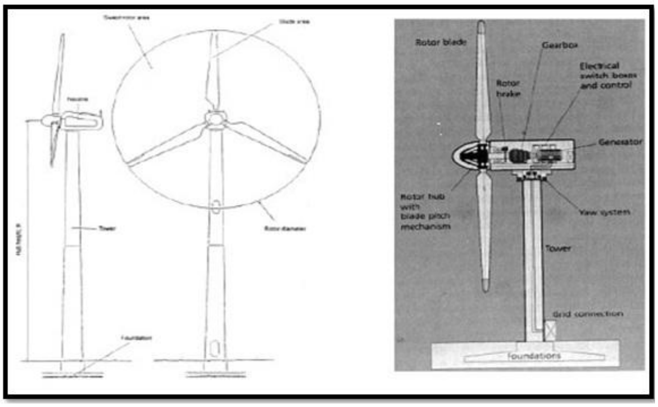
- Improve the price complexity
- Easy installation of plant
- Fast and reliable construction
- Easy power generation
- Improve the system reliability
- Pollution free

TYPES OF WIND TURBINES:-

There are mainly two types of wind turbines are used according to the rotor settings.

- Horizontal axis design
- Vertical axis design

Here in this thesis we only used horizontal axis wind turbine because we assume that wind generator use horizontal axis rotor. The horizontal wind turbine design is such that the blades of wind turbine rotate front of the tower with respect to wind direction. So, we can say that axis of rotation is in parallel direction with respect to wind direction. That's why they are known as upwind rotors. The second type of wind rotor is downward rotors which blades rotate in back direction mostly upward rotor design are used for large amount of power generation. The basic and important components of wind power plant for electricity generation are rotor, transmission system and generator. The fig. shown below the general layout of horizontal axis wind turbine and also indicates the post of wind turbine.



(a) (b)

Fig 1: (a) Components of Wind Turbine (b) Cross-section of a Wind Turbine

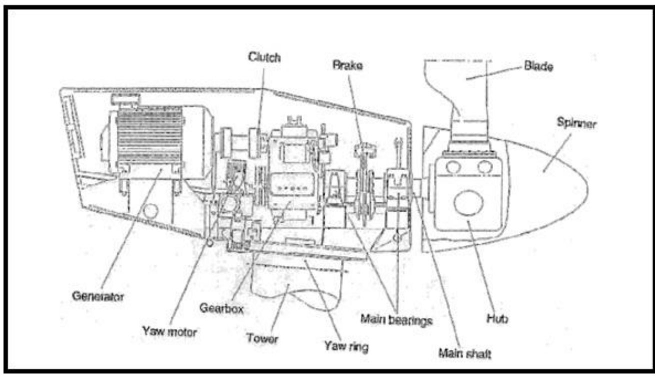


Fig 1(c): Cross-section of Wind Turbine

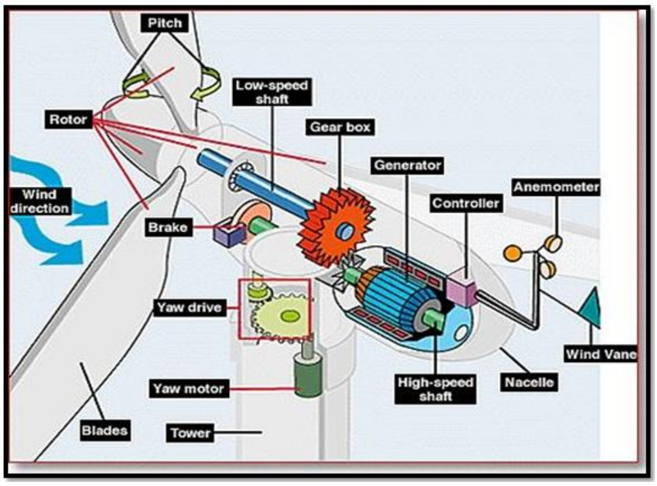


Fig 2: Components of a wind turbine

INDUCTION GENERATOR:

The induction generator is one kind of electrical generators that is mechanically and electrically similar to poly phase induction motor. Induction generators produce electrical power when their shaft is rotated faster than synchronous frequency of the induction motor. The induction generator are often used in wind turbine and also used in small hydro installation because of their capacity of useful power at varying rotor speed. The induction generators are mechanically and electrically simple and better compare to other generation types.

The induction generators are not self starting due to this it requires an external power supply to produce magnetic flux in the induction generator. The external power supply can be provided from the grid. The rotating magnetic flux from the stator induces current in the rotor of which also provide magnetic flux in the system. In the induction generator the magnetic flux is produced by the capacitor bank which has been provided at machine side in standalone system and in grid connected system magnetizing current is provided, this second one point is used in the large wind energy generating system because the speed is variable.

INDUCTION MACHINE ANALYSIS

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

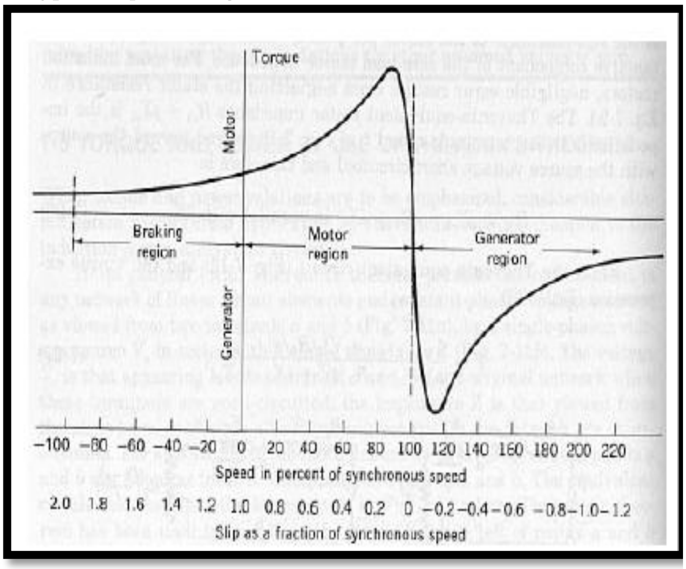


Fig 3: Torque vs. Speed Characteristics of Squirrel-cage Induction Generator

From the figure, we can seen, when the induction machine is run 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. When the induction machine is operate as a motor then the machine is run at just below the synchronous speed.

The following figure 4 shows the per-phase equivalent circuit of the induction machine.

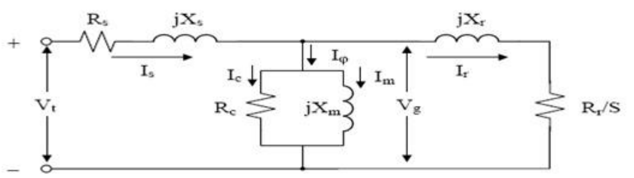


Fig. 4: Per-Phase Equivalent Circuit of an Induction Machine

On the other hand, when induction machine is operated as a generator then its stator terminals should be connected to a constant frequency voltage source and its rotor is driven above. synchronous speed. The synchronous speed and supplies the reactive power input required exciting the air gap magnetic field is fixed by the sources And hence the slip is negative.

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 behaviour 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 3.6 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.

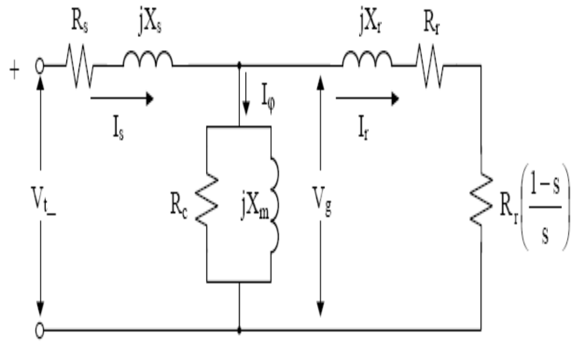


Fig 5: Alternative Form for Per-Phase Equivalent Circuit

III. INTRODUCTION OF DFIG

DOUBLE FED INDUCTION GENERATOR (DFIG):-

DFIG which is also known as Double feed induction generator which is mostly used in wind turbines. The DFIG is based on the working principle of an induction generator which is provided with multiphase wound rotor and slip ring design configurations. The alternative of DFIG is brushless wound rotor doubly fees induction machine.

PRINCIPLE OF GRID CONNECTED DOUBLE FEED

INDUCTION GENERATOR SYSTEM

The principle operation of DFIG is that the rotor windings are connected to the grid via slip rings and back to back VSC (voltage source converter) which provides the control of rotor side and grid side currents. The voltage source converter provides the control at rotor side current and also provides the active and reactive power control feeding to the grid. The principle of control is provided using direct axis control or two axis control system.

In the DFIG system the rotors are typically wound with number of turns of 2 to 3 multiple of stator turns. Due to this the rotor voltage value is higher and rotor current value is lower. So, in this configuration the operation speed of rotor is ±30% of the synchronous speed. The current rating of converter is lower due to that the cost of converter is low. The rotor voltage value is high due to that the controlled operation in operation speed range is not possible. Provide the protection against higher rotor voltage there are IGBT and diode configuration is used. Use of crowbar protection there are small currents and voltages are detected. For the continuous operation as fast as possible there is an active crowbar protection is provided. In short circuit condition the active crowbar is remove and so the rotor side converter can be started after 20-60ms from the starting of grid disturbance. So, it is possible to generate the reactive current in the grid during the voltage dip and due to that grid is recover from the fault.

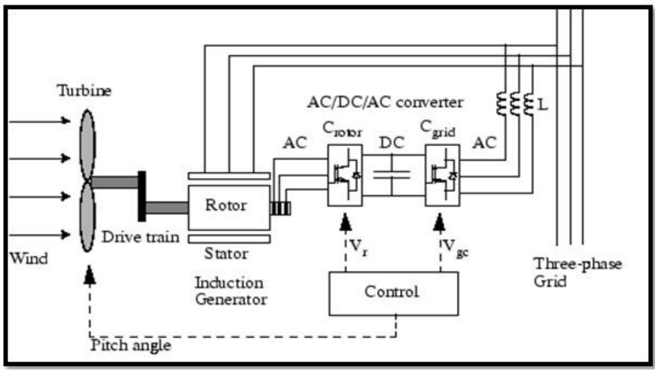


Fig 6: Operating Principle of the Wind Turbine Doubly-Fed Induction Generator

The double feed induction machine has several advantages over conventional induction machine for wind power application. The induction machine use power electronics converter the induction machine is able to import and export of reactive power in the system. Due to these kind of features the induction machine is able to provide power system stability and also provide the support to grid during voltage disturbances.

Another important feature is that induction machine is capable to synchronize with grid while wind turbine speed is variable. The variable speed wind turbine efficiently used during light wind conditions. Due to these kind of several feature and advantages the efficiently of DFIG is very good.

SYSTEM MODEL:

The model of the system electrically is developed using phase of complex vectors in synchronous rotating reference frame theory. The calculation assume + ve axis as real axis and – ve axis as imaginary axis. In different conditions the real and imaginary axis are align with vectors at different position and at different angles. The different assumption which are consider during development of electrical model of the system are:

- The losses like iron losses converter losses are neglected.
- The magnetic circuit of the machines can be represented by linear model in the system.
- The whole mechanical model of the system of the system can be modelled using lumped parameters of inertia like electrical angle and speed of induction generator.
- The power converter using in the system are represented by state space representation for their low frequency values.
- It is assumed that the wind farm networks is electrically stiff with respect to point of common coupling (PCC) and the conventional DFIG circuit is transformed into an equivalent circuit.

DFIG CONTROL:

The DFIG is connected to the network is represented by three steps which has been represented as following steps. First step is regulate the stator voltage with respect to reference voltage. Second step is the power control and regulation between stator and network.

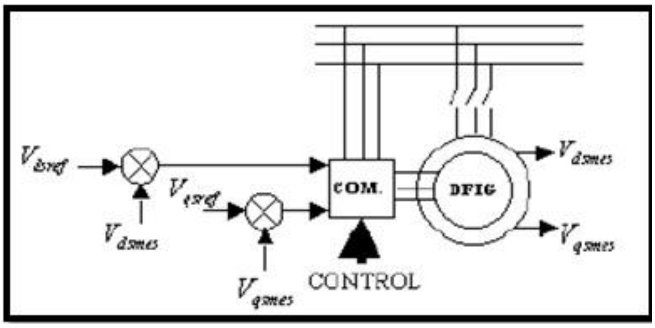


Fig 7: First step of DFIG control

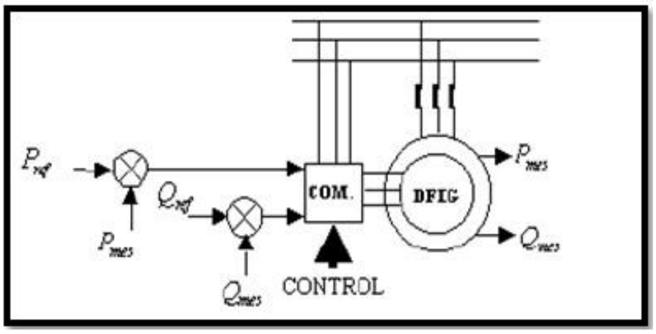


Fig 8: Second step of DFIG control

PROPOSED SYSTEM

The proposed technology is two layer control strategies with energy storage system.

- Low layer (wind turbine generator controller)
- High layer (wind farm supervisory control)

Wind turbine generator controller and wind farm supervisory controller is used to control active power and reactive power into electrical power grid. Control of the DFIG is achieved by controlling the RSC, the GSC, and the ESS.

A. ROTOR SIDE CONVERTER CONTROL:
In rotor side converter control the independent control of stator active and reactive power has been achieved by rotor current regulation using rotating reference frame theory. In the RSC control there are two cascade control loops are provided. The inter loop and outer loop are two loops which is used in RSC control. The outer loop provides active and reactive power control, while the inter loop control the current regulation in the system. In the outer loop the reference signal is generated by the high layer WFSC.

B. GRID SIDE CONVERTER CONTROL:
In the grid side converter control the d.c. link voltage and also provides the control of reactive power exchange between grid side converter and grid using the rotating reference frame theory. Here GSC control, there are two control loops are used for controlling system. The outer loop control the d.c. link voltage and reactive power and it will also generates reference signal for d-axis and q-axis. At the other side outer current control loop provides current regulation of the system. The output currents of two controller are compensated by cross coupling. These are gate signal are generated using PWM control strategies to drive the grid side converter. For this operation the reference signal is generated by the high layer WFSC.

C. DESIGN CONFIGURATION AND CONTROL OF THE ESS:
In this DFIG system, there are super capacitor bank and two quadrant dc-dc converter is provided for common dc link in system. The two quadrant dc-dc converter used two IGBT switches to regulate the active power exchanged between GSC and grid of system.

IV. MODELLING AND SIMULATION

DFIG WIND TURBINE WITH ENERGY STORAGE
The design configuration of DFIG based wind turbine connected with super capacitor bank based energy storage system is shown in fig below. In the given system the low speed wind turbine drives the high speed DFIG using gearbox system. The DFIG is wound rotor type induction machine which is connected to the power grid at stator and rotor terminals. The stator is directly connected to the system while the rotor is connected through grid side converter and rotor side converter to the grid in the system. The DFIG based wind turbine generator rotates at the operational speed of 20-30% to the synchronous speed in the system and the active and reactive power is controlled independently in the system. In this design configuration the energy storage system is provided using super capacitor bank and two quadrant dc-dc converter. The ESS works as a source or sink to control the active power to the wind turbine generator system.

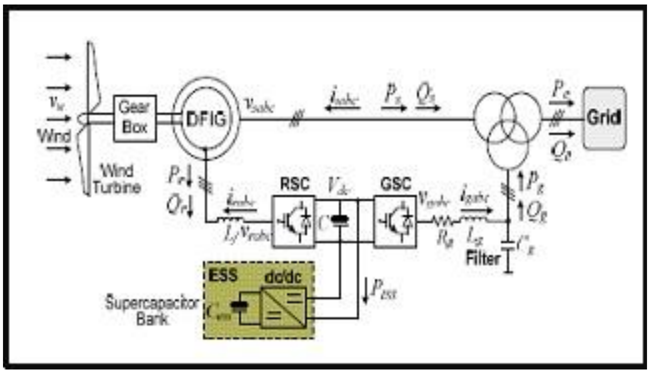


Fig 9: DFIG wind turbine with ESS

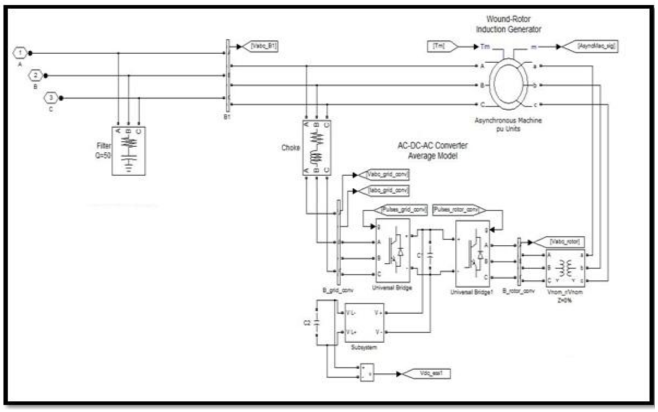


Fig 10: Converter control system

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.
5.3.3 WIND TURBINE CONTROL
In the wind turbine control system as input voltage from transmission line Vabc_stator, stator current Iabc¬¬¬¬¬_stator, grid side current Iabc_grid_conv, rotor side current Iabc_rotor, generated voltage Vdc_V, power reference Pref, wind speed wr etc. wind turbine control system control pulses of grid side converter, pulses of rotor side converter, pitch angle of turbine and active and reactive power.

There are different control system are present in the wind turbine control system
1. Filtering and measurements
2. Grid side converter control system
3. Rotor side converter control system
4. Speed regulator and pitch control

FILTERING AND MEASUREMENTS
In this block the input parameters of the system are filtered by the filtering system. In this system the inputs filter block

included in which rotor and grid side parameters like Iabc_grid, Iabc_r, Vabc_r, Vabc_g, and DC voltage Vdc, reference power etc. parameters filtered by the filtering circuit. So, we get the pure signal of these parameters. While this block also includes PLL, P,Q&V measurement and D-Q transformation block. The PLL provides control strategies for the DFIG system. In which for required value of power and voltage we generate or locked the phase value due to which we get the constant output power.

GRID SIDE CONVERTER CONTROL SYSTEM

In the closed loop of grid side and rotor side control, we provide the grid side converter control using PI controller. In this block the value of Vdc of the converter make constant using PI controller. The three phase system abc is to be converted into dq transformation. After this calculation has become simplified and compare with reference value and modulation index value. After that the inverse dq transformation is also provided for dq transformation to abc value of system. By using grid side control system we can produce pulses to control switching operation of grid side converter and we can convert voltage at the rated value.

ROTOR SIDE CONVERTER CONTROL SYSTEM

In the closed loop of rotor side converter, we provide the rotor side converter control system using PI controller. In this system voltage regulator is also used to regulate the voltage by comparing with the reference voltage. In this system also three phase system abc is to be converted into dq transformation. After this calculation has become simplified and compare with reference value and modulation index value. After that, the inverse dq transformation is also provided for dq transformation of system. By using rotor side control system we can produce pulses to control switching operation of rotor side converter and we can convert voltage at the rated value.

SPEED REGULATOR AND PITCH ANGLE CONTROL

In this block the value of measured wind speed value is compare with reference value with PI controller and required value has been taken by multiply with constant gain value. Due to these strategies we can control the wind speed. In this block the value of pitch angle is also control. In this block the value of power is compare with reference value with the PI controller and the required value has been taken by multiply with constant gain value. Due to this strategy we provide the pitch angle control in the wind turbine system.

TRANSMISSION LINE

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.

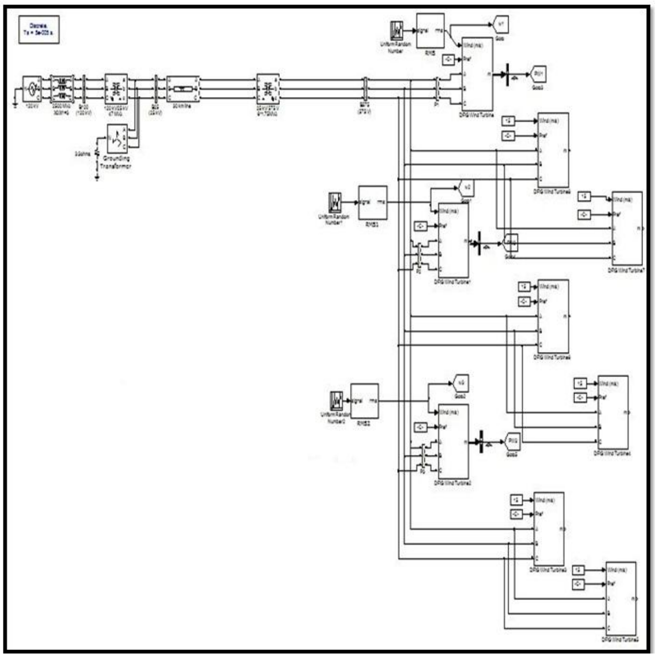


Fig 11: Simulink model of DFIG wind turbine with control strategies and energy storage system

SIMULATION RESULTS

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

WIND SPEED

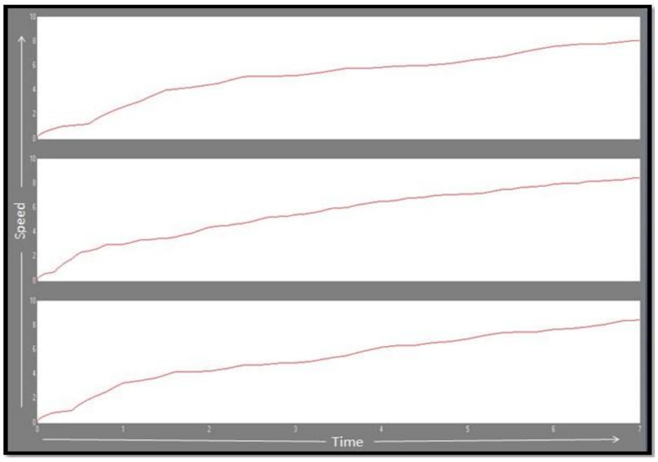


Fig 12: Wind speed of wind turbine 1,2 & 3

Fig 15 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.

VOLTAGE AT ENERGY STORAGE SYSTEM

Voltage across energy storage system is shown in fig 16 which indicate voltage between rotor side converter and grid side converter.

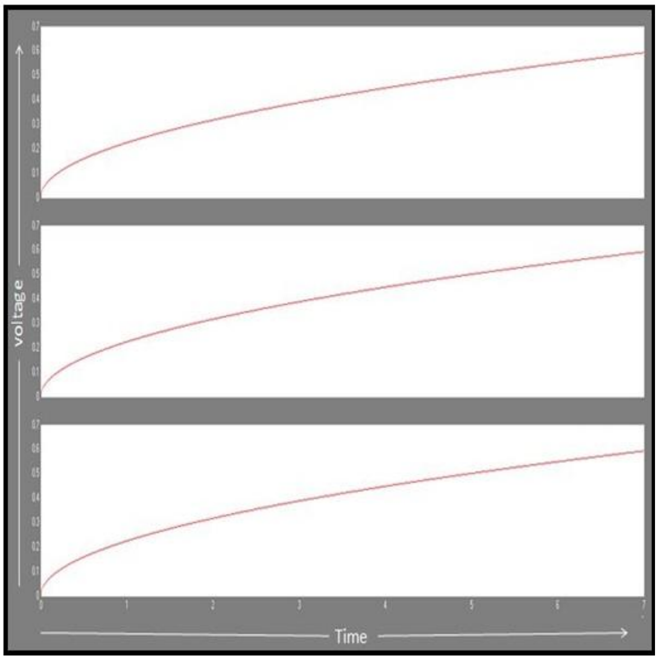


Fig 13: Voltage at energy storage system

POWER CONTROL DURING VARIABLE WIND SPEED

Fig 17, 18&19 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 20 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.

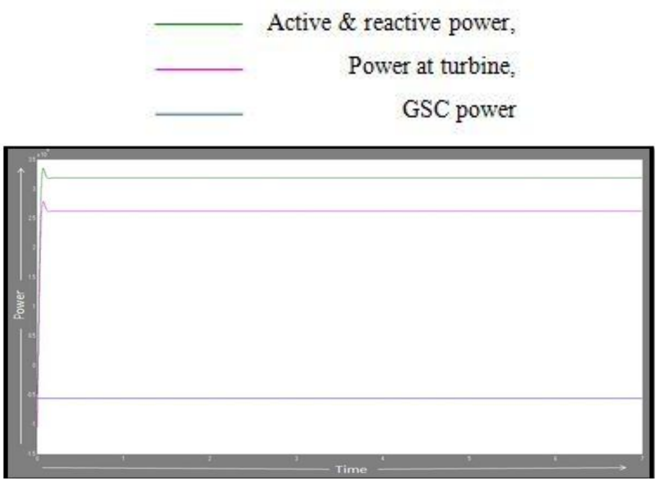


Fig 14: Wind Turbine 1 - active & reactive power, power at wind turbine, GSC power

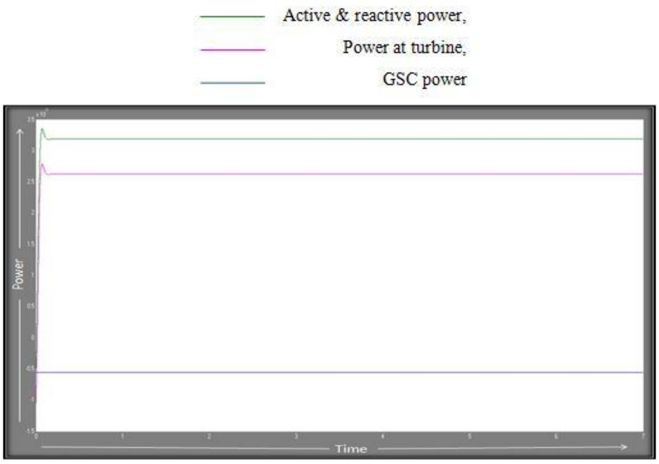


Fig 15: Wind Turbine 2 - active & reactive power, power at wind turbine, GSC power

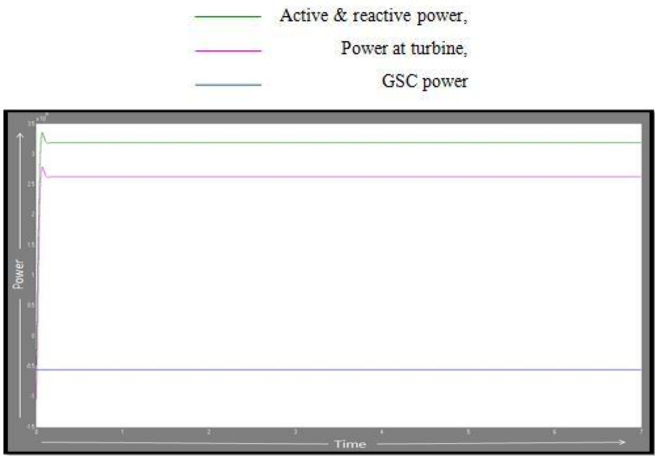


Fig 16: Wind Turbine 3 - active & reactive power, power at wind turbine, GSC power

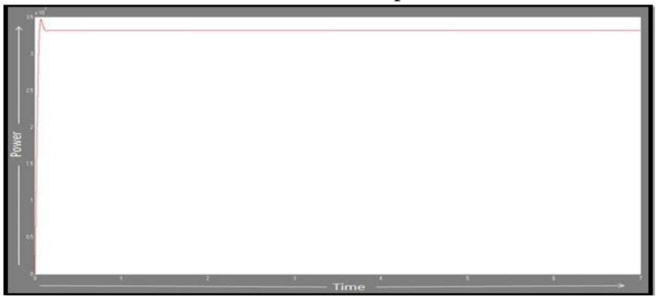


Fig 17- Active & reactive power at bus 575

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.

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