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SIMULATION AND ANALYSIS OF FLICKER MITIGATION IN WINDFARM USING INDIVIDUAL PITCH ANGLE CONTROL STRATEGY

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Abstract: Energy demands of the world are enormously increasing. In this scenario the non-renewable sources play an important role in meeting the energy needs. Wind energy have a lot of potential for generating large amounts of energy with zero input cost and no by-products. Therefore it is very important to maintain the power quality while generating the power through wind turbine. In this paper IPC control scheme is proposed a new scheme to reduce the power fluctuations which are responsible for reduction of the generated power quality. This scheme is applicable to MW – level DFIG based variable speed wind turbine.IPC scheme uses the active power generated and azimuth angle of blade as reference for reduction of flicker.IPC along with FLC reduces the oscillates in active power generated to a great extent. The proposed scheme is designed and implemented in MATLAB/Simulink.

I. GENERAL

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. Currently, wind energy only provides about 1%–2% of the U.S.'s electricity supply. At such a penetration level, it is not necessary to require WTGs to participate in grid frequency regulation, unit commitment, or to supply a constant amount of active power as required by the grid operator. 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.

With the increase of wind power penetration into the grid, the power quality becomes an important issue. One important aspect of power quality is flicker since it could become a limiting factor for integrating wind turbines into weak grids, and even into relatively strong grids if the wind power penetration levels are high. Flicker is defined as "an impression of unsteadiness of visual sensation induced by a light stimulus, whose luminance or spectral distribution fluctuates with time". Flicker is induced by voltage fluctuations, which are caused by load flow changes in the grid. Grid-connected variable speed wind turbines are fluctuating power sources during continuous operation. Due to the wind speed variation, wind shear and towershadow effects, grid connected wind turbines are the sources ofpower fluctuations which may produce flicker during continuousoperation. This project presents a model of an MW-level variable speedwind turbine with a doubly fed induction generator to investigatethe flicker emission and mitigation issues. An individual pitchcontrol (IPC) strategy is proposed to reduce the flicker emission atdifferent wind speed conditions. The IPC scheme is proposed andthe individual pitch controller is designed according to the generatoractive power and the azimuth angle of the wind turbine. The modelling of the wind turbine system is carried out using FAST and Simulink. On the basis of the presented model, flicker emission is analysed and investigated in different mean wind speeds. To reduce the flicker emission, a novel control scheme by IPC is proposed. The generator active power oscillation which leads to flicker emission is damped prominently by the IPC in both high and low wind speeds. It can be concluded from the simulation results that damping the generator active power oscillation by IPC is an effective means for flicker mitigation of variable speed wind turbines during continuous operation.

II. 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.

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

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.

III. Induction Machine Analysis

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

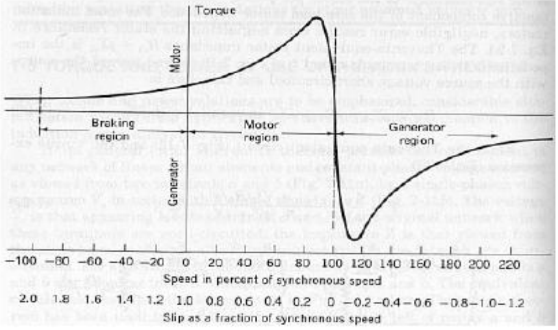


Fig: Torque vs. Speed Characteristics of Squirrel-cage Induction Generator

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.

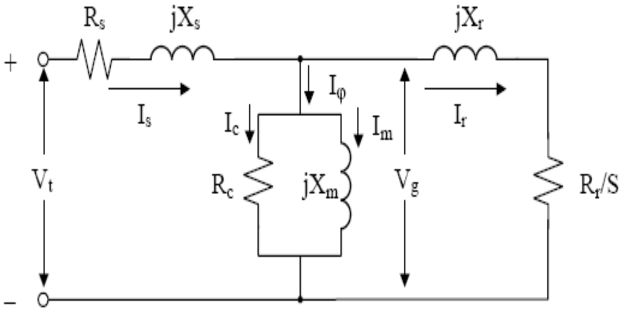


Fig. : Per-Phase Equivalent Circuit of An Induction Machine

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.

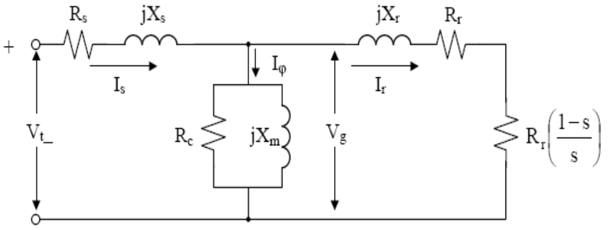


Fig: Alternative Form for Per-Phase Equivalent Circuit

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.

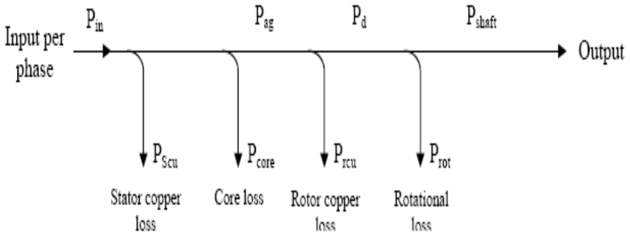


Fig: Power Flow Diagram

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).

IV. 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 rotorfrequency 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.

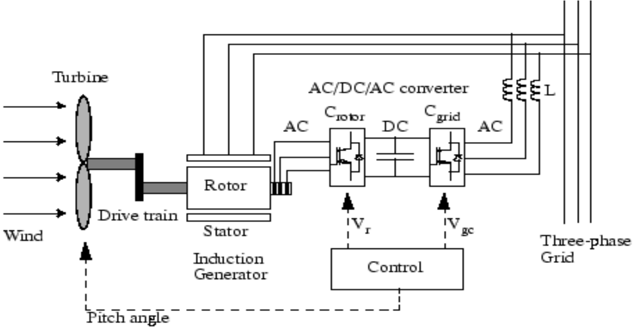


Fig-Operating Principle of the Wind Turbine Doubly-Fed Induction Generator

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 modelled using a lumped inertia parameter referred to the electrical angle and speed of the induction generator.

4) The power converters can be modelled 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 model under these assumptions The complete set of nonlinear state equations are

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

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

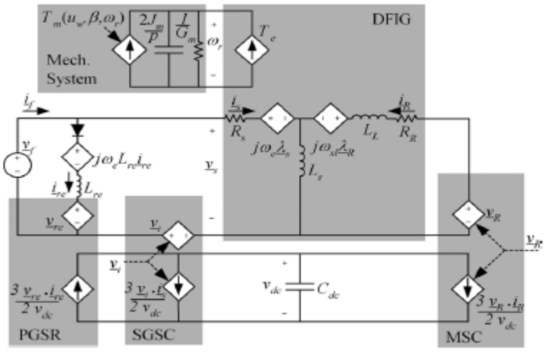
$$+\underline{\lambda}_s\left(\frac{R_s}{L_s} + j\omega_r\right) + \underline{v}_R - \left(\underline{v}_f + \underline{v}_i\right)\Big]$$

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

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

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

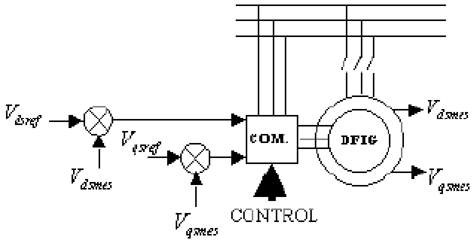
where $u(\cdot)$ is the unit step function.



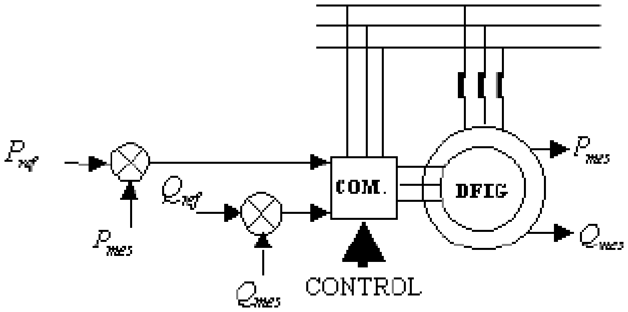
The complex vector dynamic state equations are used form the evaluation of steady state properties and the development of control laws. The dynamic states of the system include the stator flux, , rotor current , rectifier current , dc link voltage, , and rotor speed, . Controllable inputs to the system 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-Types of double fed induction generator:

Brushless doubly-fed induction electric generator:

Brushless doubly-fed induction electric generator (i.e., electric motors or electric generators) are constructed by adjacently placing two multiphase winding sets with unlike pole-pairs on the stator body. With unlike pole-pairs between the two winding sets, low frequency magnetic induction is assured over the speed range. One of the stator winding sets (power winding) is connected to the grid and the other winding set (control winding) is supplied from a frequency converter. The shaft speed is adjusted by varying the frequency of the control winding. As a doubly-fed electric machine, the rating of the frequency converter need only be fraction of the machine rating. The brushless doubly-fed induction generator does not utilize core real-estate efficiently and the dual winding set stator assembly is physically larger than other electric machines of comparable power rating.

In addition, a specially designed rotor assembly tries to focus most of the mutual magnetic field to follow an indirect path across the air-gap and through the rotor assembly for inductive coupling (i.e., brushless) between the two adjacent winding sets. As a result, the adjacent winding sets are excited independently and actively participate in the electro-mechanical energy conversion process, which is a criterion of doubly-fed electric machines.

The type of rotor assembly determines if the machine is a reluctance or induction doubly-fed electric machine. The constant torque speed range is always less than 1800 rpm @ 60 Hz because the effective pole count is the average of the unlike pole-pairs of the two active winding sets. Brushless doubly-fed electric machines incorporate a poor electromagnetic design that compromises physical size, cost, and electrical efficiency, to chiefly avoid a multiphase slip ring assembly. Although brushless doubly-fed electric machines have not seen commercial success since their conception in the early 1970s, the promise of a low cost, highly efficient electronic controller keeps the concept under perpetual study, research, and development.

V. MODELLING AND SIMULATION

Proposed System with fault condition:-

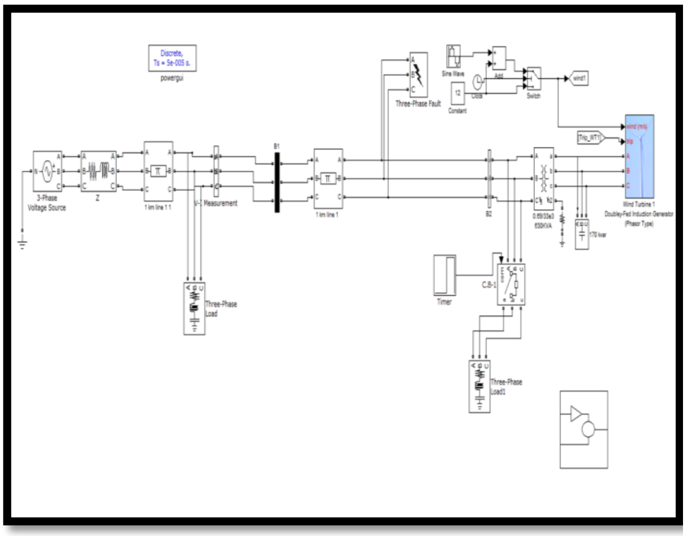


Fig Proposed Matlab model with fault condition

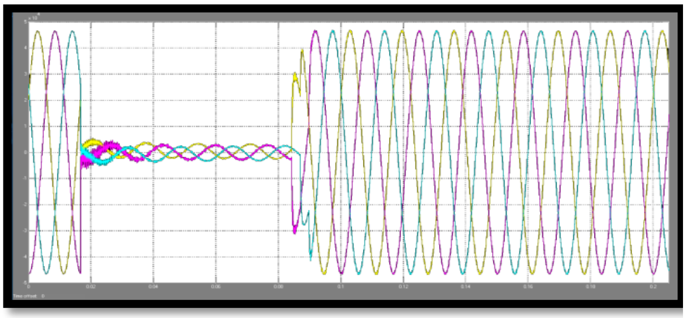


Fig Voltage at B-1 during fault condition

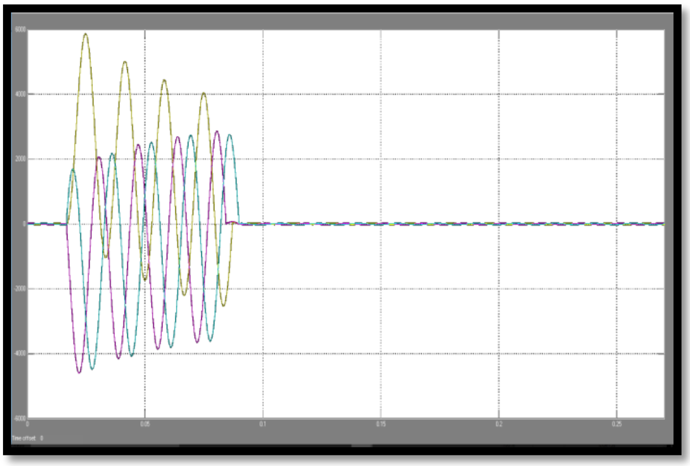


Fig Current at B-1 during fault condition

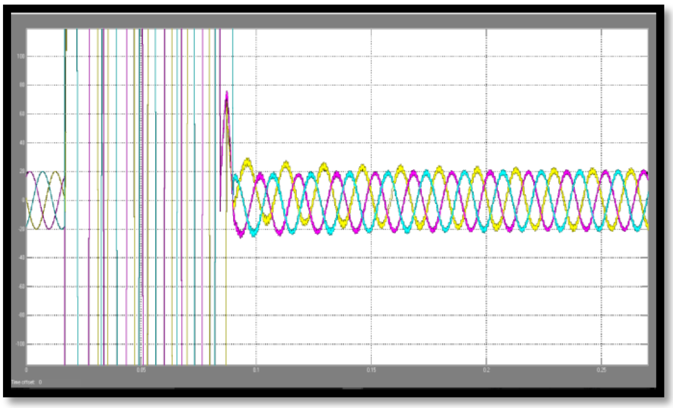


Fig Current at B-1 during fault condition with Zoom Scale

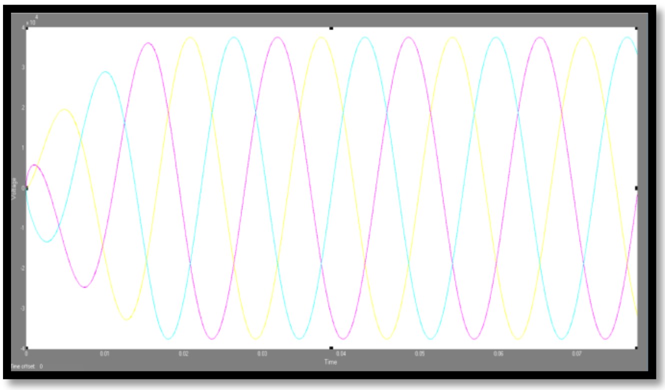


Fig Voltage at B-2 during fault condition

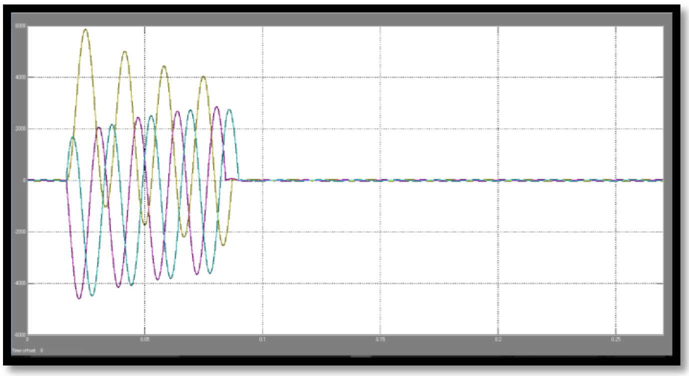


Fig Current at B-2 during fault condition

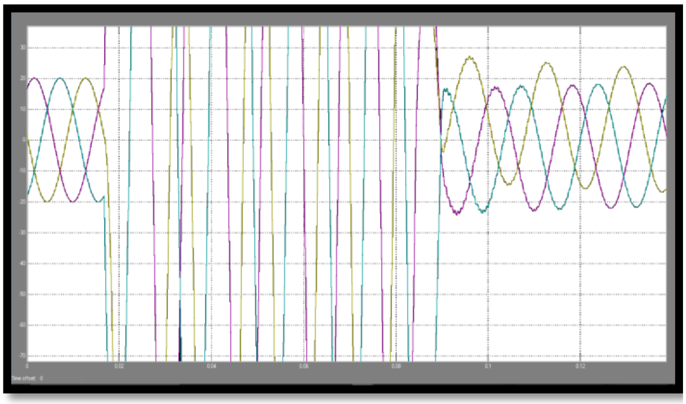


Fig Current at B-2 during fault condition with Zoom Scale

VI. MATLAB DESIGN OF CASE STUDY & RESULTS

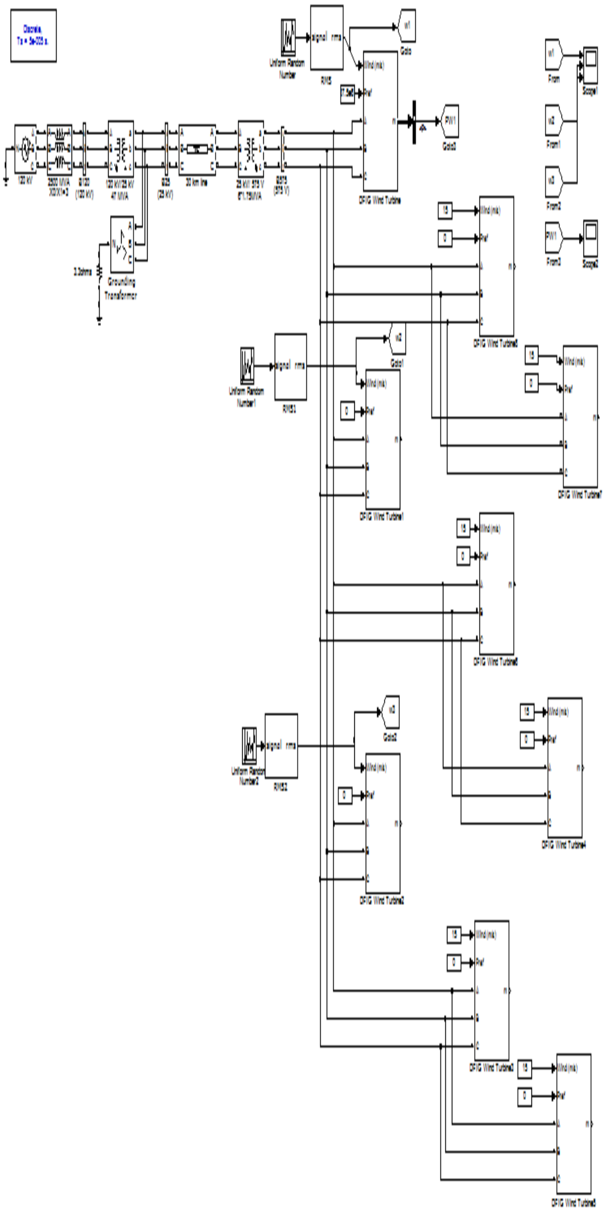


Fig Simulink model of DFIG wind constant power

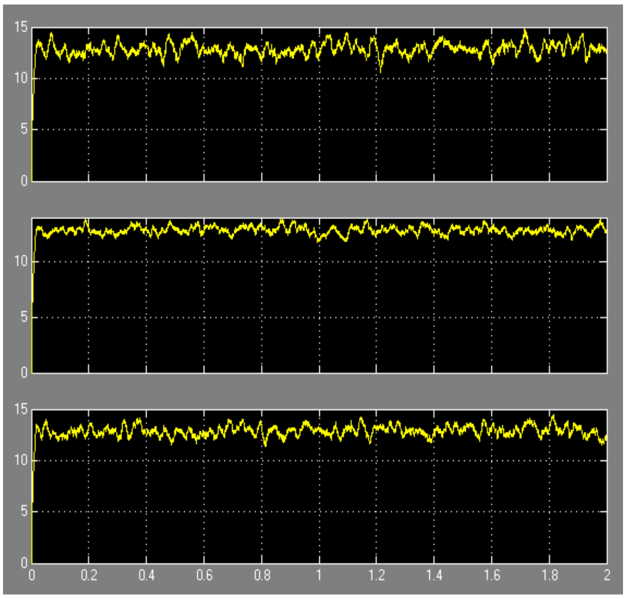


Fig: wind speeds of turbines

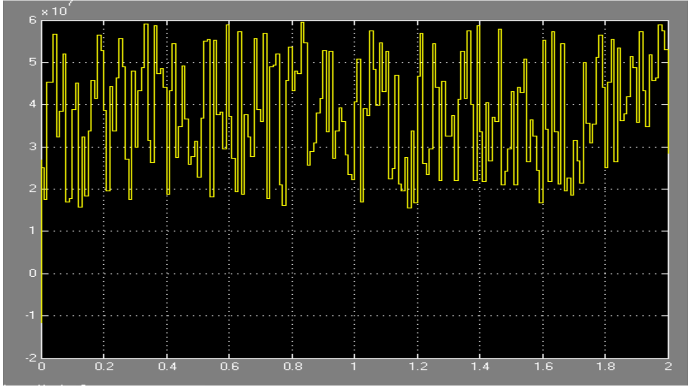


Fig: DFIG wind turbine power

SIMULATION WITH DFIG CONTROL STATEGIES

CONVERTER CONTROLLER

Stepped up or stepped down voltage is given to the rotor side converter. In rotor side converter voltage is converted from AC to DC voltage. In the rotor side converter switching operation of switching device IGBT/Diode is controlled by rotor side converter control system to improve power quality. DC voltage which is produced by rotor side converter is not pure. It have harmonics in it so, to reducing harmonics in dc voltage capacitor is connected across it. This DC voltage is supply to the grid side converter. Grid side converter is connected with inductive load because generator we are used 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.

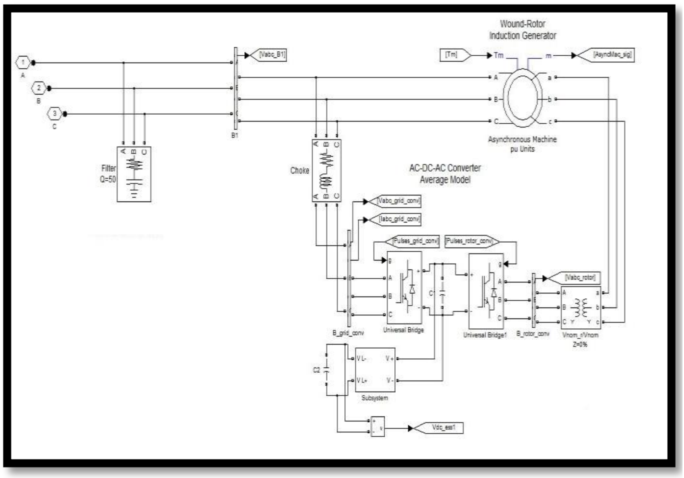
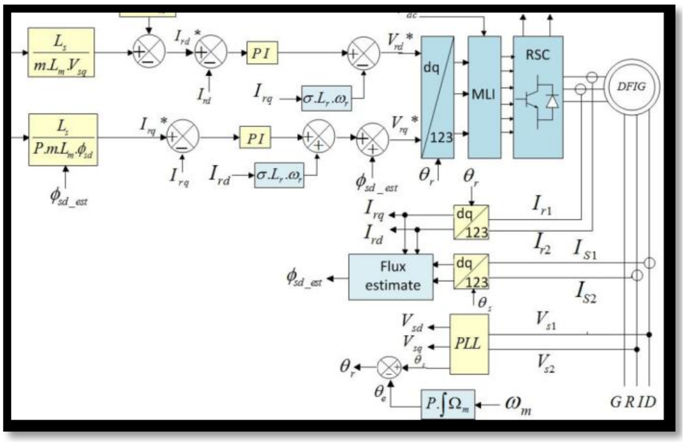


Fig: Converter control system

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.

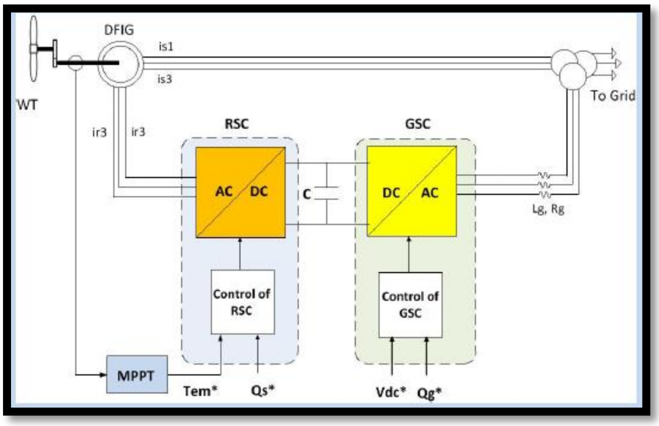


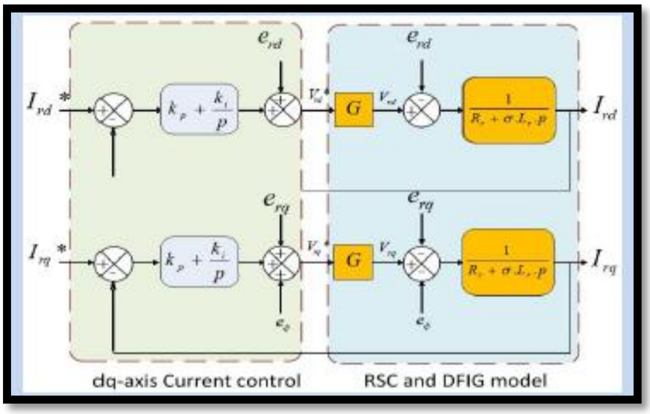
To generate the reference current of the rotor, it is necessary to estimate the stator flux according to the d-axis. In our study, the grid is assumed to be stable and the dq reference chosen is related to the stator rotating field. Thus, the d-axis stator flux can be estimated from measurements of the d-axis stator and rotor currents in open loop :-

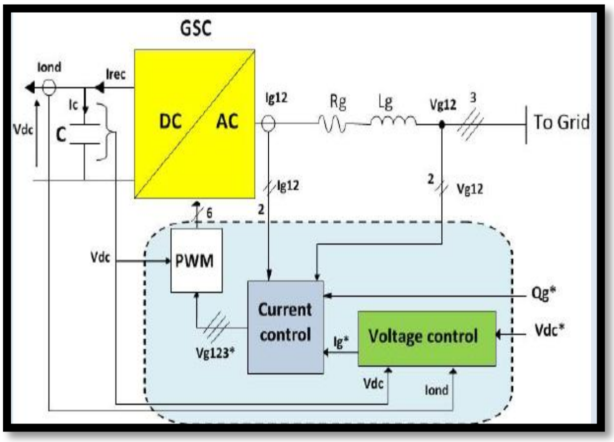
$$\Phi_{sd-est} = L_s I_{sd} + m.L_m.I_{rd}$$

Once the stator flux is estimated, it is necessary to generate the dq-axes rotor reference currents. The electromagnetic torque is proportional to the q-axis rotor current (according to Equation above), so we can establish a relation between the irq* current and the electromagnetic torque Tem* from block control by:-

$$I_{rq} * = \frac{L_s}{P.m.L_m \Phi_{sd\_est}}.T_{em}$$







Simulation Results:-

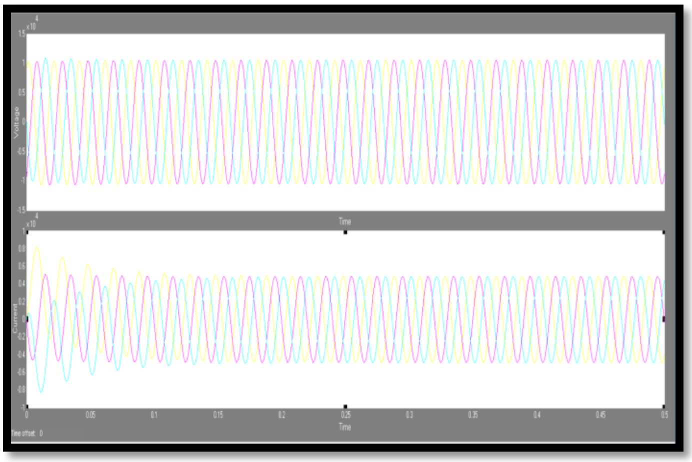


Fig Voltage and Current waveform at Source Side (B-1)

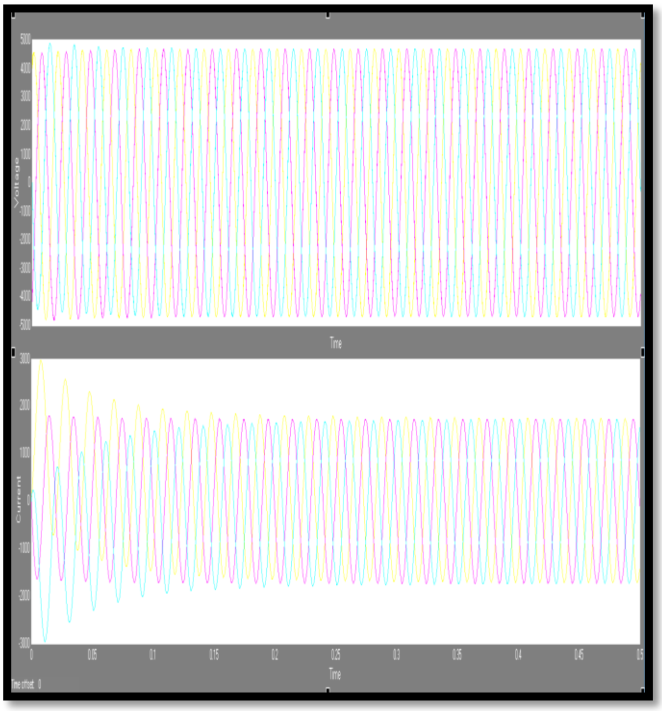


Fig Voltage and Current waveform at load Side (B-2)

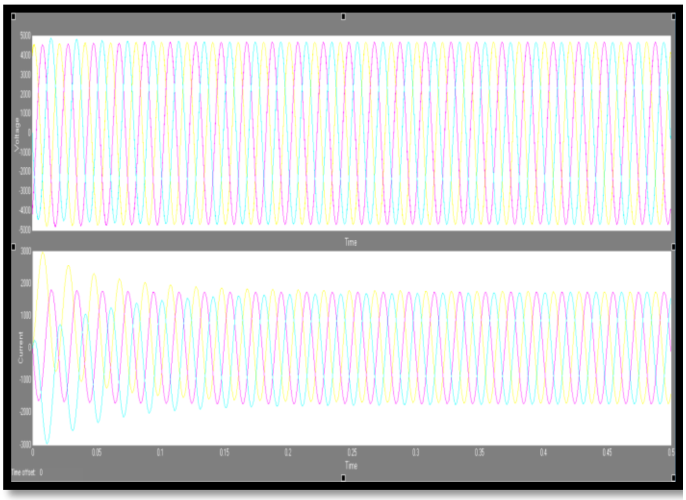


Fig Voltage and Current waveform at load Side (B-3)

VII. 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.

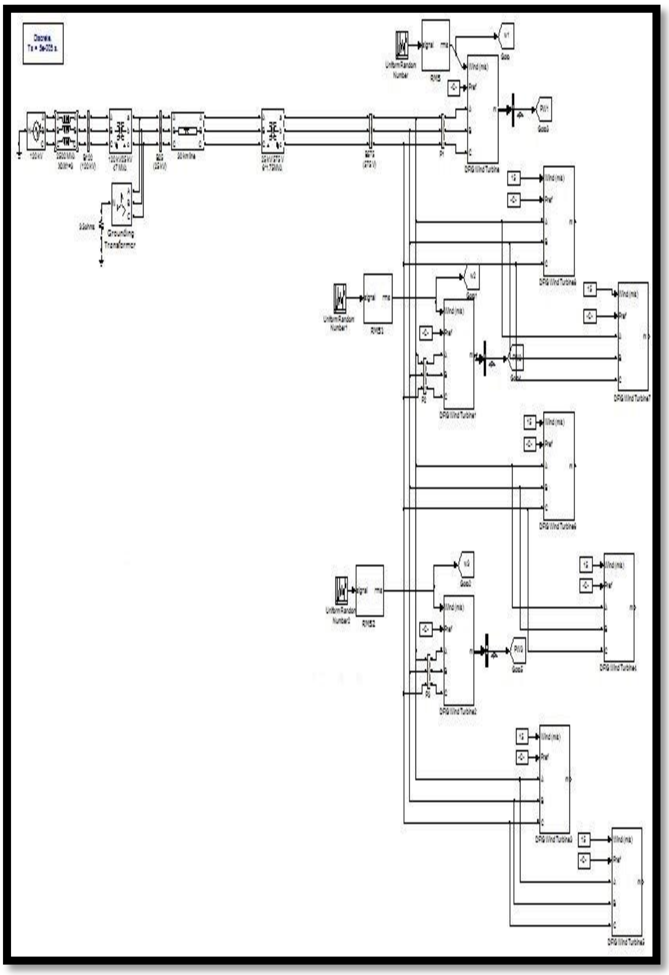


Fig 5.27: Simulink model of DFIG wind turbine with control strategies and energy storage system

VIII. SIMULATION RESULTS

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

WIND SPEED

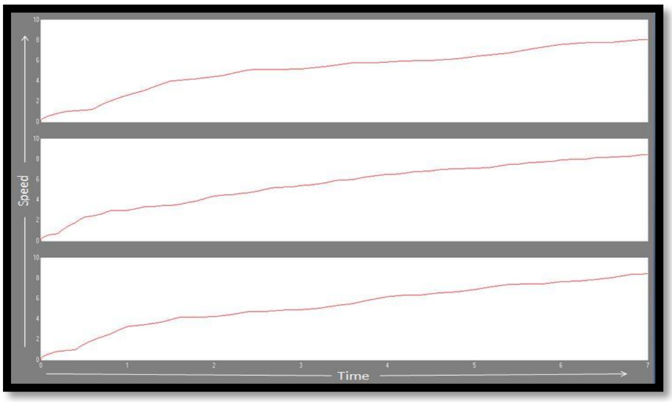


Fig 5.28: Wind speed of wind turbine 1,2 & 3

Fig 5.28 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 5.29 which indicate voltage between rotor side converter and grid side converter.

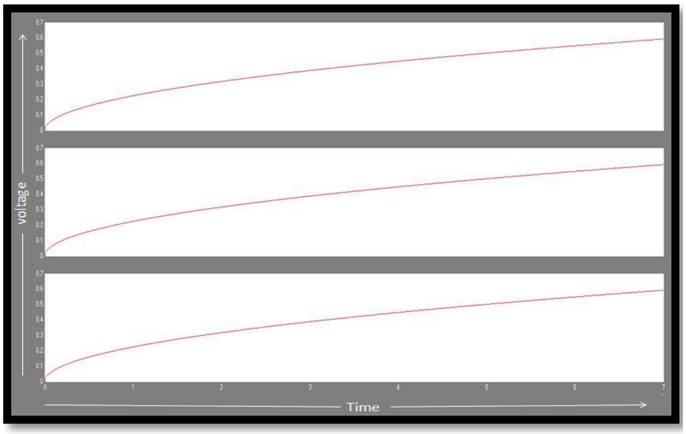


Fig 5.29: Voltage at energy storage system

POWER CONTROL DURING VARIABLE WIND SPEE

Fig 5-30, 31&32 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 5.30 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.

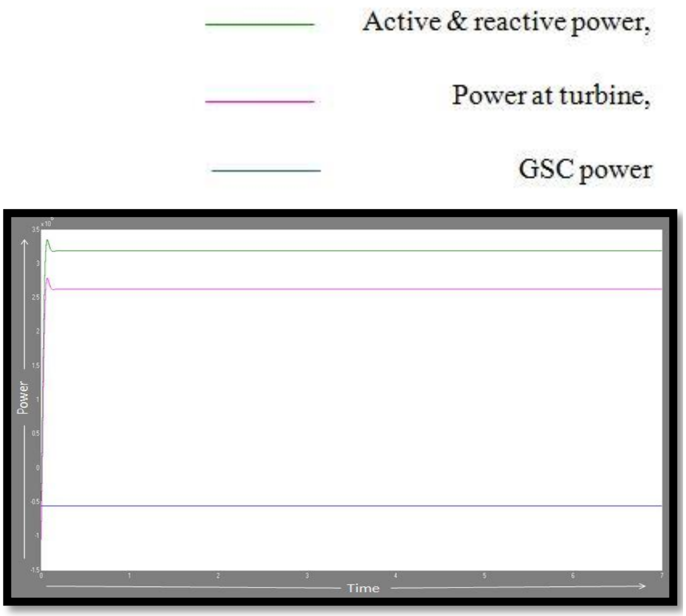


Fig 5.30: Wind Turbine 1 - active & reactive power, power at wind turbine, GSC power

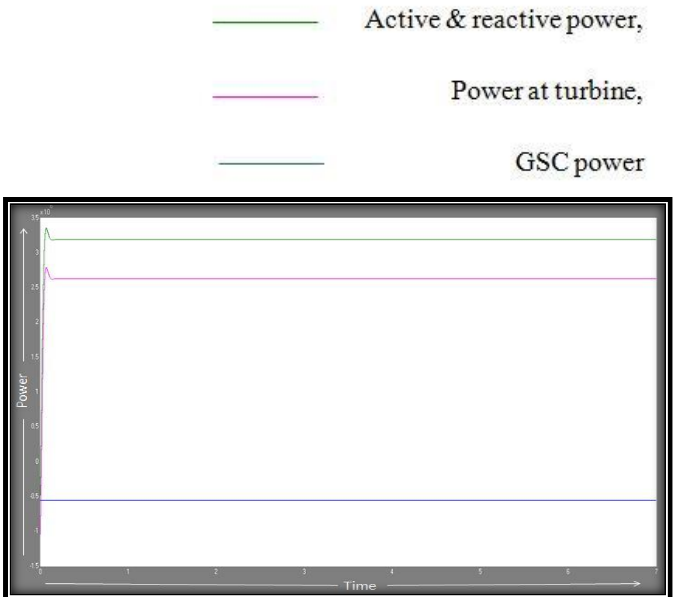


Fig 5.31: Wind Turbine 2 - active & reactive power, power at wind turbine, GSC power

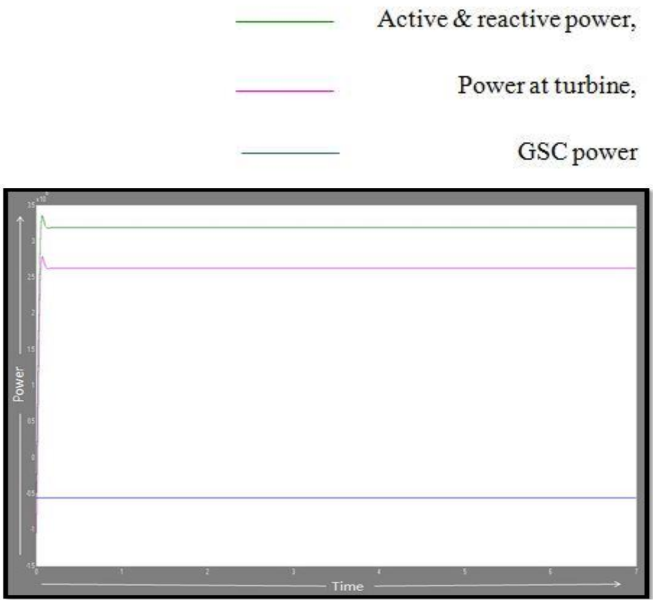


Fig 5.32: Wind Turbine 3 - active & reactive power, power at wind turbine, GSC power

Fig 5.33: Active & reactive power at bus 575

IX. 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 output of WTG without any control strategies, there is fluctuation in electrical quantities. So, by implementation of two layer CPC scheme for wind farm and DFIG wind turbines. Each will equip with energy storage system, electrical quantities will not get fluctuate and will get stable. So, we will enable the wind farm actively participate in active power regulation in grid and help to get more penetration of wind power into the electrical grid. The Matlab Simulation of Pitch angle control will provides constant output power and flicker mitigation and pure sinusoidal output voltage and current waveform.

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