REAL TIME SIMULATION OF DFIG BASED WECS SYSTEM USING MATLAB

A project report submitted in partial fulfillment of the requirements for the degree of B.Tech in Electrical Engineering

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This is to certify that the project work entitled **REAL TIME SIMULATION OF DFIG BASED WECS SYSTEM USING MATLAB** is the bona fide work carried out by **KALYAN PRAMANIK(11701619052),RISHAVDAS(11701619054),SUDIPDAS(11701619050),SUBHADIP DAS(11701619049)** a student of B.Tech in the Dept. of Electrical Engineering, RCC Institute of Information Technology (RCCIIT), Canal South Road, Beliaghata, Kolkata-700015, affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT), West Bengal, India, during the academic year 2021-22, in partial fulfillment of the requirements for the degree of Bachelor of Technology in Electrical Engineering and this project has not submitted previously for the award of any other degree, diploma and fellowship.

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ABSTRACT

The present research work deals with the control of grid frequency by controlling the operation of doubly fed induction generator and also control regulation of active power of demand and supplied by grid with help of doubly fed induction generator. The evolution of technology related to wind systems industry leaded to the development of a generation of variable speed wind turbines that present many advantages compared to the fixed speed wind turbines. These wind energy conversion systems are connected to the grid through Voltage Source Converters (VSC) to make variable speed operation possible. The studied system here is a variable speed wind generation system based on Doubly Fed Induction Generator (DFIG). The rotor side converter (RSC) usually provides active and reactive power control of the machine while the grid-side converter (GSC) keeps the voltage of the DC-link constant. The additional freedom of reactive power generation by the GSC is usually not used due to the fact that it is more preferable to do so using the RSC. This paper deals with the introduction of Doubly fed induction generator, AC/DC/AC converter control and finally the SIMULINK/MATLAB simulation for isolated Induction generator as well as for grid connected Doubly Fed Induction Generator and corresponding results and waveforms are displayed.

Keywords: DFIG, Rotor Side Converter, Converter Control Diagram, Simulink Diagram, Wind Turbine Modeling, Wind Energy.

Aim:

The aim of this work is to use a specific software, Power Factory, to study the DFIG behavior.

It will be seen in this work that Power Factory offers two built-in DFIG models. Another model
is built, which enables us to get insights into creating models with this software. The three models are compared and one of them is used to study a specific controlstrategy.

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INTRODUCTION

Wind industry is becoming one of the world's fastest growing energy sectors nowadays, helping to satisfy global energy demand, offering the best opportunity to unlock a new era of environmental protection, and starting the transition to a global economy based on sustainable energy. Wind turbines based on doubly fed induction generators have attracted particular attention because of their advantages such as variable speed constant frequency operation, reduced flicker and independent control capabilities for active and reactive powers. Active power from the generator is determined by the turbine control and must of course be within the capability of the turbine generator system. Voltage is primarily determined by the reactive power injection into the node, and since the generator must operate within its reactive capability curve it is not possible to control the voltage outside certain limits. The reactive capability of a generator depends on a number of quantities, such as active power, bus voltage and other operating conditions. The doubly fed induction generator construction caused a good performance when the voltage reduction occurs in these conditions, without losing any dynamic balance; it will remain connected to the power system. DFIGs are variable speed generators with advantages than others, they are used more in wind turbine because its control is easier and energy efficiency is higher than other generators and power quality is improved in this type of generator, controlled power electronic converters are used for improving the efficiency.

Advantages

The primary advantage of doubly-fed induction generators when used in wind turbines is that they allow the amplitude and frequency of their output voltages to be maintained at a constant value, no matter the speed of the wind blowing on the wind turbine rotor. Because of this, doubly-fed induction generators can be directly connected to the ac power network and remain synchronized at all times with the ac power network. Other advantages include the ability to control the power factor (e.g., to maintain the power factor at unity), while keeping the power electronics devices in the wind turbine at a moderate size. It can operate like a synchronous generator and at variable speed, although its stator is directly connected to the grid. The converter can adequately control the voltage (phase and magnitude) that is applied to the rotor and as a consequence control the magnetic field's frequency or speed. It actually forms an AC excitation with a variable frequency, just like the DC excitation used in synchronous generators. This operation gives the DFIG the benefits of a synchronous generator. These benefits include the separate control of reactive and active power, or the control of the wind turbines power factor. The DFIG wind turbines are better than other designs in terms of grid compatibility.

It can operate at variable speed, sub- or super synchronously. The optimum speed can be chosen by adjusting the frequency and phase of the voltage that is applied to the rotor, and is such that maximum power is obtained by the wind, in different wind speeds.

Since it can operate as synchronous generator, a major advantage of large DFIG wind turbines is that they can contribute to the system's stability after a fault occurs. However, this relies heavily on the control options given by the power converter. Moreover, A DFIG wind turbine can generate reactive power even when the mechanical part is not operating and in not delivering active power.

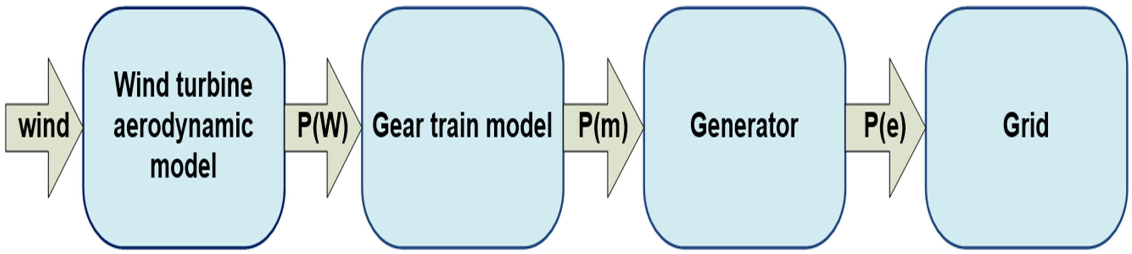
Relative to other variable speed generators, DFIG's power converter is rated at lower power (i.e. about 30% of the wind turbine's rated power), since only part of the total power delivered by the wind turbine is transferred through the converter. This makes the wind turbine cheaper and lighter.

Compared to other generators with variable speed, which use external rotor resistances to allow variable speed, DFIG are more energy efficient, since there is little power dissipated in the converter.

WIND ENERGY CONVERSION SYSTEM

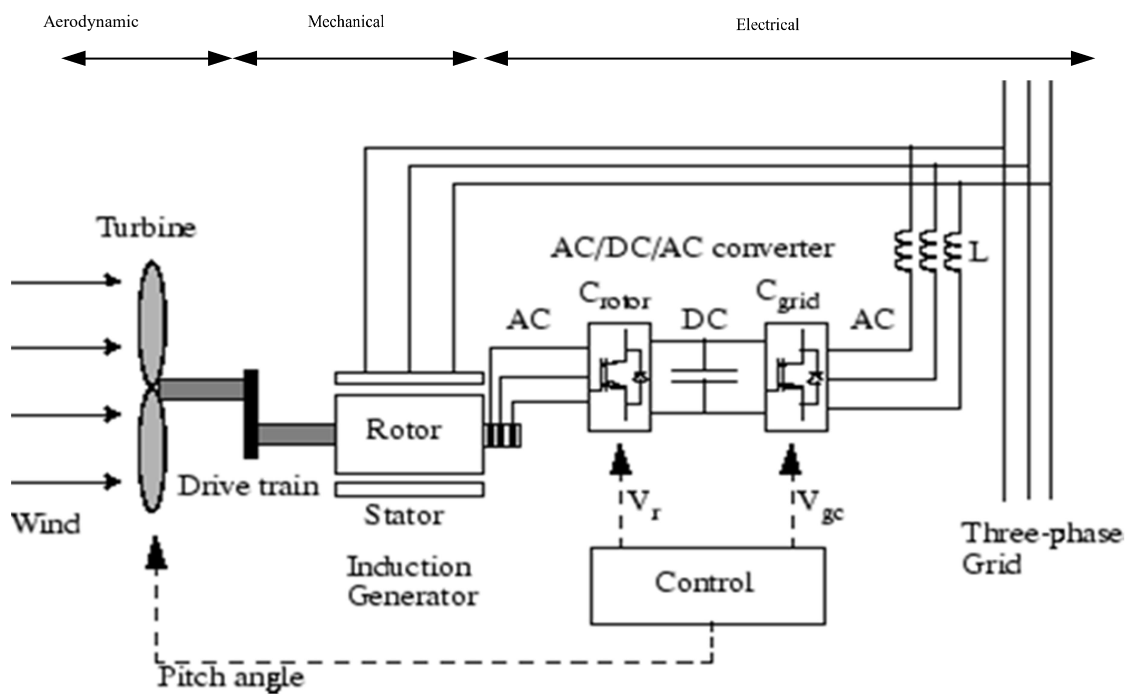
The development in wind turbine systems has been steady for the last 25 years and four to five generation of wind turbine exist. The main components of a wind turbine system,

including the turbine rotor, gearbox, generator, transformer, and possible power electronics, are illustrated.



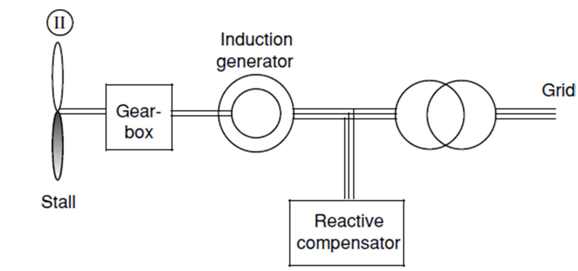
Wind Energy Conversion System with Three Types of Components.

The turbine rotor converts the fluctuating wind energy into mechanical energy, which is converted into electrical power through the generator, and then transferred into thegrid through a transformer and transmission lines. Wind turbines capture the power from the wind by means of aerodynamically designed blades and convert it to rotating mechanical power. The number of blades is normally three and the rotational speed decreases as the radius of the blade increases. For megawatt range wind turbines the rotational speed will be 10-15 rpm. The weight-efficient way to convert the low-speed, high-torque power to electrical power is to use a gearbox and a generator with standard speed. The gearbox adapts the low speed of the turbine rotor to the high speed of the generator. The gearbox may be not necessary for multipole generator systems. The generator converts the mechanical power into electrical energy, which is fed into a grid through possibly a power electronic converter, and a transformer with circuit breakers and electricity meters. The connection of wind turbines to the grid is possible at low voltage, medium voltage, high voltage, and even at the extra high voltage system since the transmittable power of an electricity system usually increases with increasing the voltage level. While most of the turbines are nowadays connected to the medium voltage system, large offshore windfarms are connected to the high and extra high voltage level.



GENERATOR SYSTEMS FOR WIND TURBINES

Both induction and synchronous generators can be used for wind turbine systems. Induction generators can be used in a fixed-speed system or a variable-speed system, while synchronous generators are normally used in power electronic interfaced variable-speed systems. Mainly, three types of induction generators are used in wind power conversion systems: cage rotor, wound rotor with slip control by changing rotor resistance, and doubly fed induction generators. The cage rotor induction machine can be directly connected into an ac system and operates at a fixed speed or uses a full-rated power electronic system to operate at variable speed. The wound rotor generator with rotor-resistance-slip control is normally directly connected to an acsystem, but the slip control provides the ability of changing the operation speed in a certain range. The doubly fed induction generators provide a wide range of speed variation depending on the size of power electronic converter systems. In this paper we first discuss the systems without power electronics except the thyristor soft starter, and then discuss the variable-speed wind turbine systems, including those with partially rated power electronics and the full-scale powerelectronic interfaced wind turbine systems



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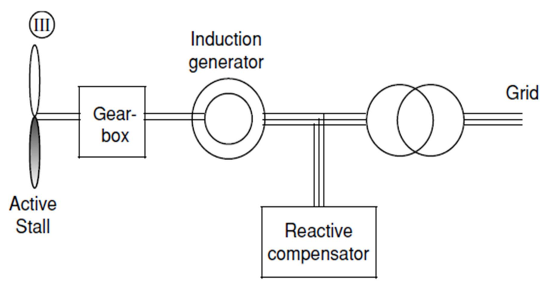

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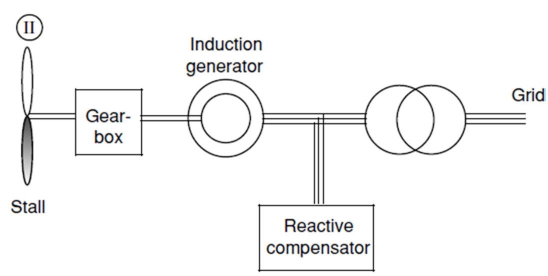


(b)

Wind turbine systems without power converter, butwith aerodynamic power control.(a) Pitch controlled (System I), (b) stall controlled (System II), and (c) active stall controlled.

Fixed-Speed Wind Turbines-

A. In fixed-speed wind turbines, the generator is directly connected to the mains supply grid. The frequency of the grid determines the rotational speed of the generator and thus of the rotor. The generator speed depends on the number of pole pairs and the frequency of the grid. The basic configurations of three different fixed speed concepts are shown in Fig.2. The advantage of wind turbines with induction generators is the simple and cheap construction. In addition, no synchronization device is required.

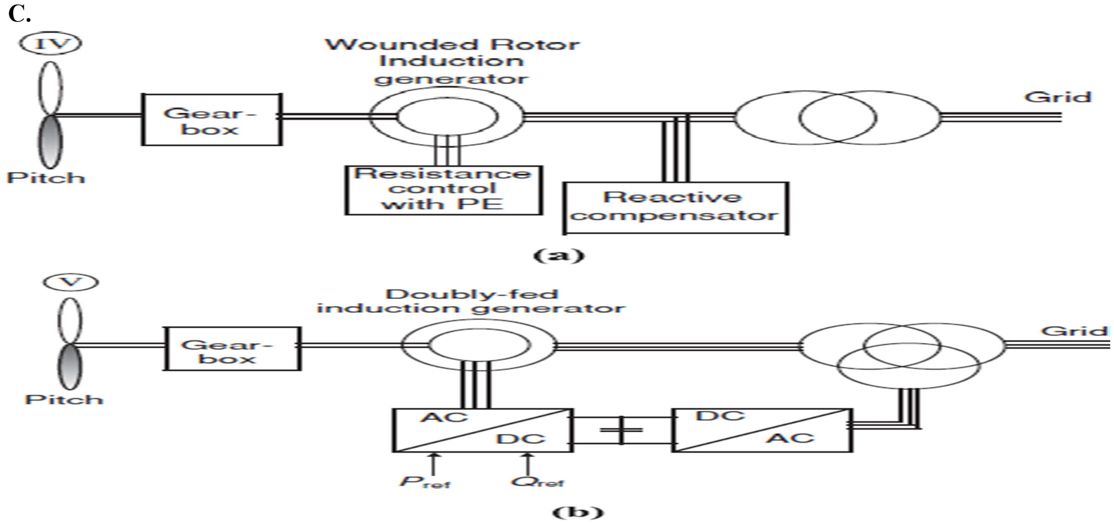
Variable Speed Wind Turbines-

B. In fixed-speed wind turbines, the generator is directly connected to the mains supply grid. The frequency of the grid determines the rotational speed of the generator and thus of the rotor. The generator speed depends on the number of pole pairs and the frequency of the grid. The basic configurations of three different fixed speed concepts are shown in Fig.2. The advantage of wind turbines with induction generators is the simple and cheap construction. In addition, no synchronization device is required.

Variable Speed Wind Turbines-

In variable-speed systems the generator is normally connected to the grid by a power electronic system. For synchronous generators and for induction generators without rotor windings, a full-rated power electronic system is connected between the stator of the generator and the grid, where the total power production must be fed through the power electronic system. For induction generators with rotor windings, the stator of the generator is connected to the grid directly. Only the rotor of the generator is connected through a power electronic system. This gives the advantage that only a part of the power production is fed through the power electronic converter. This means the nominal power of the converter system can be less than the nominal power of the wind turbine. In general the nominal power of the converter may be 30% of the power rating of the wind turbine, enabling a rotor speed variation in the range of 30% of the nominal speed. By controlling the active power of the converter, it is possible to vary the rotational speed of the generator and thus of the rotor of the wind turbines. The generator for wind turbine systems shown in Fig.3 is an induction generator with a wounded rotor.

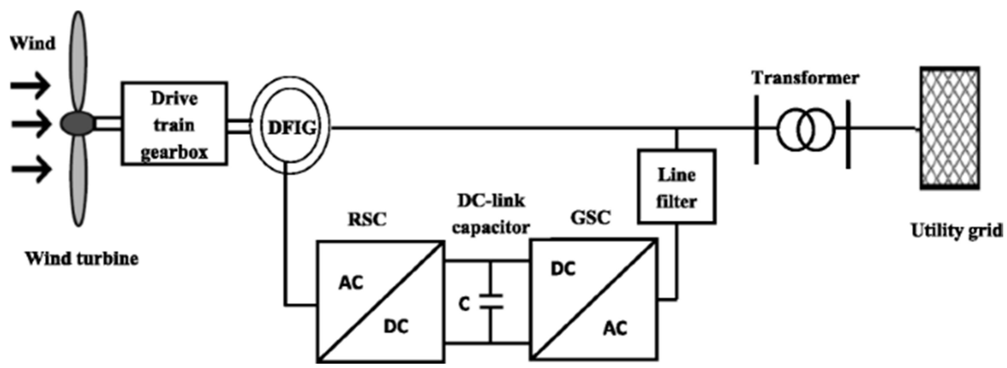
C.

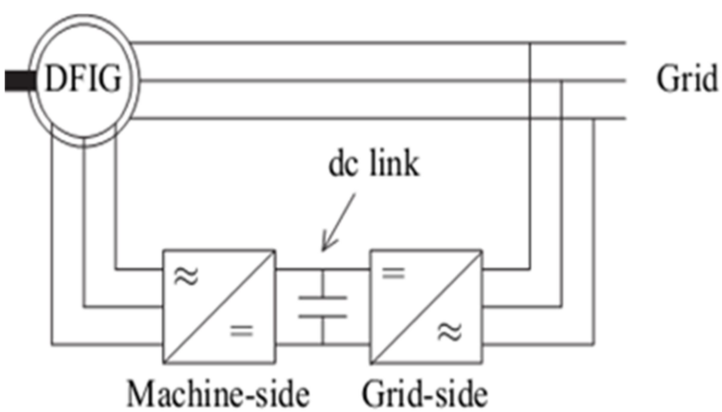


Wind turbine topologies with partially rated power electronics and limited speed range. Rotor-resistance converter (System IV) and doubly-fed induction generator (System V).

DOUBLEFED INDUCTION GENERATOR

Doubly-fed electric machines are basically electric machines that are fed ac currents into both the stator and the rotor windings. Most doubly-fed electric machines in industry today are three-phase wound-rotor induction machines. Although their principles of operation have been known for decades, doubly-fed electric machines have only recently entered into common use. This is due almost exclusively to the advent of wind power technologies for electricity generation. The primary advantage of doubly-fed induction generators when used in wind turbines is that they allow the amplitude and frequency of their output voltages to be maintained at a constant value, no matter the speed of the wind blowing on the wind turbine rotor. Because of this, doubly-fed induction generators can be directly connected to the ac power network and remain synchronized at all times with the ac power network. Other advantages include the ability to control the power factor, while keeping the power electronics devices in the wind turbine at a moderate size. A more detailed picture of the DFIG system with a back-to- back converter can be seen in Fig.4. The back-to-back converter consists of two converters, i.e., machine-side converter and grid-side converter that are connected back-to- back. Between the two converters a dc-link capacitor is placed, as energy storage, in order to keep the voltage variations (or ripple) in the dc-link. With the machine-side converter it is possible to control the torque or the speed of the DFIG and also the power factor at the stator terminals, while the main objective for the grid-side converter is to keepthe dc-link voltage constant.

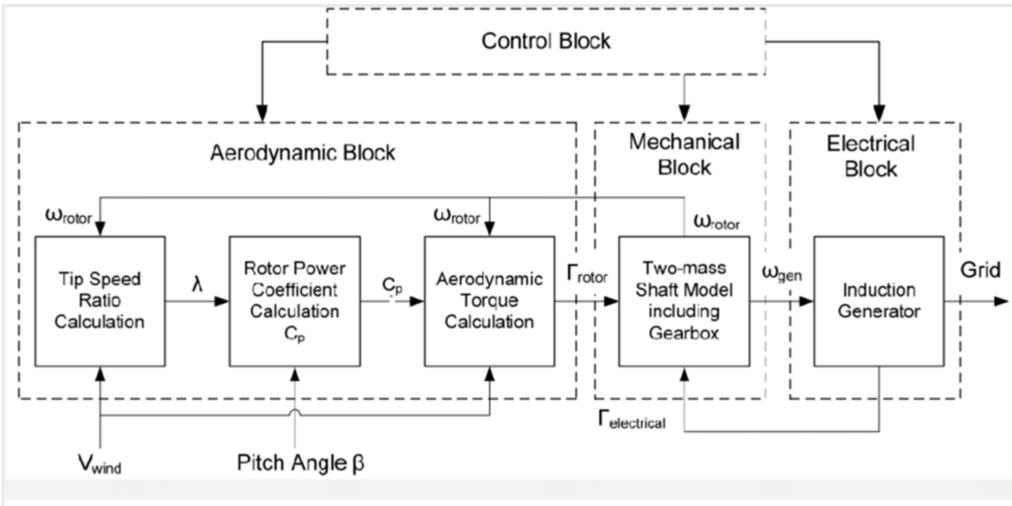




Modeling of DFIG based Wind Turbine

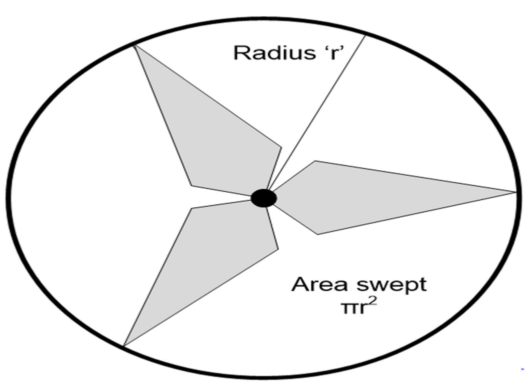
Wind turbine is a complex electromechanical device and in order to tackle complexity, it can be thought of as a collection of subsystem which can be modeled individually.

I. Aerodynamic Model
II. Mechanical Drive train
III. Pitch system
IV. Electrical Machine and Power Converter
V. Control System



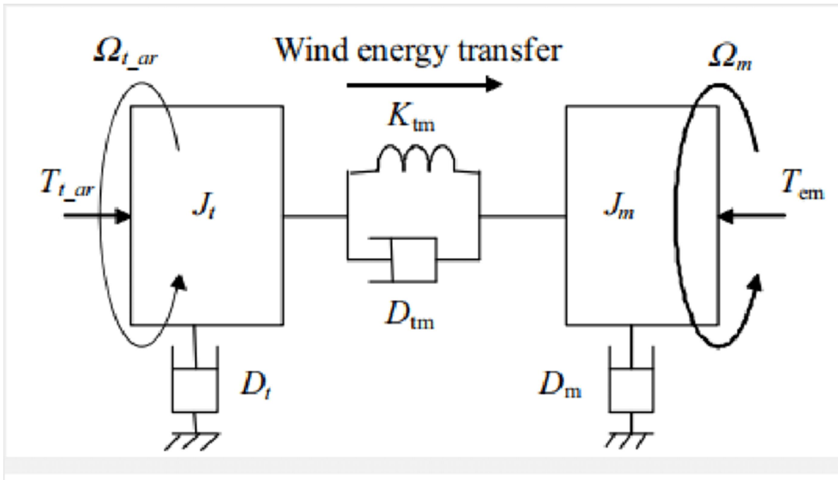
I. Aerodynamic Model

The aerodynamic model represents the power extraction of the rotor, calculating the mechanical torque as a function of the air flow on the blades.



II. Mechanical Drive train

Considering the designing aspect, the mechanical representation of the entire wind turbine is complex. Wind Turbine drivetrain can be considered as a two mass system coupled through gear train.

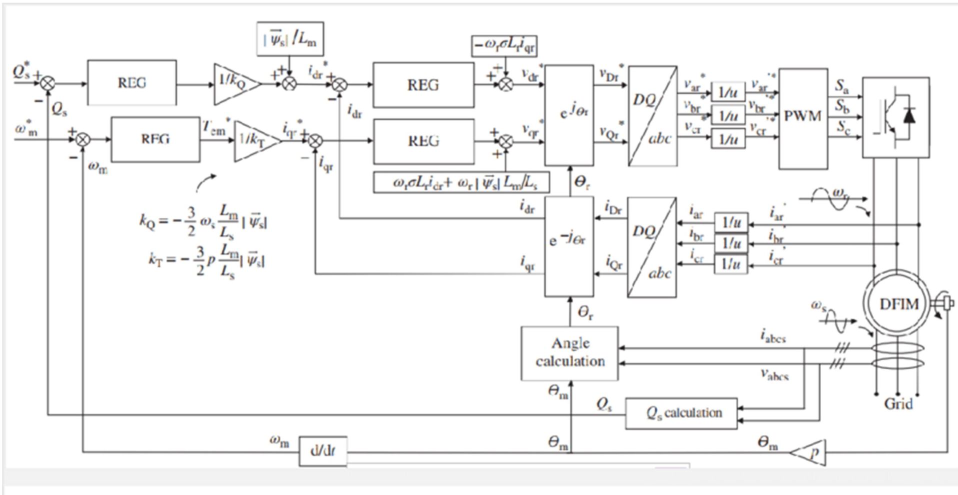


III. Pitch system

For wind turbine pitch control system is important for power limitation purpose at high wind speed condition greater than rated wind speed.

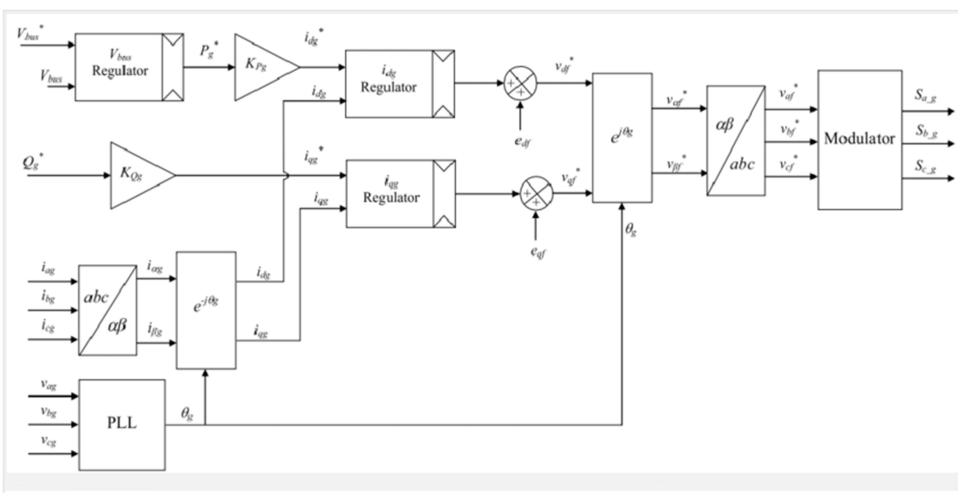
1. Rotor Side Control-

Rotor side DFIG is connected to grid through bi-directional AC-DC-AC converters.



2. Grid Side Control-

The aim of the grid side control is to maintain DC link voltage at a constant level irrespective of the rotor and guarantees unity power factor operation in rotor circuit.



OPERATING PRINCIPLE OF WOUND-ROTOR INDUCTION MACHINE

A wound-rotor induction machine can be operated as a doubly-fed induction machine (DFIG) when a power converter is present in its rotor circuit. This converter directs the power flow into and out of the rotor windings. Because the DFIG can operate as either a motor or a generator at sub- synchronous and super-synchronous speeds. When the machine runs above synchronous speed, this operation is termed super-synchronous operation. Similarly, operation below synchronous speed is called sub-synchronous operation. In both sub- and super-synchronous operation, the machine can be operated either as a motor or a generator. In the motoring mode of operation, the torque produced by the machine is positive. On the other hand, during generating operation, the machine needs mechanical torque as input; thus, the torque is negative during generating operation. So, basic concepts of slip and frequency is yields

$$\text{Slip} = s = \frac{\omega_s - \omega_m}{\omega_s} \qquad (1)$$

$$= \frac{n_s - n_m}{n_s}$$

$$n_s = \frac{60 f_s}{p} \text{ rpm}$$

$$n_m = n_s (1\text{-}s)$$

$$\omega_m = \omega_s (1\text{-}s)$$

The induced rotor voltages have frequency of

$$\omega_r = \omega_s - \omega_m$$

$$s = \frac{\omega_r}{\omega_s}$$

$$\omega_r = s\omega_s$$

$$f_r = s f_s$$

Where,

n_s = synchronous speed of machines

f_s = stator frequency or supply frequencyp = number of pole pairs

Synchronous speed induces an emf in the rotor windings according to

$$e_{ind} = (\bar{v} \times \bar{B}) . \bar{L}$$

Where,

e_{ind}= induced emf in one conductor of rotor

v = velocity of conductor relative to stator flux rotation

B = stator magnetic flux density vector

L = length of conduct

POWER AND TORQUE EXPRESSION OF DFIG

Power balance relation:

$$P_{mech} = P_s + P_r - P_{loss,s} - P_{loss,r} \quad \textbf{(4)}$$

Where,

P_s and P_r are powers entering the machine through stator and rotor windings, $P_{loss,s}$ and $P_{loss,r}$ are the stator and rotor winding losses

$$P_{mech} = 3\left|I_r^{\ 2}\right|(R_{eq}) - 3\mathrm{Re}\{\underline{V}_{eq}\underline{I}_r *\} \quad \textbf{(5)}$$

$$= 3\left|I_r^{\ 2}\right|\left(\frac{R_r(1-s)}{s}\right) - 3\mathrm{Re}\left\{\underline{V}_r\left(\frac{1-s}{s}\right)\underline{I}_r *\right\}$$

$$= 3\left|I_r^{\ 2}\right|\left(\frac{R_s(1-s)}{s}\right) - 3\left(\frac{1-s}{s}\right)\mathrm{Re}\{\underline{V}_r\underline{I}_r *\}$$

Since,

$$P_{mech} = T_{em}\Omega_m$$

$$= T_{em}\frac{\omega_m}{p}$$

$$T_{em} = P_{mech}\ \frac{p}{\omega_m} \quad \textbf{(6)}$$

$$= 3\frac{p}{\omega_m}\left|I_r^{\ 2}\right|\left(\frac{R_r(1-s)}{s}\right) - 3\frac{p}{\omega_m}\mathrm{Re}\left\{\underline{V}_r\left(\frac{1-s}{s}\right)\underline{I}_r *\right\}$$

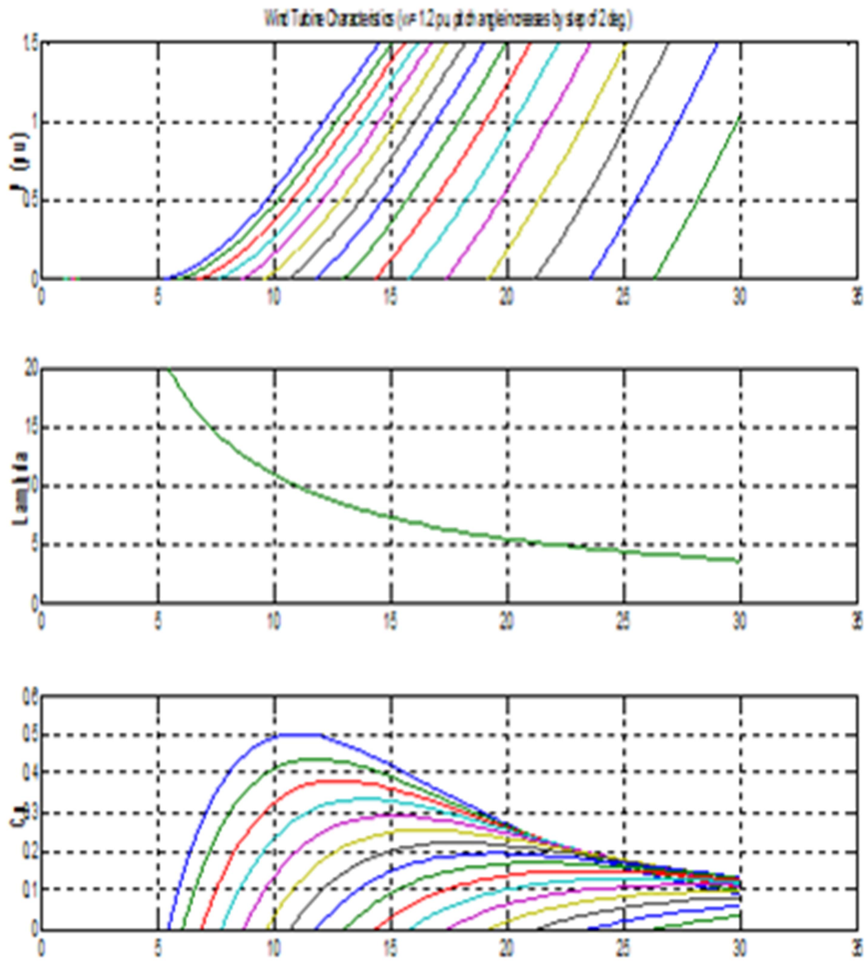
$$T_{em} = 3\frac{p}{\omega_m}\left|I_r^{\ 2}\right|\left(\frac{R_r\omega_m}{\omega_r}\right) - 3\frac{p}{\omega_m}\left(\frac{\omega_m}{\omega_r}\right)\mathrm{Re}\{\underline{V}_r\underline{I}_r *\}$$

$$= \frac{3p\left|I_r^{\ 2}\right|R_r}{\omega_r} - \frac{3p}{\omega_r}\mathrm{Re}\{\underline{V}_r\underline{I}_r *\}$$

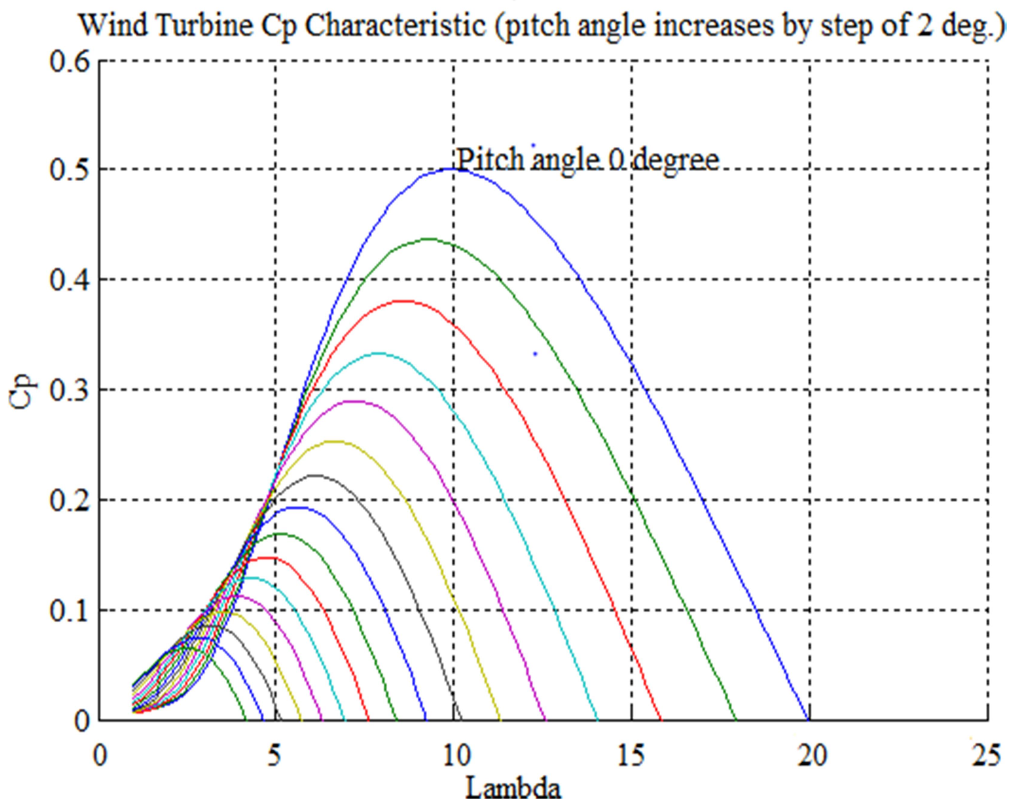
$$= \frac{3p\left|I_r^{\ 2}\right|R_r}{\omega_r} - \frac{3p}{\omega_r}V_rI_r\cos(\varphi_v - \varphi_i)$$

CHARACTERISTIC OF DFIG IN SIMULINK

The characteristics of DFIG model is shown. There are three axes. The first axis illustrates the power output in per unit versus wind speed in meter per second. Since the cut in wind speed is 5 m/s and cut out windspeed is 30 m/s, the curves are drawn for power versus wind speed with pitch angle increased by step of two degree. The second axis is described Lambda versus wind speed. As shown in Fig.5, Lambda value is decreased as the wind speed increased. The last axis is displayed the Power Coefficient (Cp) versus wind speed. In this axis, the power coefficient is expressed for various pitch angles as in first axis. Since the designed rated wind speed of built in DFIG is 11 m/s, the power coefficient is maximum at this wind speed. Fig.6. is illustrated the detail characteristics of power coefficient versus wind speed.

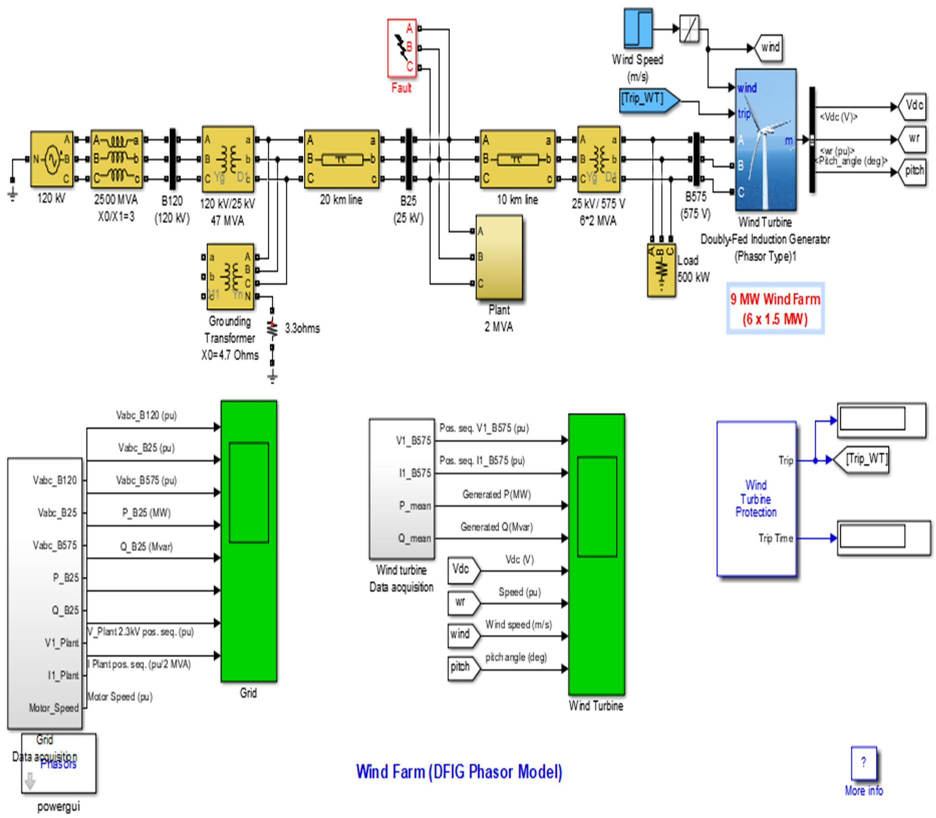


<u>Characteristics of DFIG</u>

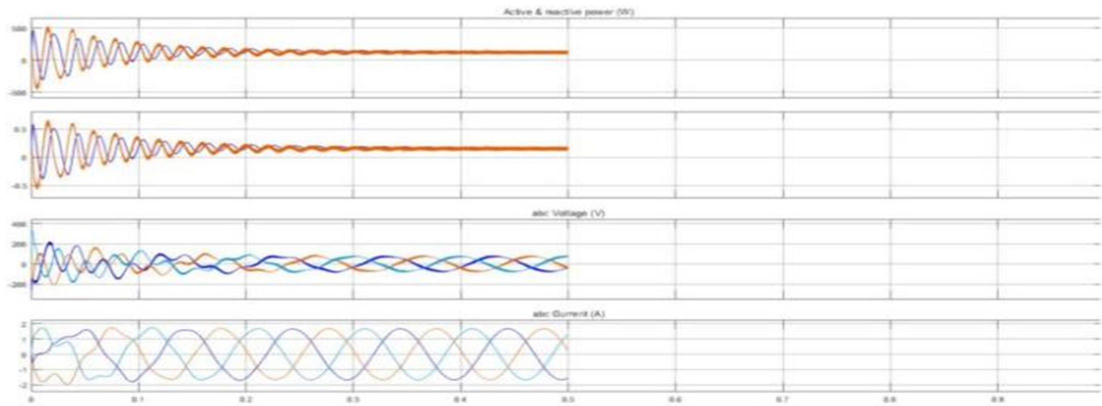


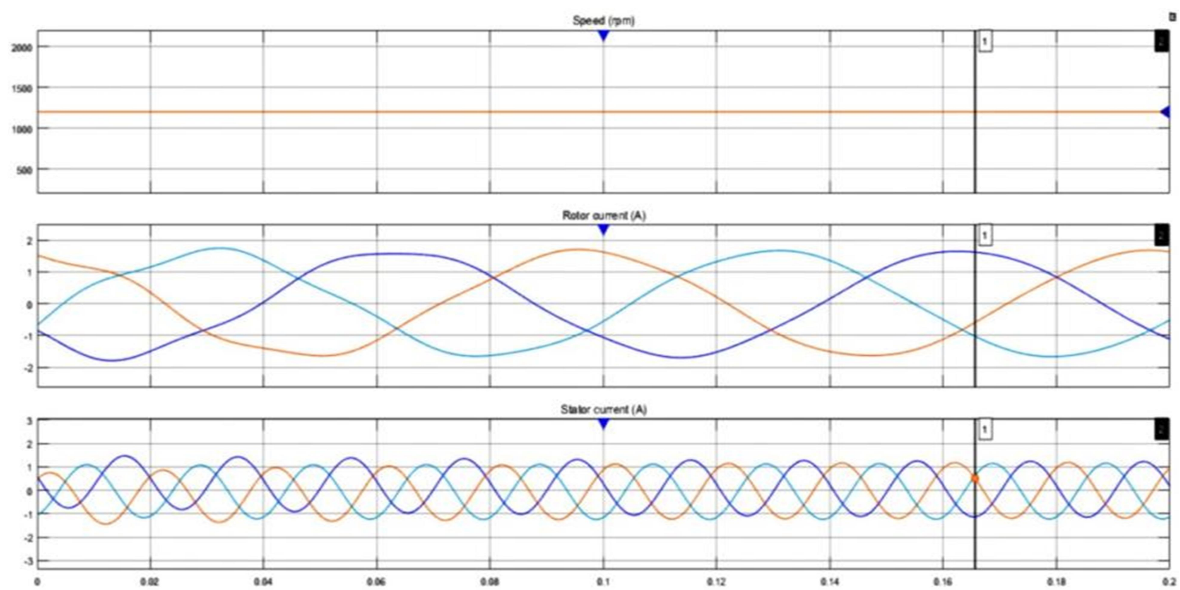
Detail Characteristics of Power Coefficient versus Wind Speed

REAL TIME SIMULATION ON MATLAB



SIMULATION RESULTS





CONCLUSION

A successful wind energy conversion system processes the ability of transform mechanical energy delivered by the wind into electrical energy that can be used to power any electrical grid . This project has addressed the modeling and control of variable speed type 3 wind turbine DFIG based.The development of this model is a part of an effort to develop generic manufacturers independent wind turbine models capable of being used for power system studies . To maintain generally various Xbox emissions and simplification have been used in the modeling process and despite all the simplifications,The developed time domain model performs admirably and is able to approximate the behavior of a real world WPP in normal condition . Aspects of the theory behind technology have also been discussed in this Project And the necessary mathematical foundation has been presented,the modeling of wind turbine generators for bulk power system stability studies is the focus of intense activity in many parts of the industry.This model is expected to give realistic and correct results when used for bulk system performance studies . It is expected that this model components will continue to evolve,in terms of Parameter values and structure as experience and additional test data are obtained . Various wind turbine systems with different generators and power electronic converters have been described. Different types of wind turbine systems will have quite different performances and controllability, which was discussed with some results from study examples. The wind farms with different turbines may need different configurations for best use of the technical merits; therefore, electrical topologies of wind farms with different wind turbines have been briefed. In general, the connection of DFIG improve the stability of the system and the load voltage. Wind power generation with DFIG provides better performance for terminal voltage recovery after the load connects suddenly.

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