Modeling and Transient Analysis of Wind Generator during Grid Voltage Drop

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ABSTRACT*: In recent years, wind energy has become one of the most important and promising sources of renewable energy, which demands maintaining better means of system stability. The performance of a grid-connected wind energy conversion system (WECS), based on a doubly fed induction generator (DFIG) fed by an AC-DC-AC converter, is presented. The stator winding of the DFIG is connected directly to the grid and the rotor of the DFIG is connected to the grid through a AC/DC/AC converter.*

The main power is transferred through the stator windings of generator that are directly connected to the grid. Around 65-75% of total power is transmitted through the stator windings and the remaining 25% of total power is transmitted using rotor windings (i.e.) through the converters. The major advantage of speed control of variable speed wind turbine generators is usually optimized which gives the maximum power in the system. This project focuses towards an efficient control strategy to improve the overall efficiency and stability in Doubly Fed Induction Generator (DFIG) using converters.

Keywords: *DFIG, Back to Back converter, wind turbine.*

I.   INTRODUCTION

Due to increasing demand on electrical energy and environmental concerns, a considerable amount of effort is being made to generate electricity from renewable sources of energy. The major advantages of using renewable sources are abundance. Wind is the one of the most abundant renewable sources of energy in nature. The wind energy can be harvested by using a wind energy conversion system, composed of a wind turbine, an electrical generator, a power electronic converter and a control system. With increased penetration of wind power into electrical grids, DFIG wind turbines are largely deployed due to their variable speed generation and they are the most important generators for wind energy applications.
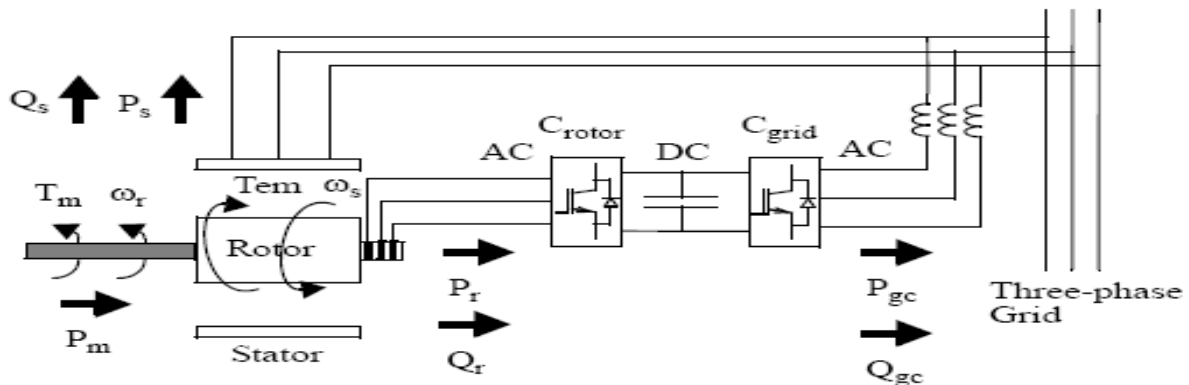

Fig 1.1 DFIG connected to Back to Back converter

In conventional implementation of a grid connected DFIG, back-to-back converters are used to connect the DFIG rotor to the utility. The rotor side converter controls the magnetizing and torque rotor currents. The grid side converter regulates the voltage in the dc bus of the back- to-back converters. It should be recognized here that thyristors are commonly used as switching devices in the shaft generator system because of their higher reliability, efficiency and easy acquisition of large ratings. Since the output frequency and voltage of the DFIG driven by the wind turbine are changed due to unexpected fluctuation in the wind, ac power generated by the DFIG is converted once into dc power with the thyristor rectifier, and then the dc power is converted again into ac power with constant frequency and constant voltage with the inverter, which is supplied to the loads (or electric power utility).

REASONS FOR USING DFIG

DFIG-based WECS are highly controllable, allowing maximum power extraction over a large range of wind speeds. Furthermore, the active and reactive power control is fully decoupled by independently controlling the rotor currents. Finally, the DFIG- based WECS can either inject or absorb power from the grid, hence actively participating at voltage control. The synchronous nature of PMSG may cause problems during startup, synchronization and voltage regulation and they need a cooling system, since the magnetic materials are sensitive to temperature and they can lose their magnetic properties if exposed to high temperature. Hence DFIG is dominantly used when compared to PMSG.

A three-phase wound-rotor induction machine can be set up as a doubly-fed induction motor. In this case, the machine operates like asynchronous motor whose synchronous speed (i.e., the speed at which the motor shaft rotates) can be varied by adjusting the frequency frotor of the ac currents fed into the rotor windings. The same wound-rotor induction machine setup can also serve as a doubly-fed induction generator. In this case, mechanical power at the machine shaft is

converted into electrical power supplied to the ac power network via both the stator and rotor windings. Furthermore, the machine operates like a synchronous generator whose synchronous speed (i.e., the speed at which the generator shaft must rotate to generate power at the ac power network frequency (fnetwork) can be varied by adjusting the frequency of the ac currents fed into the rotor windings.

In a conventional three-phase synchronous generator, when an external source of mechanical power (i.e., a prime mover) makes the rotor of the generator rotate, the static magnetic field created by the dc current fed into the generator rotor winding rotates at the same speed (nrotor) as the rotor. As a result, a continually changing magnetic flux passes through the stator windings as the rotor magnetic field rotates, inducing an alternating voltage across the stator windings. Mechanical power applied to the generator shaft by the prime mover is thus converted to electrical power that is available at the stator windings.

MODES OF OPERATION IN DFIG

Depending on the rotor speed, there are two modes of operation in a DFIG WECS. (1) Super-synchronous mode, in which the generator operates above the synchronous speed , (2) sub synchronous mode, in which the generator operates below the synchronous speed. The slip is negative in the super-synchronous mode and becomes positive in the sub-synchronous mode. Depending on whether the slip is positive or negative, the rotor circuit can receive or deliver power from or to the grid. In the super synchronous operation mode, the mechanical power \Pm\ from the shaft is delivered to the grid through both stator and rotor circuits. The rotor power \Pr\ is transferred to the grid by power converters in the rotor circuit, whereas the stator power is delivered to the grid directly. Neglecting the losses in the generator and converters, the power delivered to the grid |Pg| is the mechanical power |Pm| of the generator. For the sub synchronous operation the rotor receives the power from the grid. Both mechanical power |Pm| and rotor power |Pr| are delivered to the grid through the stator. Although the stator power is the sum of |Pm| and |Pr|, it will not exceed its power rating since in the sub-synchronous mode the mechanical power |Pm| from the generator shaft is lower than that in the super-synchronous mode. As in the previous case, neglecting the losses, the total power delivered to the grid |Pg| is the input mechanical power |Pm|.

II.   MODELING OF WIND TURBINE

The modeling of wind turbine consists of three important parameters. They are a) Transmission system b) Wind turbine system c) Distribution system.

TRANSMISSION SYSTEM

The electrical energy produced at various power stations are transferred to the consumers through conductor lines.It consists of a voltage source, step-up transformer, transmission line, a bus bar, step down transformer, V-I measurement block, scope and a resistive load.

1) AC Power Supply Scheme
    The large network of conductors between the power station and the consumers can be broadly divided into two parts namely transmission and distribution systems. Each part is subdivided into primary and secondary transmission.
2) Generating Station
    The generating station where electric power is produced by 3-phase alternator is operated in parallel. The usual generating voltage is 11kv. For economy in the transmission of electric power, the generated voltage is stepped up to 132kv at the generating station with the help of 3-phase transformers.
3) Primary Transmission
    The electric power at 132kv is transmitted by 3- phase, 3-wire overhead system. This forms the primary transmission.
4) Secondary Transmission
    The primary transmission line terminates at the receiving station. At the receiving station the voltage is reduced to 33kv by step-down transformers. From this station, electric power is transmitted at 33kv by 3-phase 3-wire over head System to various sub-stations. This forms the secondary transmission.
5) Primary Distribution
    The secondary transmission line terminates at the sub-station where voltage is reduced from 33kv to 11kv 3-phase, 3-wire. This forms the primary distribution. From this the large consumers which are using 11kv are distributed from here.
6) Secondary Distribution
    The electric power from primary distribution line (11kv) is delivered to distribution sub-stations. These sub-stations step down the voltage to 400V, 3-phase and 4-wire for secondary distribution. The voltage between any two phases is 400V and between any phase and neutral is 230V. From this the voltage is supplied to the feeders and to the consumers.

Wind turbines convert the kinetic energy present in the wind into mechanical energy by means of producing torque. Since the energy contained by the wind is in the form of kinetic energy, its magnitude depends on the air density and the wind velocity. The wind power developed by the turbine is given by the equation (1.1):

$P = ½ Cp\rho AV3 … (1.1)$

Where Cp is the power co-efficient, ρ is the air density in kg/m3, A is the area of the turbine blades in m3 and V is the wind velocity in m/sec. The power coefficient Cp gives the fraction of the kinetic energy that is converted into

mechanical energy by the wind turbine. It is a function of the tip speed ratio λ and depends on the blade pitch angle for pitch-controlled turbines. The tip speed ratio may be defined as the ratio of turbine blade linear speed and the wind speed.

$$\lambda = R\omega/V \ldots (1.2)$$

Substituting (1.2) in (1.1), we have:

$$P = \tfrac{1}{2}\, C_p\, (\lambda)\, \rho A(R/\lambda)\, \omega 3 \ldots (1.3)$$

The output torque of the wind turbine Turbines calculated by the following equation (1.4)

$$Turbine = \tfrac{1}{2}\, \rho A C_p V/\lambda \ldots (1.4)$$

where R is the radius of the wind turbine rotor(m). There is a value of the tip speed ratio at which the power coefficient is maximum. Variable speed turbines can be made to capture this maximum energy in the wind by operating them at a blade speed that gives the optimum tip speed ratio. This may be done by changing the speed of the turbine in proportion to the change in wind speed.

III.   Converter Methodology

Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT based PWM converter. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generator. Where Vr is the rotor voltage and Vgc is grid side voltage. The AC/DC/AC converter is basically a PWM converter which uses sinusoidal PWM technique to reduce the harmonics present in the wind turbine driven DFIG system. Here Crotor is rotor side converter and Cgrid is grid side converter. To control the speed of wind turbine gear boxes or electronic control can be used.

IV.   Control Parameters

The block diagram for control parameters shows different modes of operation in which we can select the voltage regulation mode and Var regulation mode. Also we can set the external reactive current Iq ref for grid side to zero which gives flexibility to simulate various fault conditions. Here we input the required values of voltage regulator gains (both proportional and integral), power regulator gains, current regulator gains and their respective rate of change.

V.   Induction Machine Model

The model of the IG is an instantaneous values full order one, i.e. fifth order with the derivative of the stator fluxes included. This is the best choice to accurately simulate transients in the power systems when the electrical dynamics of the IG is of primary interest. The values of the IG parameters have been chosen as per the requirements. The DFIG wind farm is composed of 6 aggregated units of 1.5MW each.

VI.   Grid Side Converter

The GSC is modeled using a universal bridge model with IGBTs connected to the IG terminals through a series RL filter. The control of the GSC aims at keeping the DC-link capacitor voltage constant at nominal value. It does not contribute to grid voltage regulation or reactive power injection (Iq = 0). The converter maximum power is half the IG rated power.

VII.   Rotor Side Converter

The RSC controls the active power delivered by the DFIG, by determining a torque reference (following a power-speed curve). This torque reference is used along with a flux estimate to determine the reference rotor current Idr. The RSC model has been modified so as to support the grid voltage with reactive power injection. The reference for the reactive power is determined through a PI controlled by measuring the grid voltage and comparing it with a reference.

VIII.   Network Model

A 9-MW wind farm consisting of six 1.5 MW wind turbines connected to a 25-kV distribution system exports power to a 120-kV grid through a 30-km, 25-kV feeder. A 2300V, 2-MVA plant consisting of a motor load (1.68 MW induction motor at 0.93 PF) and of a 200-kW resistive load is connected on the same feeder at bus B25.
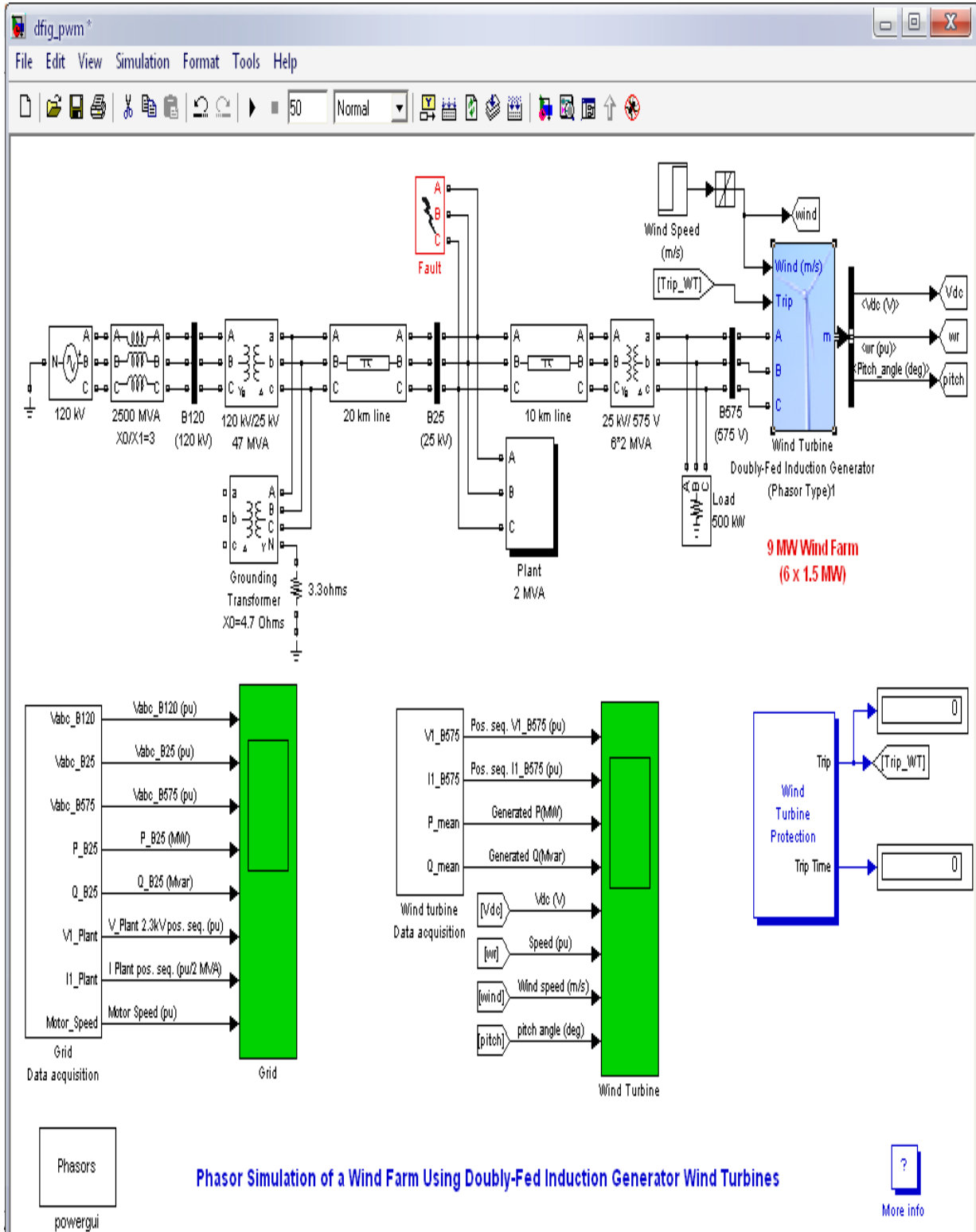
MATLAB/SIMULINK MODEL

Fig 1.2 DFIG Matlab/Simulink Model

IX.   Results and Discussions

In the "Wind Speed" step block specifying the wind speed. Initially, wind speed is set at 8 m/s, then at t = 5s, wind speed increases suddenly at 14 m/s.
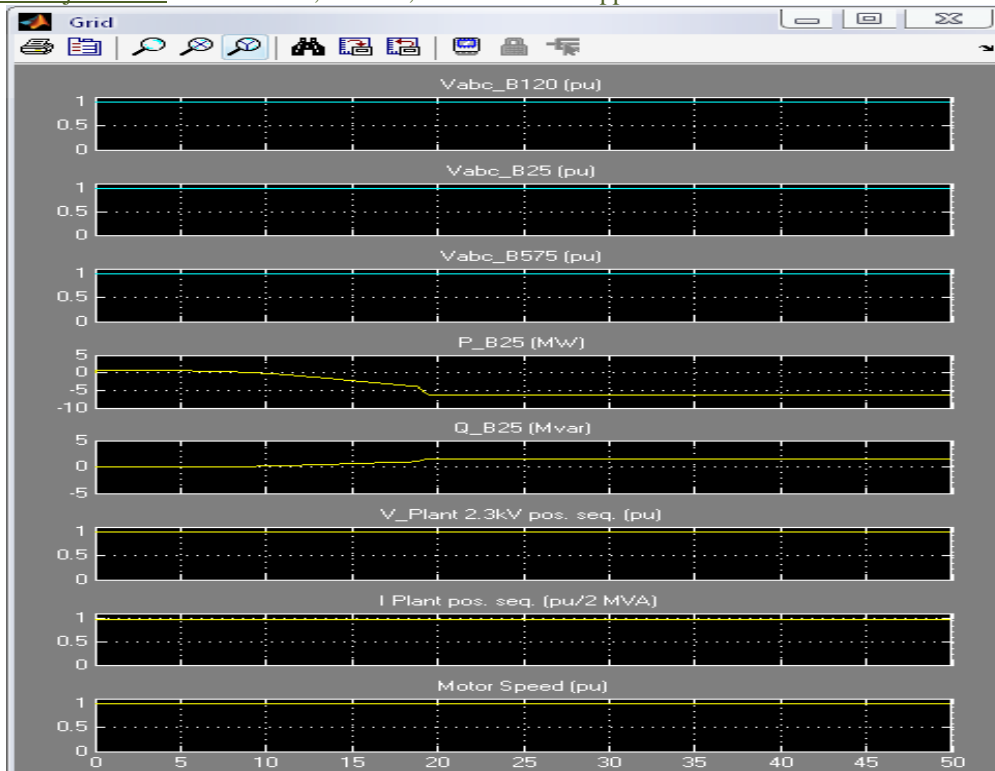
Fig 1.3 Outputs of Grid

Start simulation and observe the signals on the "Wind Turbine" scope monitoring the wind turbine voltage, current, generated active and Reactive powers, DC bus voltage and turbine speed. At t = 5 s, the generated active power starts increasing smoothly (together with the turbine speed) to reach its rated value of 9 MW in approximately 20 s.Over that time frame the turbine speed will have increased from 0.8 PU to 1.21 PU. Initially, the pitch angle of the turbine blades is zero degree and the turbine operating point follows the red curve of the turbine power characteristics up to point D. Then the pitch angle is increased from 0 deg to 0.76 deg in order to limit the mechanical power. We also observed the voltage and the generated reactive power. The reactive power is controlled to maintain a 1 PU voltage. At nominal power, the wind turbine absorbs 0.68 Mvar (generated Q = - 0.68 Mvar) to control voltage at 1PU.
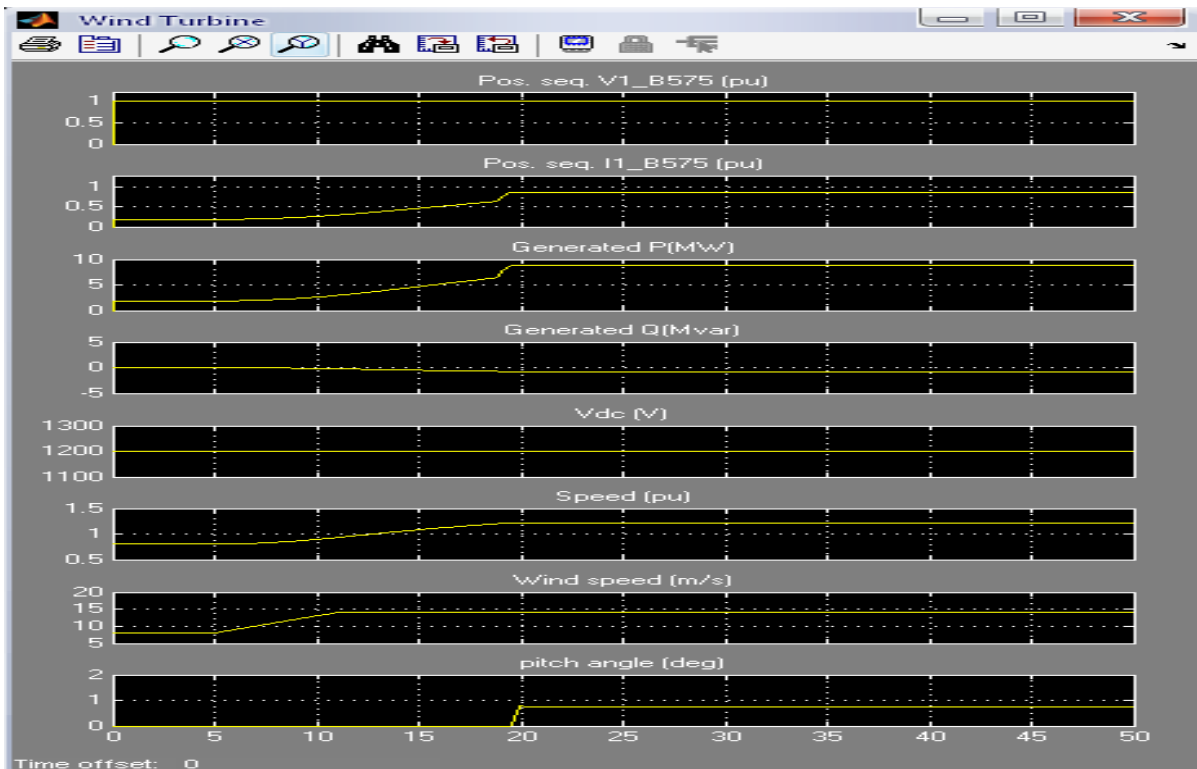

Fig 1.4 Outputs of Wind turbine

X.   Conclusion

The wind farm is built with the rectifiers and the inverters. The features are low cost, low commutation power losses and high reliability. 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. So finally we simulated grid side and wind turbine side parameters and the corresponding results have been displayed.

The model is a discrete-time version of the Wind Turbine Doubly-Fed Induction Generator (Phasor Type) of MATLAB/SimPowerSystems. Here we also took the protection system in consideration which gives a trip signal to the system when there is a fault (single phase to ground fault) on the system. The faults can occur when wind speed decreases to a low value or it has persistent fluctuations. The DFIG is able to provide a considerable contribution to grid voltage support during short circuit periods. Considering the results it can be said that doubly fed induction generator proved to be more reliable and stable system when connected to grid side with the proper converter control systems.

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