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Wind Turbine Modeling and Analysis Using Doubly Fed Induction Generator

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Abstract **- Wind energy is a popular renewable energy source that has shown to be a sustainable source of power with little environmental effect. When contemporary wind farms are connected to the grid, they may potentially provide a reliable source of energy to supplement the base power provided by thermal, nuclear, and hydro power plants. Any loss of wind output has major consequences for system stability and may lead to a cascading outage. To incorporate these massive wind farms into the grid, the performance of grid-connected wind farms in both steady state and transient scenarios is required. The bulk of today's large wind generating plants employ doubly fed induction generators. The controller designs are based on classic decoupled vector control methodologies, and the present work uses a sixth-order mathematical model of a grid-connected doubly fed induction generator. The simulations are used to validate the DFIG model for wind energy systems. The whole simulation is run in the MATLAB/SIMULINK environment.**

Keywords**: renewable energy source, grid, doubly fed induction generators**

1 INTRODUCTION

It is common practise for wind turbine generators (WTGs) to be set to generate the most electrical output possible under average wind conditions. However, wind speed variations affect the WTG's output, making it difficult to predict how much electricity will be produced. In the United States, wind energy today accounts for 1%–2% of total power generation.

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A. Aerodynamic Conversion

The rotor blades of a wind turbine convert the kinetic energy in the wind into mechanical energy. The so-called Cp (,)-curve may be utilised for steady-state estimations of mechanical power from a wind turbine [2]. The following is a general formula for the relationship between wind speed and mechanical power derived from the wind

$$P_m = (\rho/2) A_r C_p(\lambda, \beta) v_w^3$$

where, P_m is the power extracted from the wind; ρ is the air density;

C_p is the performance coefficient or power coefficient;

λ is the tip-speed ratio; $A_r = \Pi R^2$ is the area covered by the wind turbine rotor blades;

R is the radius of the rotor;

v_w denotes the wind speed;

β is the blade pitch angle.

The tip-speed ration λ is defined as

$$\lambda = \frac{\omega_r R}{v_w}$$

where, $\omega_r = P/2 * \omega_m$ is the electrical speed (elec. rad/s), P is the number of pole DFIG,
and ω_m is the mechanical speed of the rotor (mech. Rad/s). By combining Eq. (2.1) and (2.2), we can see that

$$P_m = \frac{\rho}{2} pi * R^5 Cp \frac{\omega_r^3}{\lambda^3}$$

Aerodynamic power control is used to restrict the wind turbine's input power when the wind blows hard. Aerodynamic power may be managed in three ways: stall, pitch, and active stall control. High wind speeds don't need

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any kind of pitch mechanism, which is what "stall control" refers to.

B. Wind Energy Conversion Systems (WECS)

It is possible to arrange wind turbines to run at a constant speed (within a 1 percent range) or at a variable speed. Directly linked to the grid are fixed-speed wind turbine generators. In order to minimise the start-up current, a soft starter is often used. Reactive power demand from wind turbines may be reduced (nearly eliminated) with the use of a reactive power compensator. Rotational energy from wind turbulence cannot be stored since the speed of the turbine is set to the grid frequency and cannot be adjusted.

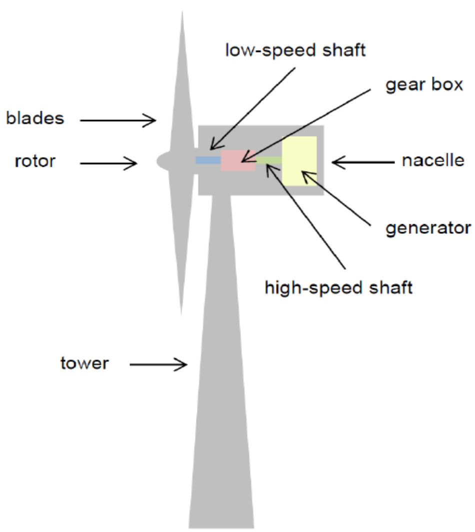

FIGURE 2 Wind turbine.

As wind speeds fluctuate, wind turbine generators (WTGs) are becoming more significant in terms of their ability to adjust their output power in response. Figure 1.3 depicts the four major kinds of wind turbine generators now on the market.

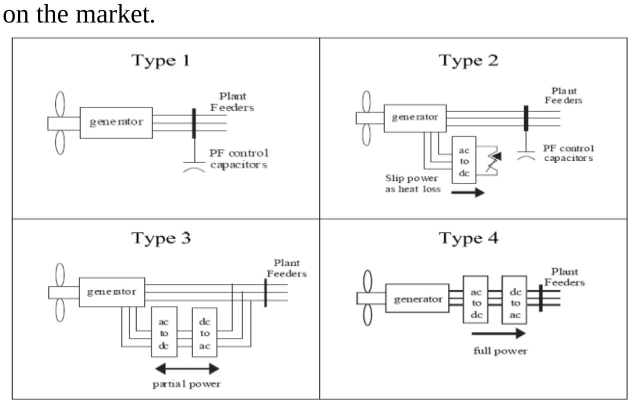

FIGURE 3 Type of wind turbine generators.

When the turbine is directly linked to the grid, the topologies Types 1 and 2 are considered to be the simplest. Because this kind of machine lacks reactive power management, a switch is needed to prohibit the unit from operating at low wind speeds. It also consumes a lot of electricity in the form of reactive energy. Using a rotor resistance that can be electronically regulated, Type 2 is able to influence machine torque speed variations. There are four types of converters that may be used in Type 4. The reactive power and the speed are completely under control in this design. Applications requiring a lot of power are almost often Type 3. (1.5 MWs and above). Dual-fed induction generator wind turbines are a possibility for this project.

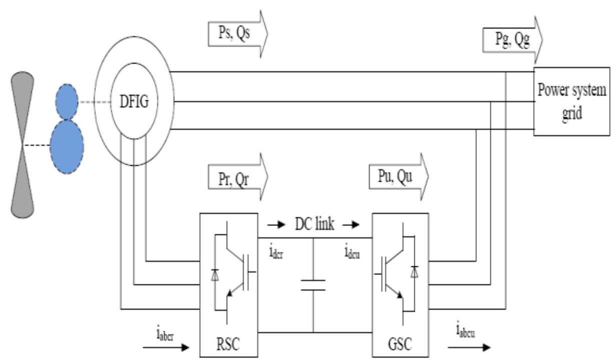

FIGURE 4 Doubly-fed induction generator system diagram.

It is becoming increasingly popular for high-power applications because of its inherent advantages, such as complete control of the reactive power using rotor side converter (RSC) and the grid side converter (GSC); rotor speed can vary by 33% from the synchronous speed of the machine; the converters for this topology need to be rated at most around 25% to 30% for supplying slip power. Power electronic switches and converter losses are reduced as a result; Four quadrant active and reactive power flow capabilities with constant frequency are also provided by this method.

II REVIEW OF ENERGY STORAGE SYSTEM

Electrochemical, kinetic, pressure, potential, electromagnetic, chemical, and thermal sources of energy are among the many that can be stored via batteries, flywheels, compressed air, pumped hydro, ultra capacitors, and SMES (super magnetic energy storage).

The following characteristics are included in this review of energy storage systems:

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1. specific power
2. kinetic energy
3. reaction time (maximum time to ramp up or down)
4. storage capacity
5. practicality
6. self-discharge rate
7. Have a contingency plan
8. level of technical sophistication
9. environmental impact
10. site/location constraints
11. operating and capital costs
12. charging cycles / life time
13. heat sensitivity/rate of charge-discharge
14. Maintenance

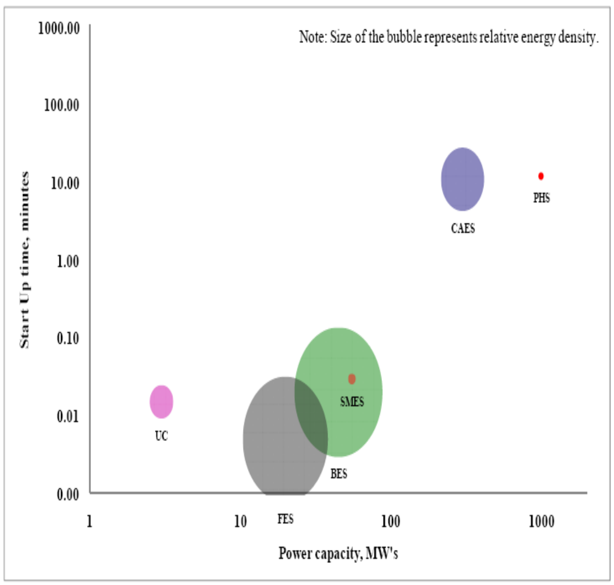


FIGURE 5 Start-up time vs. storage capacity.

The attributes of a technology should be compared to the demands of the application to determine whether it is suitable for that application.

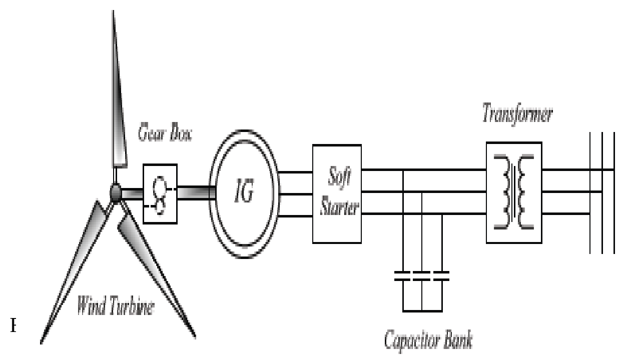
The suitability study shows that no one storage technology can fulfil all of the power system's requirements. As a consequence, specialised storage can only be employed for a limited number of applications.

III Development and Validation of Model for a Grid Connected DFIG

Various generating technologies have been developed and are now in use. This section provides a quick overview of the various generator topologies suitable for fixed and variable speed wind turbines.

A. Wind turbines having a constant rotational speed

Because of their simplicity, durability, and cheap cost, induction generators are the most popular option for fixed-speed wind generation systems. Figure 1 depicts the connection of a fixed-speed wind turbine's induction generator to the power grid. Wind turbines that use fixed-speed gearboxes and generators have rotor speeds that are set by their gearbox and number of poles. Fixed-speed wind turbines typically have two speeds. With two distinct generators with different ratings, or one generator with two different windings, it is possible to achieve this effect. Increased aerodynamic capture and reduced magnetising losses are achieved at low wind speeds. Fast dynamic responsiveness and precise torque control are achieved when vector-control methods are used in the operation of induction devices.



B. Variable-speed wind turbine with DFIG (Conventional DFIG system)

Variable speed wind systems with limited slip, such as 30 percent, might benefit from the DFIG. Since only a small fraction of total system power (20–30 percent) needs to be handled by electrical equipment, the doubly-fed induction generator has become a popular choice. Power electronic equipment losses may be reduced by using a smaller converter, as opposed to power electronic equipment that regulates the whole system's power, such as an inverter or a direct-driven synchronous generator. Additional savings are made on the converter's cost as well. The stator circuit is linked to the grid in Figure 3, while the rotor circuit is connected to the converter through slip rings in Figure 3. In doubly-fed induction generators, three phase windings are installed on the rotor and stator (DFIG). Both the rotor and stator connections may provide power to them.

MSC and PGSC are two converters that make up the "back-to-back" configuration of a back-to-back system (PGSC). A dc-link capacitor serves as an energy storage device between the two converters in order to minimise voltage variations (or 7 ripples) in the dc-link voltage. As the dc-link voltage is maintained, both the machine-side converter and the Grid-side converter may adjust the DFIG's torque or speed, as well as the power factor at the stator terminals.

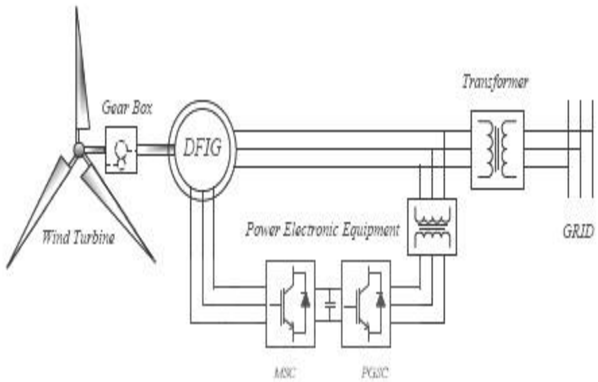


FIGURE 7 Diagram of a grid-connected variable-speed wind turbine with DFIG.

C. Doubly Fed Induction Generator for Wind System

As long as the variable speed range is confined to 30 percent of the system's speed, the DFIG is a viable option. It is seen in Figure 4 that the DFIG includes all of its converters back-to-back. In a "back to back" converter, there are two converters, one on the machine side and one on the grid side, connected "back to back". A DC-link capacitor is put between the two converters. The DFIG's torque or speed may be adjusted using the machine-side converter.

Double-fed induction machines may be used as both a generator and a motor at both sub-synchronous and super-synchronous speeds by adjusting the rotor or machine side converter. When it comes to wind power production, sub-synchronous and super-synchronous speeds are the only modes that matter.

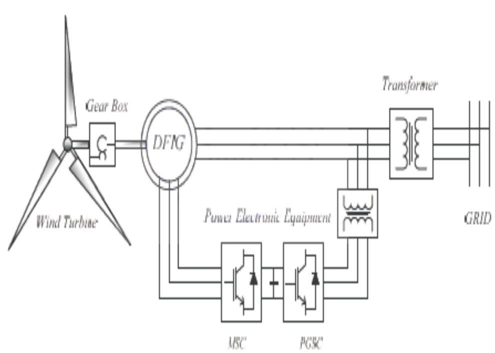


FIGURE 8 Schematic of Conventional DFIG wind system

Figure depicts the DFIG system's speed–torque characteristics. The DFIG may function as a motor or generator, as shown in the diagram, with a rotor-speed range of rmax around the synchronous speed, ws.

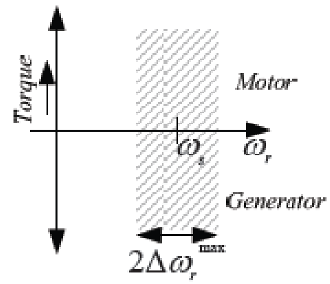


FIGURE 9 Speed–Torque characteristics of DFIG

D. Equivalent Circuit of DFIG

The analogous circuit of a doubly-fed induction generator, which includes the magnetising losses, is shown in Figure . The steady-state values may be calculated using this comparable circuit.

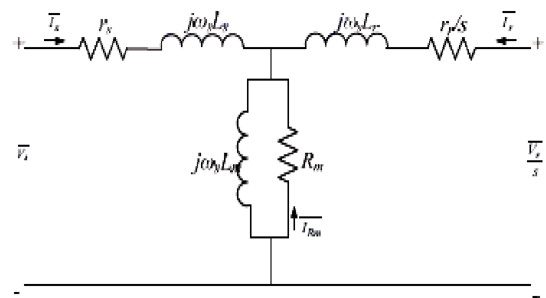


FIGURE 10 Equivalent circuit of doubly fed induction generator

DFIG's equivalent circuit becomes a standard cage-bar induction machine if the rotor voltage, Vr in Fig.3.6, is shorted. The stator current Is and the rotor current Ir are used in the usual motor direction. In terms of stator winding resistance and leakage reactance, they are rs and rl (jsLs). The rotor winding's resistance (rr) and leakage reactance (rr) are measured on the rotor (jsLr). The reciprocal reaction is represented by the (jsM). It is the slip that changes the rotor resistance, which is measured in terms of rr/s when the rotor spins at an angular velocity of r electrical rad/sec. VSC injects balanced three-phase voltage on the rotor side at ss slip frequency, Vr power, and'angle (Vra, Vrb, Vrc). Vr = Vr, which is a phasor of (Vra, Rb, and Rc), must be divided by the slips to get the rotor voltage (Vr)/s, since Fig.6 uses stator frequencies. Kirchhoff's voltage law is applied to the circuit seen in Fig.

$$V_s = r_s I_s + j\omega_s L_s I_s + j\omega_s L_m (I_s + I_r + I_{Rm})$$

$$\frac{\overline{V_r}}{s} = \frac{r_r}{s}\overline{I_r} + j\omega_s L_r \overline{I_r} + j\omega_s L_m (\overline{I_s} + \overline{I_r} + \overline{I_{Rm}})$$

$0 = R_m I_{Rm} + j\omega_s L_m (I_s + I_r + I_{Rm})$

where, Vs is the stator voltage;

IRm is the magnetizing resistance current.

The air-gap flux, stator flux and rotor flux are defined as

$$\Psi_m = L_m (I_s + I_r + I_{Rm}) \quad --$$

$$\Psi_s = L_s I_s + L_m (I_s + I_r + I_{Rm}) = L_s I_s + \Psi_m$$

$$\Psi_r = L_r I_r + L_m (I_s + I_r + I_{Rm}) = L_r I_r + \Psi_m$$

The equations describing the equivalent circuit, i.e., Eqs. can be rewritten as

$Vs = rs\, I\, s + j\omega s\, \Psi s$

$$(\frac{\overline{\Psi_r}}{s} = \frac{r_r}{s}\overline{I_r} + j\omega_s \overline{\Psi_r}$$

IV SMALL SIGNAL ANALYSIS OF CONVENTIONAL DFIG

A. *Modeling of DFIG and drive train*

Fig.6.1 shows the schematic of the conventional grid connected DFIG.

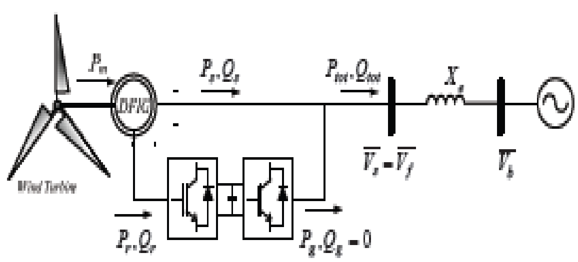


FIGURE 11 Power flow of the grid connected conventional DFIG system.

B. *DFIG Model in dq form*

The following transformation is used to convert the three phase variables into 'dq' variables.

$X_{dqo} = C_1 X_{abc}$ ---------- (6.1)

where, 'C' is the 'abc' to dq transformation matrix; $X_{dq0} = [X_d\ X_q\ X_0]$ and

$X_{abc} = [X_a\ X_b\ X_c]$;

$$C_1 = \frac{2}{3}\begin{bmatrix} \sin(\theta) & \sin(\theta - \frac{2\Pi}{3}) & \sin(\theta + \frac{2\Pi}{3}) \\ \cos(\theta) & \cos(\theta - \frac{2\Pi}{3}) & \cos(\theta + \frac{2\Pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

The inverse transformation matrix is the transpose of C1, since C1 is orthogonal.

V MODELING AND CONTROL OF DFIG WITH INTEGRATED ENERGY STORAGE SYSTEM

The rotor speed of the DFIG has an effect on the overall quantity of produced power. If the machine is operating at sub-synchronous or super-synchronous rates, the rotor power will also be negative (consumed) (provided). Wind power fluctuation is a problem that cannot be resolved, despite DFIG's assistance in generating electricity at the vast majority of average wind speeds.

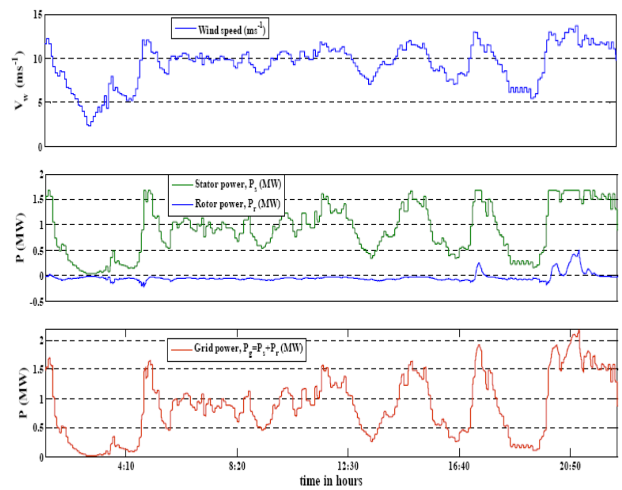


FIGURE 12 Output power of DFIG WTG for a realistic wind profile.

A. *Study On Integration Of Ultra Capacitor (Uc) Energy Storage*

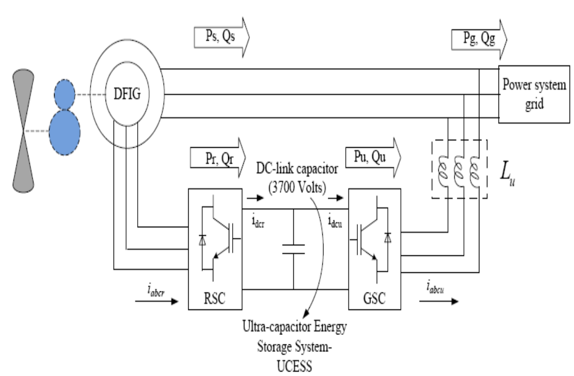


FIGURE 13 DFIG with integrated UC ESS.

For ultra-capacitor energy storage to work, the RSC's minimum dc voltage, which is directly related to the amount of rotor power needed by the system at changing wind speeds, must be established. The WTG's power curve has been tweaked in order to get the most out of the system (see Figure). Using this WTG feature, wind gusts might be harnessed for power. Min. Wind Speed vs. Stator (Ps) and Rotor (Pr)

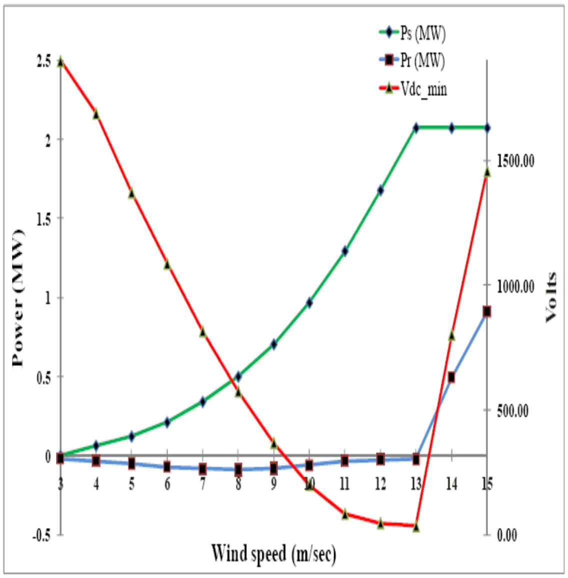


FIGURE 14 Stator power (*Ps*), rotor power (*Pr*) & *Vdc min* vs. wind speed.

B. System Operation

The illustration depicts a typical DFIG setup. The power electronic converters restore some of the stator energy to the machine while the machine is operating in the sub-synchronous mode. Super-synchronous functioning of the rotor generates power that is coupled with the stator's output to create total generated power. In the workplace, these processes are referred to as standard operating procedures.

VI SIMULATION RESULTS

The simulation results of the proposed DFIG wind generating system are described in this chapter. MATLAB/SIMULINK is used to run all of the simulations.

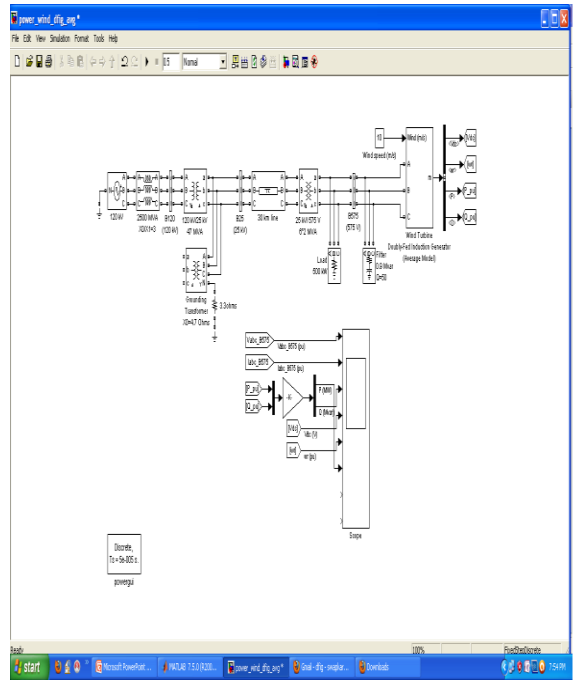


FIGURE 15 Main Simulation diagram.

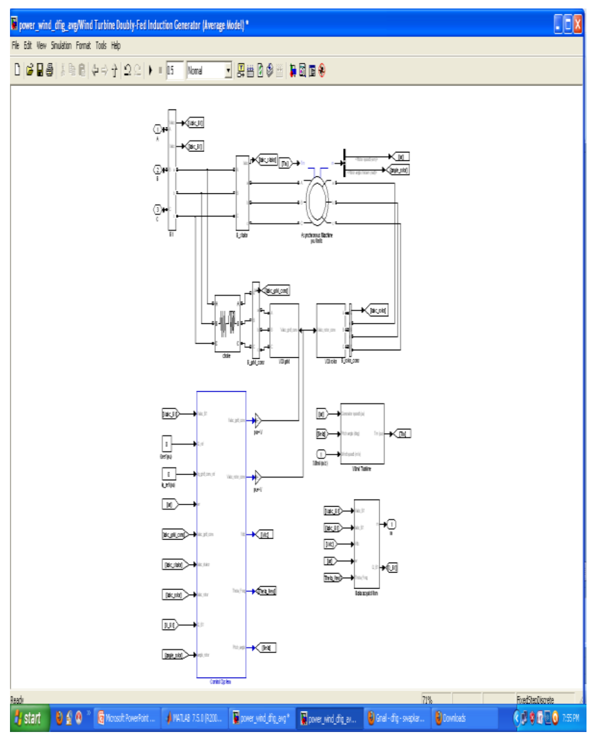


FIGURE 16 DFIG Model in SIMULINK.

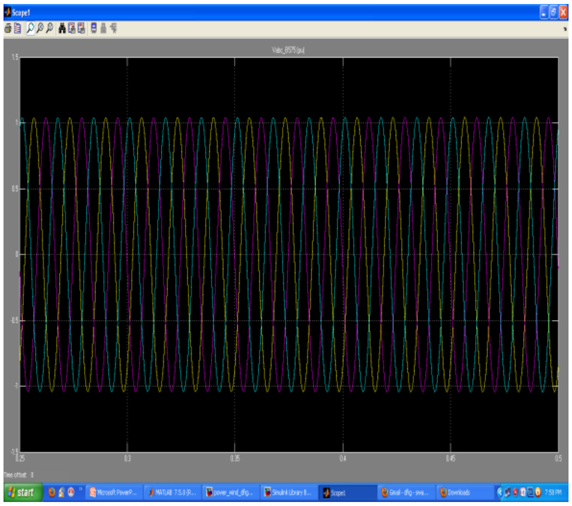


FIGURE 17 Voltage waveform

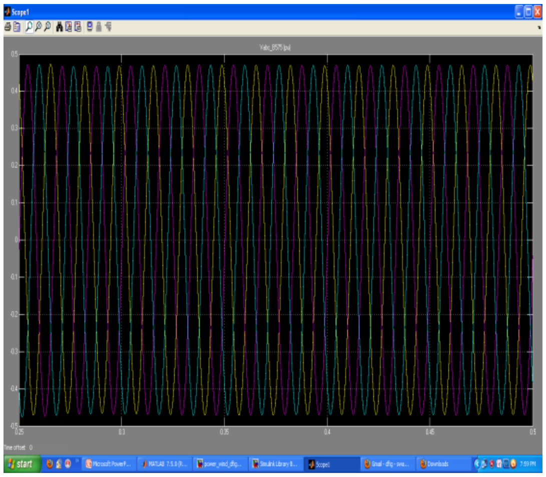


FIGURE 18 Current Waveform.

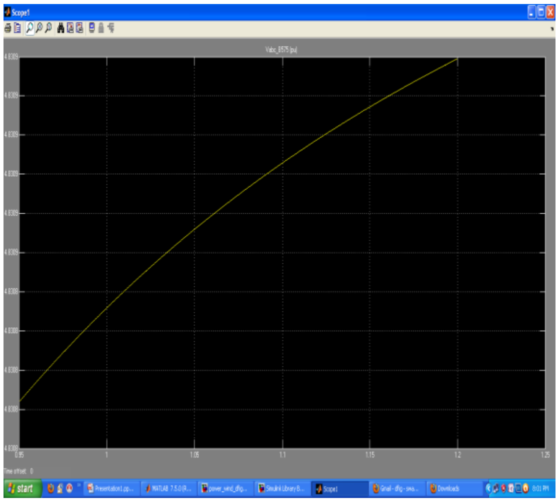


FIGURE 19 Power waveform.

CONCLUSION

Following are the conclusions of this project.

- The doubly fed induction motor model is developed
- The DFIG is implemented in Wind energy system.
- The control circuit is also developed for WES.

FUTURE SCOPE

Following aspects are the left as future scope of this project.

- The inverter configuration can be changed in the WES.
- The more effective and advanced control methods can be applied.
- The system can be integrated with the grid.

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