

Design of Voltage-Speed Controller for Grid Connected Wind Power Applications

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ABSTRACT

This paper proposes the plan and implementation of a non-linear controller for a doubly fed induction generator (DFIG) to supply support to power grid operation. The controller associates with voltage and speed regulator that guarantees the active power and reactive power delivered by the generator square measure mechanically adjusted to support the grid once a modification happens. Simulation results square measure enforced by mistreatment Matlab Simulation.

INTRODUCTION

Wind energy is the fastest growing and most widely utilized emerging renewable energy technologies in electrical energy conversion systems at present. This high penetration of wind energy in the power system has been closely related to the advancement of the wind turbine technology and the way of how to control. Integration of wind turbine based on doubly fed induction generator (DFIG) into the electrical grid has become an important part of electrical generation in many countries and its importance is continuing to increase ^[1]. Therefore, the analysis of wind power dynamics with the DFIG wind turbines has become a very important research issue, especially during transient faults

Wind turbines should remain connected to the grid when severe faults occur while supporting the grid voltage and frequency during normal operations. Several researchers are still investigating the best control system for wind generators with these new operating constraints. Feng et al. ^[2] gave a feedback linearization based nonlinear voltage and slip controller is proposed for a DFIG connected to an infinite bus. A direct active and reactive power controller based on stator flux estimation is discussed in study by Lei et al. ^[3]. This paper proposes a basic hysteresis controller. In a study, Muller et al. ^[4], the well-known vector control is proposed to regulate the active power and reactive power generated by a DFIG. In a study Hughes et al. defines ^[5] a DFIG control strategy that is very similar to the conventional Automatic voltage regulator for synchronous generator is utilized to support the power grid voltage and frequency. The main drawback of the aforementioned works is their inability to cope with large changes in grid parameters.

DFIG has more advantages compared with other wind generators. A wind power generation system equipped with DFIG requires a converter with only one-third of the power rating, leading to a less expensive system with reduced power loss. It controls reactive power separately from active power with a reasonable adoption of orientation frame. This paper proposes a PI control strategy that makes possible for a wind generator to adequately support the grid voltage and frequency. A fast responsive controller is proposed so that it's possible to follow changes that occur in the power grid ^[6].

Proposed System

This paper proposes a coordinated management of the rotor aspect converters (C_{rotor}) and grid aspect converters (C_{grid}) of doubly-fed induction generator (DFIG) primarily based wind power systems below unbalanced voltage conditions. It changes once the voltage and frequency changes. Quick response controller is projected so it's ready to follow changes that occur within the facility. Simulation results mistreatment Matlab / Simulink square measure conferred for a DFIG wind power system to validate the projected management theme and to indicate the improved system operation throughout unbalanced voltage

In **Figure 1** The diagram of DFIG connected wind system is shown. The grid and rotor aspects of the controller has been enforced within the projected system. A PI management is employed to stabilize the grid voltage.

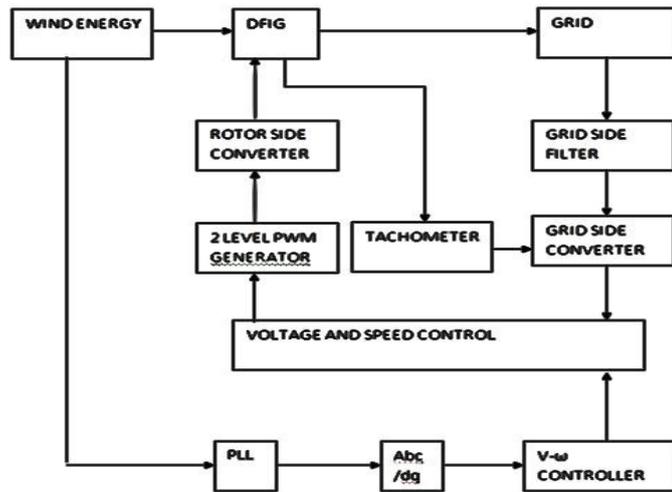


Figure 1. Block diagram of projected system.

The turbine converts the K.E. within the wind into mechanical power. And this mechanical power are often used for specific tasks or a generator will convert this mechanical power into electricity to power homes, businesses, schools, and therefore the like. The DFIG at the present the system of selection for multi MW wind turbines.

The principle of the DFIG is that rotor windings square measure connected to the grid via slip rings and succeeding voltage supply device that controls each the rotor and therefore the grid currents. An electrical grid may be a network of synchronized power suppliers and customers that square measure connected by transmission and distribution lines and operated by one or additional management centre's. Once the majority observes the facility grid, they're relating the gear for electricity (**Figure 2**). The rotor is the heard of a turbine. It consists of multiple rotor blades connected to a hub. The rotor converts the wind energy into a rotation. The energy within the wind turns two/three mechanical device like blades around a rotor. The rotor is connected to the most shaft that spins a generator to form electricity.

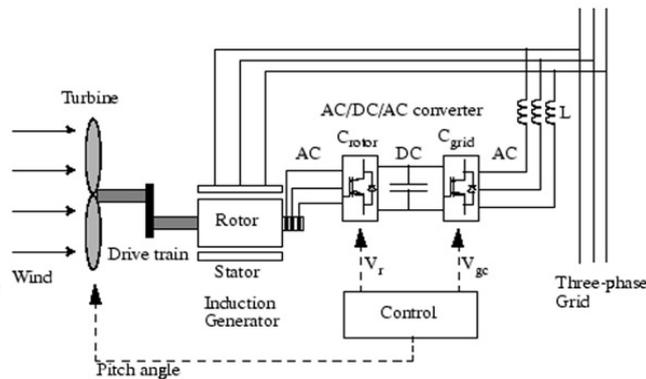


Figure 2. Circuit diagram of wind fed DFIG.

Converter is reborn the AC / DC voltage into DC voltage. The measuring instrument is required to get the rotor position from its speed. The part loop lock (PLL) is needed to get the stator coil flux position. These angular positions square measure employed by the abc/dq module that offers the rotor d-axis and q-axis currents.

The AC/DC/AC device is split into 2 components: the rotor-side device (C_{rotor}) and therefore the grid-side device (C_{grid}). C_{rotor} associated C_{grid} square measure Voltage-Sourced Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage supply. A condenser connected on the DC aspect acts because the DC voltage supply. A coupling inductance L is employed to attach C_{grid} to the grid. The three-phase rotor winding is connected to C_{rotor} by slip rings and brushes and therefore the three-phase stator coil winding is directly connected to the grid. The facility captured by the turbine is reborn into wattage by the induction generator and it's transmitted to the grid by the stator coil and therefore the rotor windings.

The power obtained from a given wind speed is expressed by the subsequent equation (1):

$$P_w = 0.5\rho\pi R^2 v^3 C_p(\lambda, \beta) \tag{1}$$

with “ ρ ” being the air density, “ R ” the effective space lined by the rotary engine blades, “ v ” the mean of the wind speed at the peak of the rotor axis, “ C_p ” the facility constant of the turbine and “ β ” the pitch angle.

The tip speed quantitative relation is outlined as in eqn.(2):

$$\lambda = \omega_w R / v \tag{2}$$

The mechanical torque is defined as in eqn.(3)

$$T_w = P_w / \omega_w \tag{3}$$

with ω_w being the turbine rotor speed.

The constant C_p is outlined as in eqn (4)

$$C_p = C_1 / \lambda - C_3 \beta - C_4 \varepsilon - C_5 / \lambda + C_6 \lambda \tag{4}$$

Doubly Fed Induction Generator

Wound rotor induction generators (WRIGs) square measure supplied with 3 part windings on the rotor and on the stator coil. They will be equipped energy at each rotor and stator coil terminals. Hence they're referred to as doubly-fed induction generators (DFIGs) or double output induction generators (DOIGs) within the generator mode. Each driving and generating operation modes square measure possible provided the facility electronic converters that offer the rotor circuit via slip-rings and brushes square measure capable of handling power in each direction.

Operational Principle of DFIG

The thought high power wind energy conversion systems (WECSs) square measure supported doubly fed induction generators (DFIGs). The stator coil windings of DFIGs square measure directly connected to the grids, and rotor windings square measure connected to the grids through succeeding power electronic converters.

The back to back device consists of 2 converters, Rotor aspect device (C_{rotor}) and grid aspect device (C_{grid}) that square measure connected back to back as shown in **Figure 3**. Between the 2 converters a dc-link condenser is placed, as energy storage, so as to stay the voltage variations within the dc-link voltage little management of the DFIG is additional sophisticated than the management of a customary induction machine.

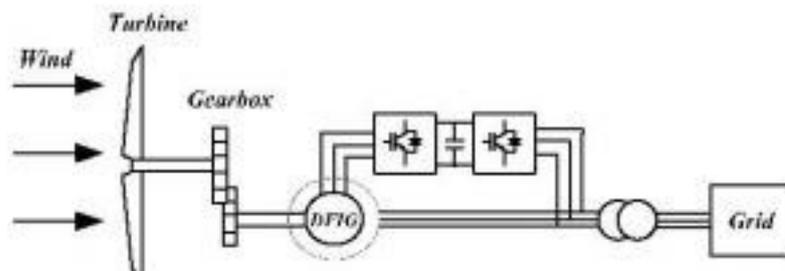


Figure 3. DFIG with wind.

Figure 3. DFIG with wind. In order to manage the DFIG the rotor current is controlled by an influence converter. Wind turbines use a DFIG consisting of a WRIG associated an AC/DC/AC power converter. The entire system is that the machine-side device controls the speed, whereas the grid-side device controls the dc-link voltage and ensures the operation at unity power issue (zero reactive power). By means that of a biface device within the rotor circuit the DFIG is ready to figure as a generator in each sub-synchronous and super-synchronous modes. Relying upon the operational condition, power is fed in to or out of the rotor (which is that the case of super synchronous mode), then it flows from the rotor via the device to the grid.

DFIG State House Model

A doubly-fed induction machine is delineated in d/q system by the subsequent equations (5), (6), (7), (8):

$$V_{ds} = R_s i_{ds} - \omega_s \psi_{qs} + d\psi_{ds}/dt \tag{5}$$

$$V_{qs} = R_s i_{qs} + \omega_s \psi_{ds} + d\psi_{qs}/dt \tag{6}$$

$$V_{dr} = R_r i_{dr} + \omega_{sl} \psi_{qr} + d\psi_{dr}/dt \tag{7}$$

$$V_{qr} = R_r i_{qr} + \omega_{sl} \psi_{dr} + d\psi_{qr}/dt \tag{8}$$

where the variables V_{ds} , V_{qs} , V_{dr} , V_{qr} represent the d/q system parts for the machine stator coil and rotor voltages. Variables

$i_{ds}, i_{qs}, i_{dr}, i_{qr}$ signify the machine stator coil and rotor current within the d/q system. The machine fluxes within the d/q system square measure conferred by the variables $\Psi_{ds}, \Psi_{qs}, \Psi_{dr}, \Psi_{qr}$. Finally, variables ω_s and ω_{sl} square measure stator coil and rotor current frequencies in rad/s, severally. Parameters R_s and R_r represent rotor and stator coil resistances.

The fluxes and currents square measure connected by the subsequent pure mathematics relationships square measure as shown in eqn (9), (10), (11), (12)

$$\Psi_{ds} = L_s i_{ds} + L_m i_{dr} \tag{9}$$

$$\Psi_{qs} = L_s i_{qs} + L_m i_{qr} \tag{10}$$

$$\Psi_{dr} = L_r i_{dr} + L_m i_{ds} \tag{11}$$

$$\Psi_{qr} = L_r i_{qr} + L_m i_{qs} \tag{12}$$

where parameters $L_s, L_r,$ and L_m represent the stator coil inductance, the rotor inductance and therefore the coefficient. The electrical torsion generated by the DFIG has the subsequent expression in terms of the d/q system stator coil flux and current as shown in eqn (13)

$$T_e = p(\Psi_{ds} i_{qs} - \Psi_{qs} i_{ds}) \tag{13}$$

The parameter p is that the variety of pole pairs. Note that the rotor current frequency are often expressed in term of the stator coil current frequency and therefore the rotor speed in rad/s as follows in eqn (14)

$$\omega_{sl} = \omega_s - \omega_r \tag{14}$$

When the d-axis for the park transformation wont to notice the DFIG dynamics aligned with rotor flux axis, we've got the follow relationships as in eqn (15)

$$\Psi_{qs} = 0, \Psi_{ds} = \Psi_s = V_s / \omega_s \tag{15}$$

The parameter V_s stands for the grid voltage. Because the consequence, rotor flux parts, within the d/q system, have the subsequent expression in terms of the rotor current parts and therefore the grid voltage as in (16) and (17)

$$\Psi_{dr} = L_m V_s / L_s \omega_s + \sigma L_r L_{dr} \tag{16}$$

$$\Psi_{qr} = \sigma L_r i_{qr} \tag{17}$$

Where, $\sigma = 1 - L_m^2 / (L_s L_r)$, It is common to neglect the stator coil resistance and to assume a continuing grid voltage magnitude for the look of the wind generation generator controller. These assumptions result in a reduced order model. We have a tendency to get the subsequent equations at the stator coil in eqn (18) and (19)

$$V_{ds} = R_s i_{ds} - \omega_s \Psi_{qs} + d\Psi_{ds}/dt \approx 0 \tag{18}$$

$$V_{qs} = R_s i_{qs} - \omega_s \Psi_{ds} + d\Psi_{qs}/dt \approx \omega_s \Psi_{ds} = V_s \tag{19}$$

Next equations (20) and (21) that represent the rotor dynamics become the reduced model for the DFIG. Note that the model depends on the grid voltage V_s and frequency ω_s

$$V_{dr} = R_r i_{dr} - \omega_{sl} \sigma L_r i_{qr} + \sigma L_r di_{dr}/dt \tag{20}$$

$$V_{qr} = R_r i_{qr} + \omega_{sl} (L_m V_s / L_s \omega_s + \sigma L_r i_{dr}) + \sigma L_r di_{qr}/dt \tag{21}$$

The DFIG electrical torsion and terminal voltage may well be written in terms of the reduced order model state variables as follows in eqn (22) and eqn (23)

$$T_e = -p V_s L_m i_{qr} / L_s \tag{22}$$

$$V_s = \omega_s L_s i_{ds} + \omega_s L_m i_{qr} \tag{23}$$

The rotor speed dynamics square measure delineated by the subsequent equation (24)

$$\omega_r = -B \omega_r + T_m + T_e \tag{24}$$

Parameters J and B represent the generator inertia and therefore the mechanical friction constant, severally. Metal is that

the mechanical torsion provides by the blades.

Management Model

The doubly fed induction generator (DFIG) and therefore the synchronous generator square measure delineated by the pure mathematics differential model within the dq system. The device controllers of the DFIG have a posh model such as every mode of operational delineated.

Management of the Rotor-side Device (Crotor)

In traditional mode operation, the rotor-side device controls the injection of reactive power and therefore the developed power (P_{elec}). In fact, the utmost power depends on the rotor speed and on the incoming wind. During this operation purpose the optimum power reference (P_{opt}) is calculated taking into consideration the best rotor speed for the incoming wind by the maxim sum worth of the C_p curves. Associate encoder will offer the generator rotor position (θ) to the abc-dq0 and to the dq0-abc transformations. The direct axis element is employed to keep up the generator power think about one chemical element therefore, the absorbed reactive power reference (Q^*) is adequate zero. The construction axis element is controlled during a similar manner of the direct axis, however, it regulates the electrical power to the best worth (P_{opt}). The Cupid's disease and V_q reference signals square measure send to the dq0-to-abc transformation and, then, to the signal generator supported the PWM (Pulse breadth Modulation) methodology. Finally, V_{abc} are the three phase voltages desired at C_{rotor} output.

Management of the Grid-side Converter (Cgrid)

In normal mode operation, the C_{grid} control regulates the voltage of the DC link between C_{rotor} and C_{grid} . In fact, controlling this voltage is another way of doing the control of the active power produced in the rotor windings. The controller employs a PLL (Phase secured Loop) to give the angle (ϕ) to the bedrock to dq0 (and dq0 to abc) transformation. This angle gives the relation to the synchronization of the three-phase voltages of the converter output with the terminal voltage. The direct axis component is employed to control the DC link voltage (V_{dc}) to 1 p.u. The quadrature axis component of the reference current is set to zero ($I_q = 0$) since the power factor control is already been doing by the C_{rotor} . The V_d and the V_q references signals are sent to the dq0-to-abc transformation, then, to the PWM signal generator. Finally, V_{grid} are the three-phase voltages desired at the grid-side converter output.

Simulation Results

The controller's performance is evaluated and therefore the effects of associate electrical disturbance on the mechanical elements of turbine square measure enforced in Matlab/Simulink package. The voltage and currents transients considerably modification the generator active and reactive powers. The controller capability to stabilize the DFIG signals, once the demanded active power changes or once a brief circuit happens at the generator terminal, is tested. It takes concerning zero.3 second to the controller to stabilize the DFIG signals to their steady values. The wind generation generator is thus capable to support the facility grid frequency once the demanded power changes. This quick response ought to increase the DFIG fault ride-through capability.

The full circuit of the DFIG management is meant in Matlab/Simulink by mistreatment simscape blocksets as seeded in **Figure 4**. It contains the turbine model, drive train model, pitch management, rotor management. The circuit style has been evaluated by connecting the block sets with each other. 3 part AC supply has been generated by mistreatment DFIG and it's connected with three part grid. A rotor aspect and grid aspect management has been designed in Matlab simulink.

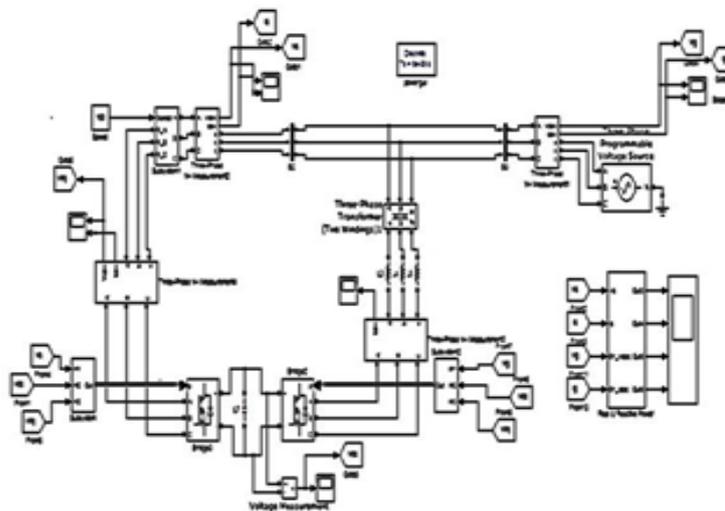


Figure 4. Full simulation circuit of DFIG.

Figure 4. Full simulation circuit of DFIG. The turbine may be a pitch controlled one. The pitch angle β management signal comes from the DFIG management block. The C_p coefficient is calculated through a look-up table and therefore the output of the turbine block is that the torsion on the induction generator axis.

The pitch angle β is merely varied to limit the over speed of the generator as shown in **Figure 5**.

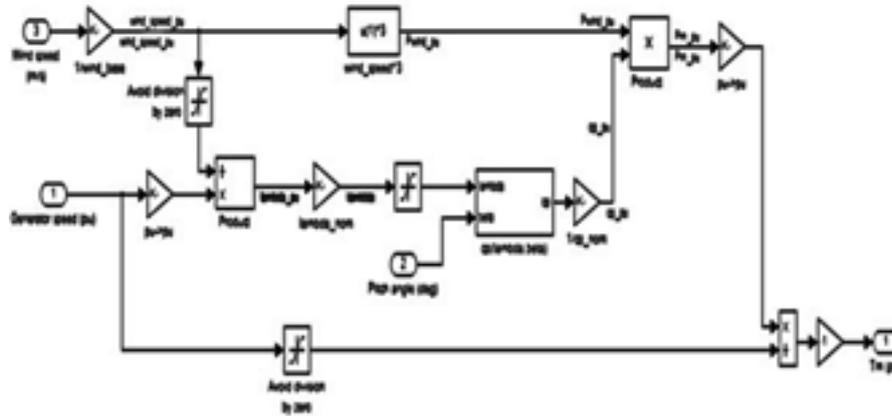


Figure 5. Full simulation circuit of turbine.

To properly describe the model of a turbine, initially we have a tendency to should begin with presenting the total model of a turbine. It implements a variable pitch turbine model. The performance constant C_p of the rotary engine is that the mechanical output power of the rotary engine divided by wind generation and a perform of wind speed, motility speed, and pitch angle (beta).

The drive train is that the mechanical a part of the system that consists of casing, shafts, rotary engine and different vital mechanical elements. during this project, the 2 mass drive train models square measure used and is conferred. The 2 mass drive train models square measure used attributable to the very fact that the rotary engine model is delineated together mass, whereas the generator is that the different mass. each plenty square measure connected with a mechanical shaft that possesses sure damping and stiffness worth as shown in **Figure 6**.

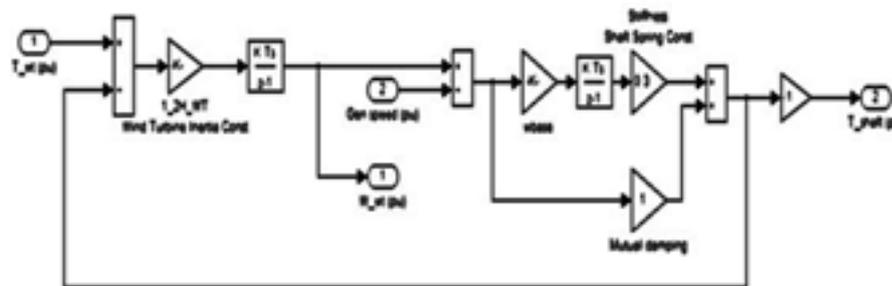


Figure 6. Full simulation circuit of drive train.

The model of the I_g is an instant 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. Saturation is not included in the model, but reference states that this only leads to small negligible errors in the prediction of the maximum short-circuit current.

The C_{grid} is modeled using a universal bridge model with Mosfets connected to the IG terminals through a series RL filter. The control of the C_{grid} aims at keeping the DC-link capacitor voltage constant at nominal value. It doesn't contribute to grid voltage regulation or reactive power injection ($I_q=0$). This can be a limitation, since reactive power injection through the C_{grid} serving to during a quicker voltage recovery. The device most power is 0.5 the I_g rated power. The grid voltage angle is calculated with a PLL. The reference for the reactive power is set through a PI controller by mensuration the grid voltage and scrutiny it with a reference.

The rotor aspect device is modelled employing a universal bridge model with Mosfets connected to the I_g rotor windings. The C_{rotor} controls the active power delivered by the DFIG, by decisive a torsion reference. This torsion reference is employed at the side of a flux estimate to work out the reference rotor current I_{dr} . The C_{rotor} model has been changed therefore to support the grid voltage with reactive power injection. The reference for the reactive power is set through a PI controller by mensuration the rotor voltage and scrutiny it with a reference. The output of three phase voltage and current of the rotor is shown in **Figure 7**. The output of three phase voltage and current of the grid is shown in **Figure 8**. The real and reactive power compensation is shown in **Figure 9**. The general and control parameters are used in the simulation of this project as shown in **Table 1**.

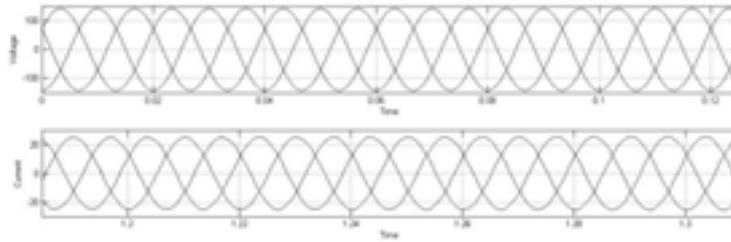


Figure 7. Rotor voltage and current.

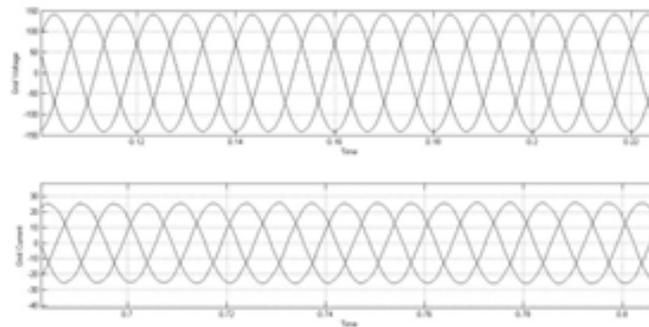


Figure 8. Grid voltage and current.

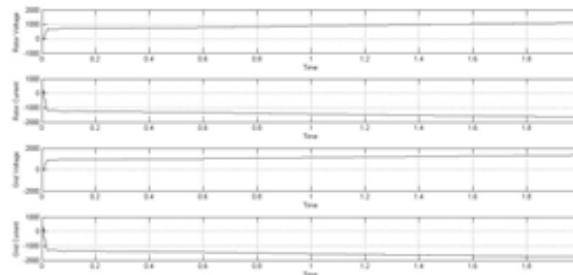


Figure 9. Real & reactive power.

Table 1. The general and control parameters are used in the simulation of this project.

Proposed system		Existing System	
Nominal Power:	8.5e3/0.9 VA	Nominal Power:	8.5e3/0.9 VA
Line to Line Voltage:	460 V	Line to Line Voltage:	460 V
Frequency:	50Hz	Frequency:	50Hz
Stator Resistance:	0.01965 P.U	Stator Resistance:	0.01965 P.U
Stator Inductance:	0.0397 P.U	Stator Inductance:	0.0397 P.U
Rotor Resistance:	0.01909 P.U	Rotor Resistance:	0.01909 P.U
Rotor Inductance:	0.0397 P.U	Rotor Inductance:	0.0397 P.U
Magnetizing Inductance:	1.354 P.U	Magnetizing Inductance:	1.354 P.U
Inertia constant:	0.09526	Inertia constant:	0.09526
Friction factor:	0.05479	Friction factor:	0.05479
Pole pairs:	2	Pole pairs:	2
Grid side Gains (Kp,Ki)	1, 0.1	-	-
Rotor side Gains(Kp,Ki)	0.1,0.01	-	-
DC Link Capacitor(Cd)	550e-3	DC Link Capacitor(Cd)	1e-3
Filter Inductors(L1,L2,L3)	4e-3, 4e-3, 4e-3	Filter Inductors(L1,L2,L3)	14e-3, 14e-3, 14e-3
Max rate of change of reference Grid voltage:	100 pu/s	Max rate of change of reference Grid voltage:	100 pu/s
Max rate of change of reference power:	1 pu/s	Max rate of change of reference power:	1 pu/s
Max rate of change of reference Current:	100 pu/s	Max rate of change of reference Current:	100 pu/s

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