

Simulation of Wind Power based Induction Generator

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Abstract: This paper describes the performance comparison of a wind power systems based on two different induction generators as well as the experimental demonstration of a wind turbine simulator for the maximum power extraction. The two induction machines studied for the comparison are the squirrel-cage induction generator (SCIG) and the doubly fed induction generator (DFIG). The techniques of direct grid integration, independent power control, and the droop phenomenon of distribution line are studied and compared between the SCIG and DFIG systems. Both systems are modeled in Matlab/Simulink environment, and the operation is tested for the wind turbine maximum power extraction algorithm results. Based on the simulated wind turbine parameters, a commercial induction motor drive was programmed to emulate the wind turbine and is coupled to the experimental generator systems. The turbine experimental results matched well with the theoretical turbine operation

Keywords: Doubly fed induction machines, field-oriented control, maximum power tracking, and wind power system.

1. Introduction

The increasing emphasis on renewable wind energy has given rise to augmented attention on more reliable and advantageous electrical generator systems. Induction generator systems have been widely used and studied in wind power system because of their advantages over synchronous generators, such as smaller size, lower cost, and lower requirement of maintenance. The straightforward power conversion technique using squirrel-cage induction generator (SCIG) is widely accepted in fixed-speed applications with less emphasis on the high efficiency and control of power flow. However, such direct connection with grid would allow the speed to vary in a very narrow range and thus limit the wind turbine utilization and power output. Another major problem with SCIG power system is the source of reactive power; that is, an external reactive power compensator is required to hold the distribution line voltage and prevent the whole system from overload. On the other hand, the doubly fed induction generator (DFIG) with variable-speed ability has higher energy capture efficiency and improved power quality and thus has attracted more attentions. With the advent of power electronic techniques, a back-to-back converter, which consists of two bidirectional converters and a dc link, acts as an optimal operation

tracking interface between generator and grid. Field-oriented control (FOC) is applied to both rotor- and stator-side converters to achieve desirable control on voltage and power. Generally, the FOC has been presented based on DFIG mathematical equations only. However, a three-phase choke is commonly used to couple the stator-side converter into the grid. Therefore, this paper proposes the FOC schemes of stator-side converter involving the choke, and it turns out that both stator- and rotor side converter voltages consist of a current regulation part and a cross-coupling part.

The modeling and simulation of SCIG and DFIG wind systems are studied. Comparison between SCIG without staticvar compensator (STATCOM) and SCIG with STATCOM as well as DFIG system clearly indicates difference in resulted distribution line voltage.

2. SCIG Wind Power System

Fig. 1 shows the schematics of the SCIG system including the wind turbine, pitch control, and reactive power compensator.

The entire system includes three stages for delivering the energy from wind turbine to the power grid.

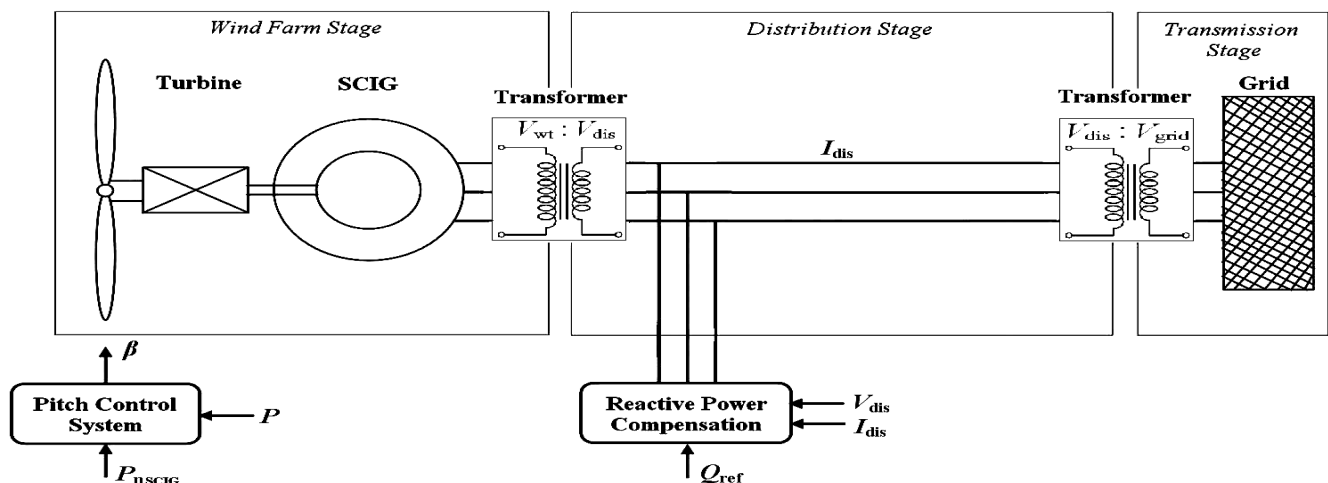


Figure 1: SCIG wind power system topology

The first one is wind farm stage which handles with low voltage V_{wt} , the second is distribution stage which has medium voltage V_{dis} , and the third is grid transmission stage which has high voltage V_{grid} . The three-phase transformers take care of the interface between stages [2]. As mentioned, nominal power P_{nSCIG} is considered as active power reference to regulate the pitch angle while V_{dis} and I_{dis} denote the distribution line-to-line voltage and phase current, and they are monitored to favor the reactive power compensation for distribution line. This fairly straightforward technique was first used since it is simple and has rugged construction, reliable operation, and low cost. However, the fixed-speed essential and potential voltage instability problems severely limit the operations of wind turbine.

Since SCIG is of fixed-speed generator, for a particular wind speed, the output active power is fixed as well. Thus, with the increase of wind speed, so does the output power until the nominal power is reached. The wind speed at this moment is called nominal wind speed.

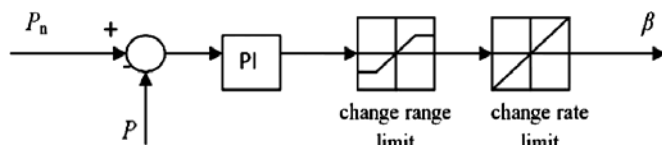


Figure 2: Pitch Angle Control

Beyond this speed, the pitch angle system will prevent the output power from exceeding the nominal value. That is, when the wind speed is below nominal value, the power capture can vary with the change of wind speed; and when the wind speed is above nominal value, the pitch angle control system will limit the generated power by changing the pitch angle. In such way, the output power will be stabilized at nominal value where the wind speed is always above nominal speed. The pitch angle is determined by an open loop control of regulated output active power and by that shown in Fig. 2. Due to the huge size of blade and, thus, inertia, pitch angle has to change in a slow rate and a reasonable range. It is also worthy to notice that, without reactive power source, in Section V, the SCIG system tends to lead to a voltage droop in distribution line which will cause overload problem. In the simulation section, the comparison between SCIG system with and without STATCOM is conducted.

3. DFIG Wind Power System

Traditionally, the dynamic slip control is employed to fulfill the variable-speed operation in wind turbine system, in which the rotor windings are connected to variable resistor and control the slip by the varied resistance. This type of system can achieve limited variations of generator speed, but external reactive power source is still necessary. Consequently, to completely remove the reactive power compensation and to control both active and reactive power independently, DFIG wind power system is one of most popular methods in wind energy applications [7]. This paper reproduces DFIG model first of all and then concentrates on the controlling schemes of power converters, in which the

active and reactive power are controlled independently. In particular, the stator-side converter control involving an RL series choke is proposed.

Both controlling of rotor- and stator-side converter voltages end up with a current regulation part and a cross-coupling part. The wind turbine driving DFIG wind power system consists of a wound-rotor induction generator and an ac/dc/ac insulated gate bipolar transistor (IGBT)-based pulse width-modulated (PWM) converter (back-to-back converter with capacitor dc link), as shown in Fig. 3. In this configuration, the back-to-back converter consists of two parts: the stator-grid-side converter and the rotor-side converter. Both are voltage source converters using IGBTs, while a capacitor between two converters acts as a dc voltage source. The generator stator windings are connected directly to grid (with fixed voltage and frequency of grid) while the rotor winding is fed by rotor-side converter through slip rings and brushes, at variable frequency.

The control system is divided into two parts stator-side converter control system and rotor-side converter control system. An equivalent circuit of DFIG is depicted in Fig. 8, and the relation equations for voltage V , current I , flux Ψ , and torque T_e involve [4], [5], [7] are

$$\begin{aligned} V_{ds} &= R_s I_{ds} - \omega_s \Psi_{qs} + d\Psi_{ds}/dt \dots\dots\dots 1 \\ V_{qs} &= R_s I_{qs} + \omega_s \Psi_{ds} + d\Psi_{qs}/dt \dots\dots\dots 2 \\ V_{dr} &= R_r I_{dr} - s\omega_s \Psi_{qr} + d\Psi_{dr}/dt \dots\dots\dots 3 \\ V_{qr} &= R_r I_{qr} + s\omega_s \Psi_{dr} + d\Psi_{qr}/dt \dots\dots\dots 4 \\ \Psi_{ds} &= L_s I_{ds} + L_m I_{dr} \dots\dots\dots 5 \\ \Psi_{qs} &= L_s I_{qs} + L_m I_{qr} \dots\dots\dots 6 \\ \Psi_{dr} &= L_r I_{dr} + L_m I_{ds} \dots\dots\dots 7 \\ \Psi_{qr} &= L_r I_{qr} + L_m I_{qs} \dots\dots\dots 8 \\ T_e &= 3/2 \{np(\Psi_{ds} I_{qs} - \Psi_{qs} I_{ds})\} \dots\dots\dots 9 \end{aligned}$$

where $L_s = L_l + L_m$; $L_r = L_l + L_m$; $s\omega_s = \omega_s - \omega_r$ represents the difference between synchronous speed and rotor speed; subscripts r , s , d , and q denote the rotor, stator, d -axis, and q -axis components, respectively; T_e is electromagnetic torque; and L_m , np , and J are generator mutual inductance, the number of pole pairs, and the inertia coefficient, respectively.

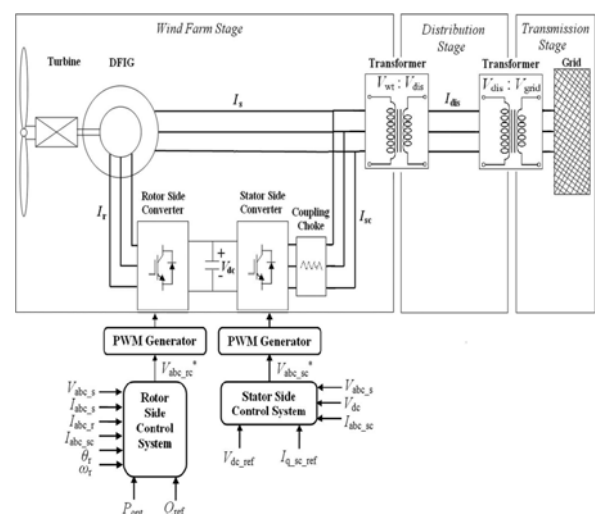


Figure 3: Wind Turbine-Doubly Fed Induction Generator System Configuration

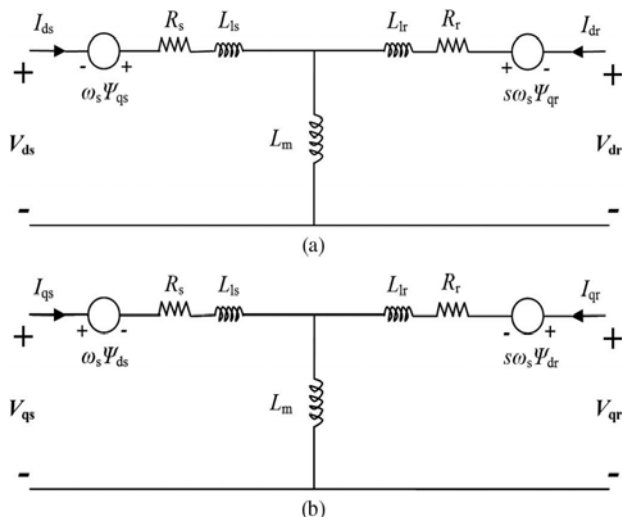


Figure 4: Equivalent circuit of DFIG. (a) d-axis model. (b) q-axis model.

3.1 Rotors-Side Converter Control

If the derivative parts in (5) are neglected, one can obtain stator flux as

$$\Psi_{ds} = (V_{qs} - R_s I_{qs}) / \omega_s$$

$$\Psi_{qs} = (V_{ds} - R_s I_{ds}) / (-\omega_s)$$

$$\Psi_s = \text{SQRT}(\Psi_{ds}^2 + \Psi_{qs}^2) \dots\dots\dots 10$$

Because of being directly connected to the grid, the stator voltage shares constant magnitude and frequency of the grid. One could make the d-axis align with stator voltage vector; it is true that $V_s = V_{ds}$ and $V_{qs} = 0$, thus $\Psi_s = \Psi_{qs}$ and $\Psi_{ds} = 0$, which is of stator-voltage-oriented vector control scheme as depicted in Fig. 9.

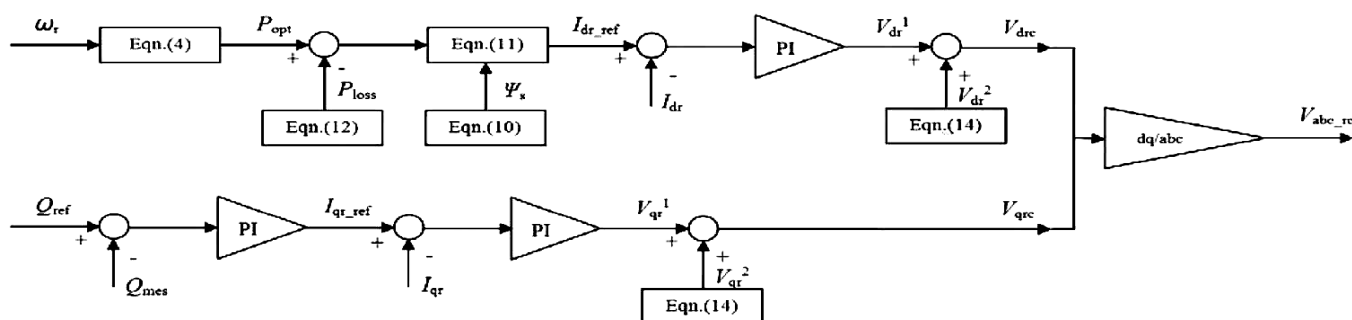


Figure 5: rotor-side converter control scheme

According to (7)–(9), the rotor-side converter reference current is derived as

$$I_{dr_ref} = -2L_s T_e / 3np L_m \Psi_s \dots\dots\dots 11$$

where

$$P_{e_ref} = P_{opt} - P_{loss} = T_e \omega_r \dots\dots\dots 12$$

$$P_{loss} = R_s I_{ds}^2 + R_r I_{dr}^2 + R_c I_{sc}^2 + F \omega^2 \dots\dots\dots 13$$

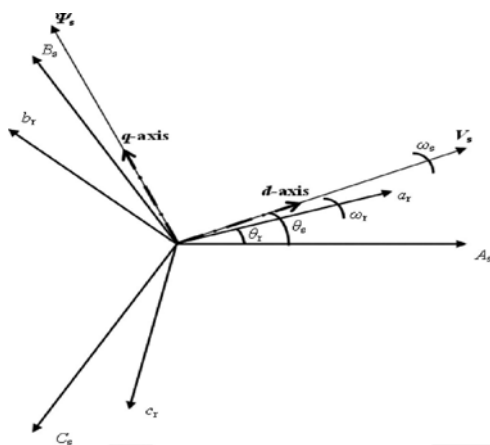


Figure 5: Stator voltage FOC reference frame.

where I_{sc} , R_c , and F are stator-side converter current, choke resistance, and friction factor, respectively. P_{opt} , P_{e_ref} and P_{loss} are desired optimal output active power, reference active power, and system power loss. Combining (10)–(12), the active power is used as command inputs to determine current reference I_{dr_ref} . Meanwhile, the output reactive

power is the stator reactive output power since the stator-side converter's reactive power is set to be zero.

3.2 Stator-Side Converter Control

Concerning the use of three-phase series RL choke between stator- and stator-side converter, a cross-coupling model is required to derive the voltage signal of stator-side converter, as described in Fig

$$V_{dsc} = V_{ds} - V_{dch} \dots\dots\dots 14$$

$$V_{qsc} = V_{qs} - V_{qch} \dots\dots\dots 15$$

where the subscripts sc and ch denote the variables of stator side converter and choke. The coupling part of voltage signals V_{2dch} and V_{2qch} is expressed as

$$V_{2dch} = R_c I_{dsc} - \omega_s L_c I_{qsc} \dots\dots\dots 16$$

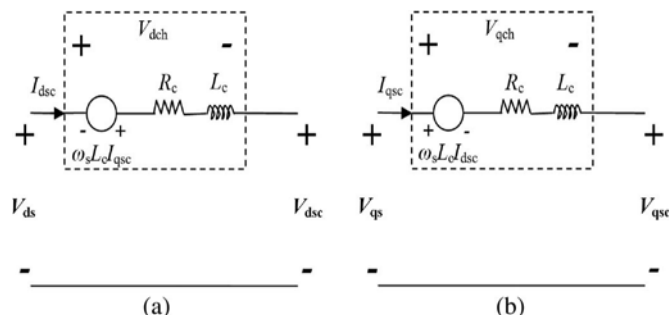


Figure 6: Equivalent circuit of stator-side-converter choke. (a) d-axis model (b) q-axis model.

$$V_{2qch} = R_c I_{qsc} + \omega_s L_c I_{dsc} \dots\dots\dots (17)$$

Moreover, V_{1dch} and V_{1qch} are determined by the regulation of currents I_{dsc} and I_{qsc} in which the current reference I_{qsc_ref} is given directly while I_{dsc_ref} is determined by the regulation of dc-link voltage V_{dc} . Thus, above all, the stator-side converter voltage signals V_{dsc} and V_{qsc} are obtained as follows and depicted in Fig. 7

$$V_{dsc} = V_{ds} - V_{1dch} - V_{2dch} \quad \dots\dots\dots 18$$

$$V_{qsc} = V_{qs} - V_{1qch} - V_{2qch} \quad \dots\dots\dots 19$$

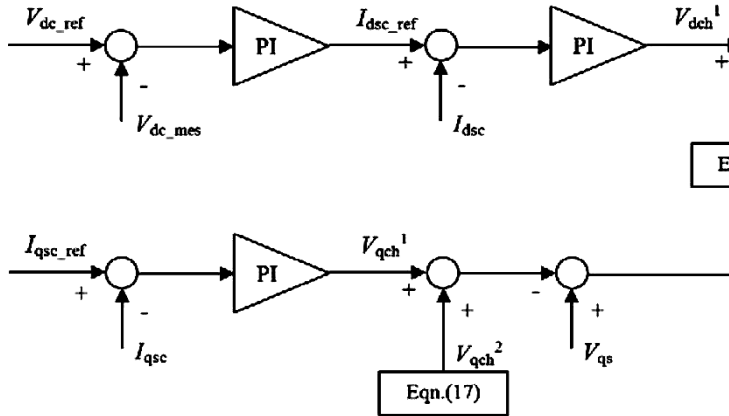


Figure 7: Stator-side converter control scheme

4. Simulation Results

By using the proposed optimal power curve as well as the system parameters listed. The DFIG wind power system is simulated. The DFIG system allows the optimal (maximum) output power operation in the absence of reactive power source. Also, the independent control of active and reactive power is achieved. In the Matlab / Simulink model, the converter switch frequency is set to be 27 times the grid frequency f .

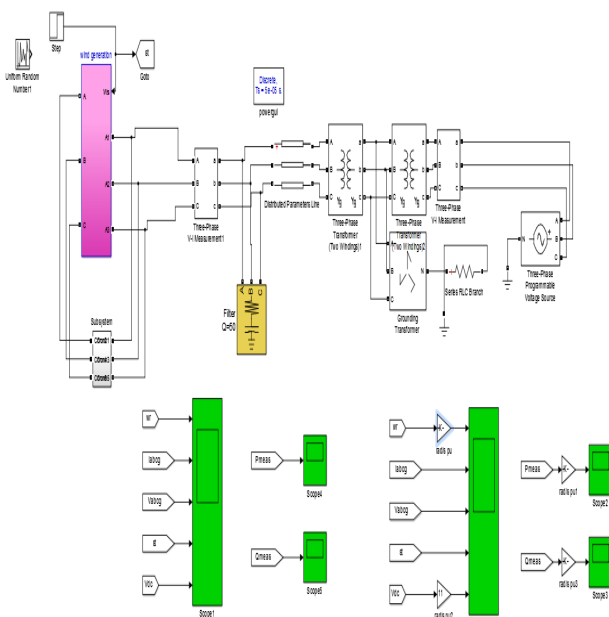


Figure 8: Proposed System, Simulation Comparisons and Implementation of Induction Generator Wind Power Systems.

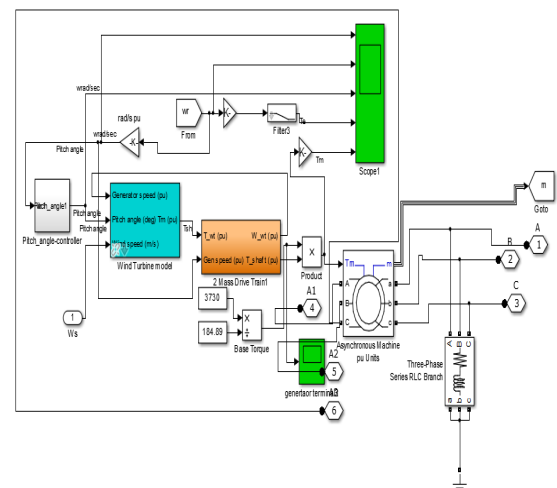


Figure 9: Subsystem of Wind Generation.

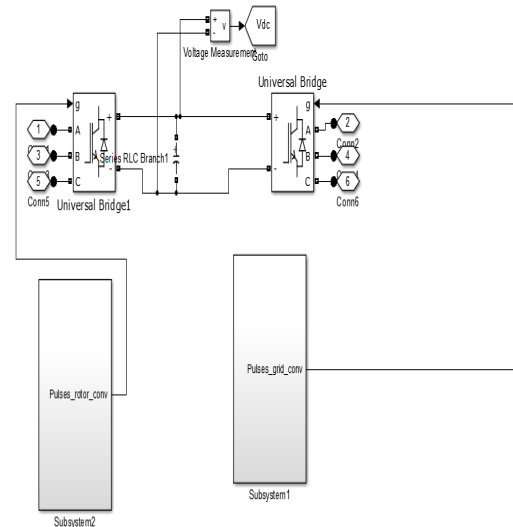


Figure 10: Control Scheme Subsystem (Rotor Side Converter and Stator Side Converter).

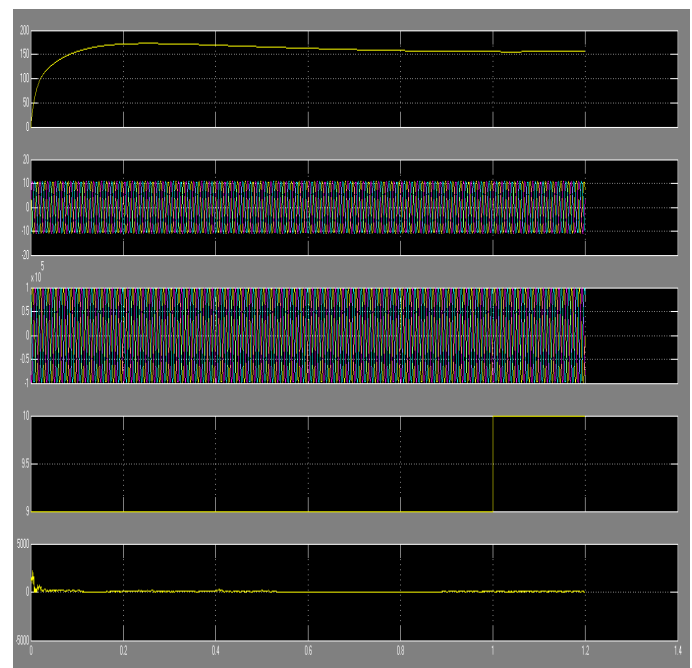


Figure 11: Results (a) Rotor speed ω_r . (b) Three phase currents. (c) Three phase Voltages (d) Wind speed v_w . (e) DC-link voltage V_{dc} .

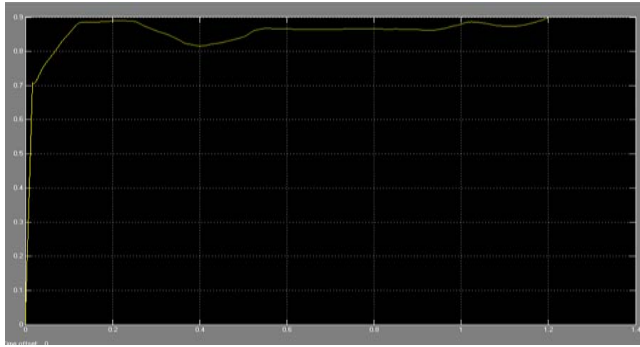


Figure 12: Active Power (P)

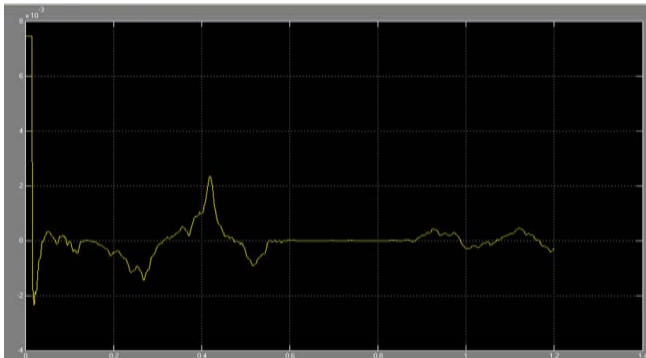


Figure 13: Reactive Power (Q)

5. Conclusion

This paper has presented the comparison of the wind turbine systems using SCIG and DFIG generator systems. With the experimentally investigated wind turbine model, a SCIG and a DFIG wind power systems are modeled and simulated in Matlab/Simulink. An optimal active-power-versus-rotor-speed relationship has been proposed for turbine model first, and it functions as a lookup table for tracking the maximum output active power. The SCIG system presents the need of external reactive power source to support grid voltage, and it can keep the output power at the nominal level by pitch control but cannot accordingly change the rotor speed to achieve maximum wind power capture at different wind speeds. In contrast, the DFIG system does not need reactive power compensator to hold distribution line voltage and achieves optimal active power controlling. Both voltage control schemes for two converters consist of a current regulation part and a cross-coupling part.

6. Future Scope

In future it has more demand because the fuel cost is zero and wind is freely available in nature. In this system the DFIG (Doubly Fed Induction Generator) is used for generating the power, here we are going to use System with considering below things.

- Direct-drive.
- Eliminate the gearbox by using a very-high pole synchronous generator.
- Resulting generator design is relatively wide and flat.
- No gearbox issues.
- Full-rated converter is required.
- Full speed and reactive power control.

By considering above all factors to improve the Wind power generation in future.

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