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MA Modeling and Simulation of VSDFIG and PMSG Wind Turbine System

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Abstract

This paper proposes a modeling and simulation of variable speed doubly fed induction generator (VSDFIG) and permanent magnet synchronous generator (PMSG) wind turbine system. During recent years wind turbine technology has undergone rapid developments. Growth in size and the optimization of wind turbines has enabled wind energy to become increasingly competitive with conventional energy sources. The proposed wind turbine model is simulated using Matlab.

Keywords: Wind turbine, Modeling, Simulation

Introduction

As energy demands around the world increase, the need for a renewable energy sources that will not harm the environment has been increased. Therefore, it is important that they should be cost effective. They need to meet any load requirements and produce energy at a minimum cost. Performance characteristics such as power output versus wind speed or versus rotor angular velocity must be optimized to compete with other energy sources.

Power Output-Practical Turbine

The fraction of power extracted from the power in the wind by a practical wind turbine is usually given by the symbol C_p, standing for the coefficient of performance or power coefficient. The actual mechanical power output can be written as

$$P_m = C_p(\tfrac{1}{2}\rho A V_w^3) = \tfrac{1}{2}\rho\pi R^2 V_w^3 C_p(\lambda, \beta) \quad (1)$$

Where,

R = Blade radius of the wind turbine (meters)

V_w= Wind speed (meter/second)
ρ = Air density (kg/meter)
C_p = Power co efficient
λ = tip speed ratio
β = blade pitch angle.

The performance coefficient C_p is a function of the tip speed ratio and the pitch angle of the rotor blades. It is determined by aerodynamic laws and it may change from one turbine to other.

Energy Conversion System

A wind turbine catches the wind through its rotor blades and transfers it to the rotor hub. The rotor hub is attached to a low speed shaft through a gear box. The high speed shaft drives an electric generator which converts the mechanical energy to electric energy and delivers it to the grid. As the wind speed varies, the power captured, converted and transmitted to the grid also varies.

Wind Turbine Generator System (WTGS)

A wind turbine generator system (WTGS) transforms the wind into electrical energy. The general scheme of a WTGS is shown figure 1.

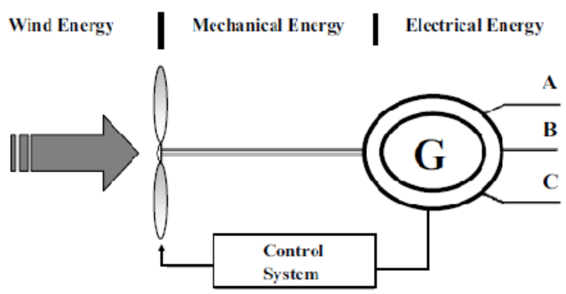


Figure 1: Wind turbine Generator System

Wind energy is transformed into mechanical energy by a wind turbine that has several blades. It usually includes a gearbox that matches the turbine low speed to the higher speed of the generator. Some turbines include a blade pitch angle control for controlling the amount of power to be transformed. Wind speed is measured with an anemometer. The electrical generator transforms mechanical energy into electrical energy. Types of wind generators are squirrel cage induction generator (SCIG), doubly fed induction generator (DFIG), wound field synchronous generator (WFSG) and permanent magnet synchronous generator (PMSG). Based on rotational speed the wind turbine generator systems can be split into two types.

Fixed speed WTGS

A fixed speed WTGS consists of a conventional, directly grid coupled squirrel cage induction generator, it has some superior characteristics such as brushless and rugged construction, low cost, maintenance free, and operational simplicity shown in figure 2.

The slip and hence the rotor speed of a squirrel cage induction generator varies with the amount of power generated. These rotor speed variations are, however, very small, approximately 1 to 2 % of the rated speed. Therefore, this type of wind energy conversion system is normally referred to as a constant or fixed speed WTGS.

The advantage of a constant speed system is that it is relatively simple. Therefore, the list price of constant speed turbines tends to be lower than that of variable speed turbines. However, constant speed turbines must be more mechanically robust than variable speed turbines. Because the rotor speed cannot be varied, fluctuations in wind speed translate directly into drive train torque fluctuations, causing higher structural loads than with variable speed operation. This partly cancels the cost reduction achieved by using a relatively cheap generating system.

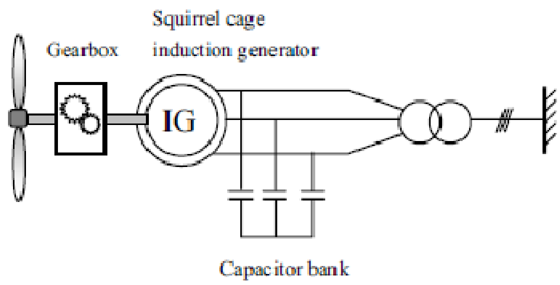


Figure 2: Fixed speed WTGS

Fixed speed WTGS, both single and double cage squirrel cage induction generators are commercially used. The squirrel cage induction generators used in wind turbines can often run at two different (but constant) speeds by changing the number of pole pairs of the stator winding.

The relation between pole pairs and rotational speed is

$$\omega_s = \frac{120f}{p} \tag{2}$$

where,

ω_s = generator rotor speed in rpm,
f= Stator voltage frequency,
p= Number of pole pairs

In practical, there is a big speed difference between the turbine hub and the squirrel cage induction generator. Therefore, a gearbox is used in this topology that matches the turbine low speed to the higher speed of the generator.

Variable speed wtgs (vs wtgs)

Another type of a wind power generation is in using variable speed wind turbine driving a doubly fed induction generator (D F I G), wound field in the synchronous generator (WFSG) or permanent magnet synchronous generator (PMSG) are shown in figure 3. a, b and c. The main advantage of variable speed operation is that more energy can be generated for a specific wind speed.

To calculate power of coefficient C_p for the values of λ and β are,

$\lambda = \omega_r / V_w$ (3)

$$\lambda_i = 1 / [\ (1/(\lambda+0.02\beta) - (0.03/ \beta^3+1))] \quad (4)$$

$$C_p(\lambda, \beta) = 0.73[\ (151/ \lambda_i) -0.58\beta - (0.002\beta^{2.14})-13.2]e^{(-18.4/ \lambda i)} \quad (5)$$

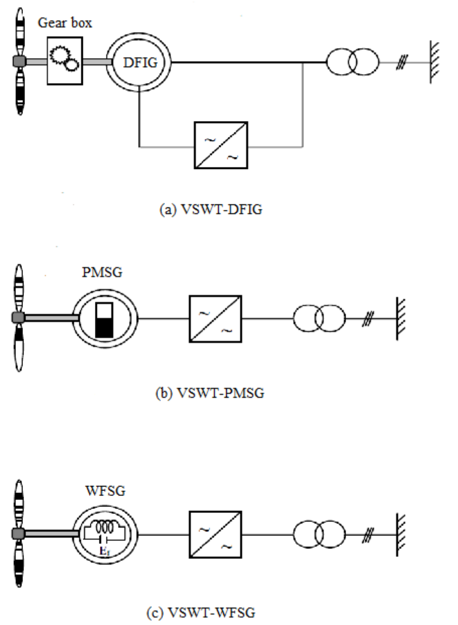


Figure 3: Different Variable Speed Wind Turbine Generator Systems

For a VSWT, generated active power depends on the power coefficient C_p is related to the proportion of power extracted from the wind hitting the wind turbine blades. From the above equation 5. the values of tip speed ratio and power coefficient are chosen as 5.9 and 0.44 respectively. For each instantaneous wind speed of a VSWT, there is a specific turbine rotational speed and that speed corresponds to the maximum active power from the wind generator. In this way, the maximum power point tracking (MPPT) for each wind speed, increases the energy generation in a VSWT.

VSDFIG Model

The complete electrical model is shown in figure 4. and it has been developed using the Simulink environment. The developed model includes the wind model, drive train model for a Variable Speed DFIG Turbine System. In order to investigate the control of the active and reactive power for this system a wind time series with an average value of 10 to 15 m/sec has been used. The synchronous speed of the machine has been considered as the base value for speed, while the rated power of the machine is the base for the active and reactive power.

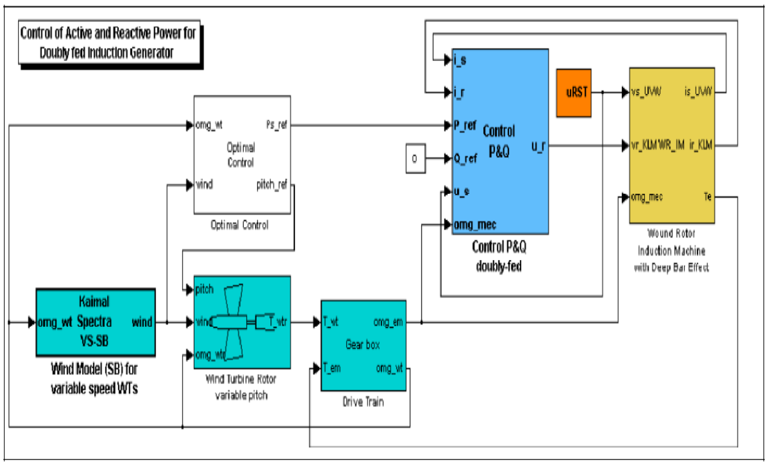


Figure 4: DFIG Wind Turbine Simulink Electrical Model

PMSG Model

The modeling and simulation for the VS PMSG wind turbine is to be done in Matlab Simulink. The wind turbine parameters used in the simulations are tabulated in Table 1.

Table 1: Wind turbine parameters

Parameter	Value	Unit
Generator Speed	2.26	rad/s
Generator Power	2.5	Mw
Mutual Inductance in q	0.7	p. u
Mutual Inductance in d	0.7	p. u
Stator leakage inductance	0.02	p. u
Stator resistance	0.0025	p:u
Compensating capacitor	0.1	p:u
Rotor radius	40	M
Air density	1.1	Kg/m^3
Optimal turbine eefficiency	0.474	-
Optimal tip speed ratio	7.5	-

Simulation Results

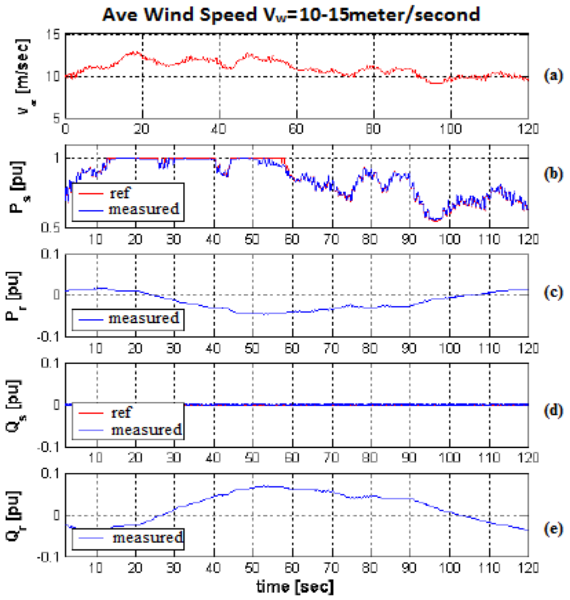
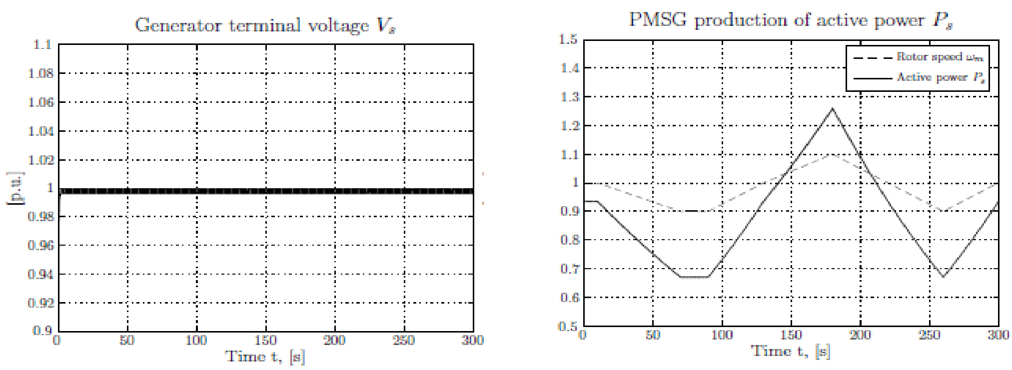
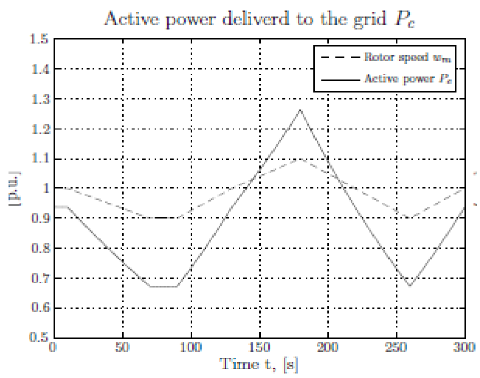


Figure 5: Simulation results for VSDFIG Wind Turbine System

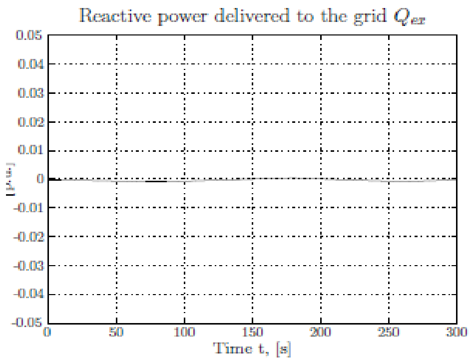
The simulations results of VSDFIG Wind Turbine system shows in figure 5. In terms of (a) the wind speed time series (V_W), (b) Stator active power (P_s), (c) Rotor active power (P_r) (d) Stator reactive power (Q_s) and (e) Rotor reactive power (Q_r). It can be observed that the power is limited at the rated value, while the speed is lower than the rated value. The results of the performed simulations of the variable speed permanent magnet synchronous generator wind turbine are (a) Generator terminal voltage (b) PMSG production of active power (c) Active power delivered to the grid and (d) Reactive power delivered to the grid shown in figure 6.



(a) (b)



(c)



(d)

Figure 6: VS PMSG Wind turbine Simulations (a) Generator terminal voltage (b) PMSG production of active power (c) Active power delivered to the grid (d) Reactive power delivered to the grid

Conclusion

The simulation model of variable speed doubly fed induction generator and variable speed permanent magnet synchronous generator was developed using various parameters and previous studies. The developed model in the selected range of the wind speed was showed.

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