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Modeling and Simulation of Grid Interfaced Synchronous Generator with Controller

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Abstract

The increasing demand of electric power necessitates the establishment of new generating stations. Wind energy conversion system (WECS) is more attractive due to its mature and clean aspects. During last decades the variable speed wind turbine concept has been increasingly receiving attention due to the fact that it is more controllable and efficient, and has good power quality. The wind turbine driven with permanent magnet synchronous generator (PMSG) feeds ac power to utility grid. For this purpose two voltage source converters are connected back to back between rotor terminals and grid via common dc link. In order to satisfy the grid code requirements such as grid stability, power quality improvement, and power control this machine is usually used. In this paper the complete mathematical modelling and simulation of wind turbine driven PMSG has been done. The stator and rotor of PMSG is connected to the grid through back to back connected two voltage source converters with a common DC link. The total system is modeled and simulated for better power quality and is capable of harnessing maximum power at various wind speeds. A new control strategy known as perturb and observation (P&O) controller is introduced in WECS for maximum power point tracking (MPPT) to improve the system operation. The simulation is done in MATLAB Simulink environment.

Keywords: b*ack to back pwm converters, grid, PMSG, WECS, wind turbine*

1. Introduction

Renewable energy including all the sources such as solar, wind, geothermal, tidal etc., is sustainable, environmentally friendly, reusable and clean. Due to increasing pollution problems and shortage in fossil fuels renewable energy source become an important source [1]. Among all the energies wind energy is most promising and fastest growing source. By the end of year 2010 worldwide cumulative installed capacity reached 199,520 MW. In India, the total installed capacity of wind energy power generation is 8754 MW in the year 2008. By the end of 2013 the total installed capacity is expected to reach 12GW according to the Ministry of renewable energy in India [2].

WECS can be run has variable speeds in which the machine is operating at varying speeds. In WECS the machine speed varies in accordance to the wind speed. In fixed speed WECS the efficiency is found to be very low, to improve the efficiency the technology is shifted from fixed speed to variable speed [3-6].

This paper completely develops the mathematical model of wind turbine, PMSG and control circuits in detail. And also it proposes the control mechanism for maximum power extraction. It also discuss about real and reactive power control based on rectifier side [6-9].

2. Wind Turbine

The kinetic energy present in the flowing air captured by wind turbine can be expressed as:

$$P_m = \frac{1}{2} \times C_p \times \rho \times A \times V^3 \qquad (1)$$

Where P_m is the wind power, $C_p$is the power co-efficient, ρ is the air density kg/m^3, A is the area of blades, v is the wind velocity in m\sec. The definition for power coefficient is output power of

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the wind turbine to the available power in the wind. At a given wind speed the "maximum" power absorbed by the wind turbine from the available wind power can be determined from the above coefficient.

Power coefficient is based on tip-speed ratio (λ) and the blade pitch angle (β). Pitch controller is used to control the blade pitch angle and tip-speed ratio is given as:

$$\lambda = \omega R/v \quad (2)$$

Where λ is generator rotational speed and R is rotor blade radius.

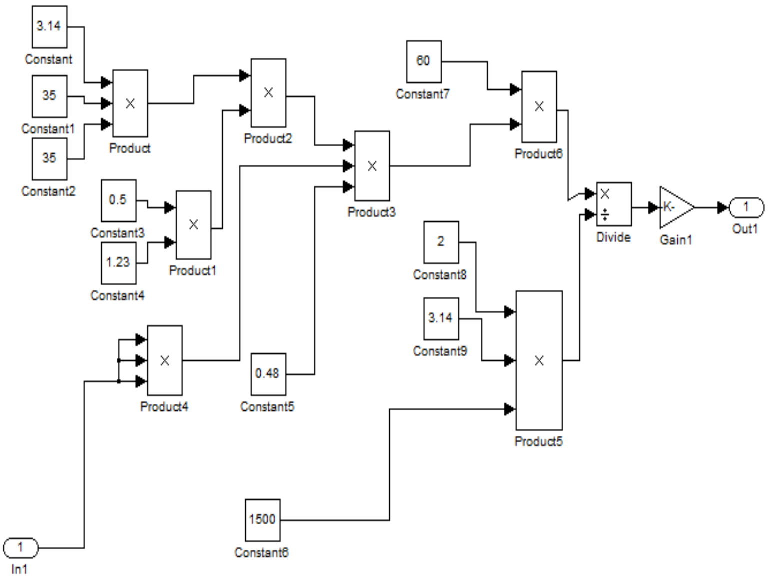

Figure 1. Model of turbine

3. Drive Train

The most common way to model the drive train is by considering a number of discrete masses connected together by springs are defined by stiffness and damping coefficients.

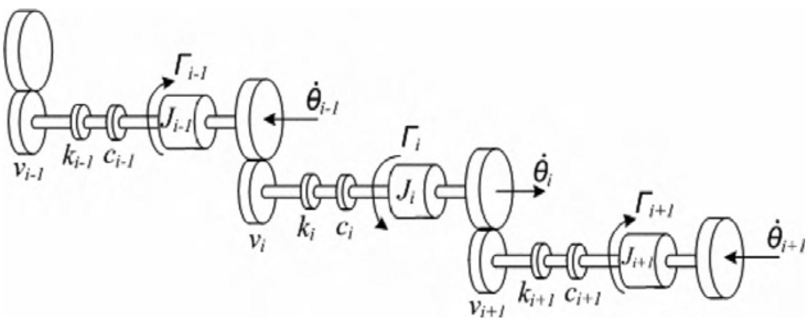

Figure 2. Transmission model of N masses connected together

For the studies based on interaction between wind energy and AC grids, one lumped mass model drive train can be considered for the sake of time efficiency and acceptable precision. The above approximation is considered for this present study and it is explained in the following equation:

$$d\omega_g \backslash dt = \tau_e - \tau_{\omega\_g} \backslash J_{eq} - B_m . \omega_g \backslash J_{eq} \quad (3)$$

Where sub-index g is the generator side, ω_g represents mechanical angular speed of generator, τ_e is electromechanical torque, τ_{ω_g} represents aerodynamic torque. This aerodynamic torque is equal to the torque produced in the rotor side due to the absence of gear box and rotational inertia is denoted by J_{eq} is derived from:

$$J_{eq} = J_g + J_w \backslash n_g{}^2 \tag{4}$$

Where J_w and J_g are the rotor rotational inertia and generator, $n_g$is gear ratio, and is equal to 1. The drive train model is implemented in simulink is shown in Figure 3.

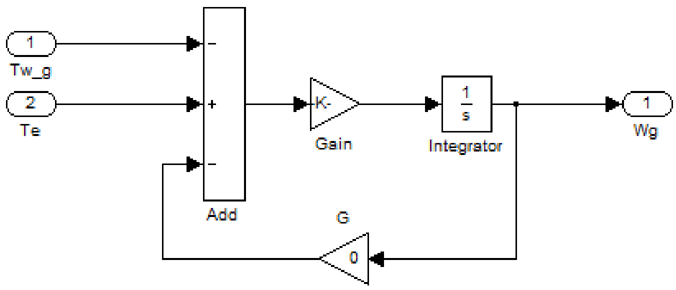

Figure 3. Model of Drive Train

4. Permanent Magnet Synchronous Generator

PMSG can be operated with low wind speeds for that it requires high number of poles. The rotor is provided with permanent magnets thus electrical dc excitation is not required. Because of equally distributed surface mounted magnets and permeability of the magnetic material is as big as the air gap permeability the reactance in d- and q- axis differs only by few percent [3], thus the surface mounted PMSGs are considered as round rotor machines.

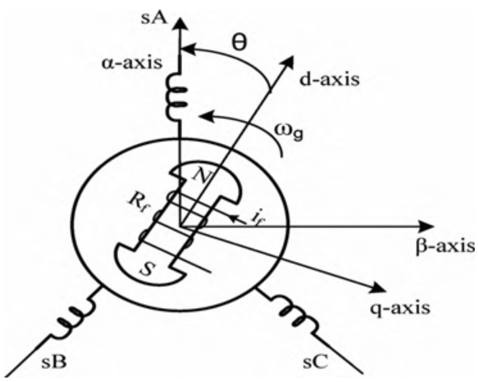

Figure 4.Salient Pole Synchronous Machine with d-q and $\alpha - \beta$ axis

The wind turbine based PMSG are shown in the Figure 1 called the wind turbine and permanent synchronous generator system. The back to back PWM converter is divided into two components: the rotor side converter and the grid side converter. Both rotor side and grid side converters are voltage source converters in order to synthesize an AC voltage from DC voltage source forced commutated power electronic devices are used. A DC link capacitor acts as a DC voltage source [10].

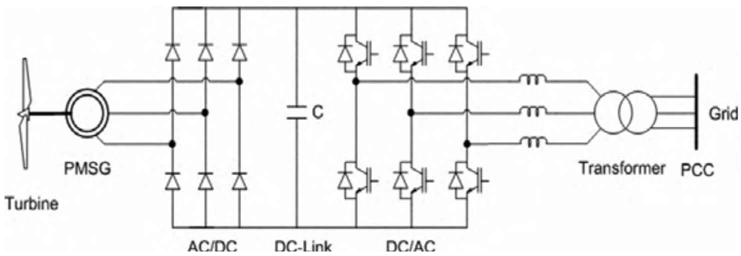

Figure 5. Wind Turbine Driven with PMSG

The three phase stator winding are directly connected to the grid. And the three phase rotor winding are connected to the grid through AC\DC\AC converter. The PMSG generates electrical power by converting the mechanical power captured by the wind turbine and it is transmitted to the grid by stator and rotor windings.

5. Mathematical Modeling of PMSG

Under various operating conditions and different control strategies a simplified mathematical model is used to analyse the behavior of any complex system. For PMSG mathematical model is derived in terms of direct and quadrature axes (dq axes) quantities in synchronous reference frame.The related expressions to this model are given by [1, 2]:

$$di_d \backslash dt = 1\backslash L_{ds} + L_{ls} \left(-R_s i_d + \omega_e \left(L_{qs} + L_{ls}\right) i_q + u_d\right) \quad (5)$$

$$di_q \backslash dt = 1\backslash L_{qs} + L_{ls}(-R_s i_q - \omega_e \left[(L_{ds} + L_{ls}) i_d + \Psi_f\right] + u_d) \quad (6)$$

Where R_s is the stator resistance [Ω], L_d and L_q are the inductances [H] of the generator, L_{lq} and L_{lq} are the leakage inductances [H] of the generator, ωe is the electrical rotating speed of the generator, Ψ_f is the permanent magnetic flux.The electrical rotating speed of the generator can be defined by:

$$\omega_e = p\, \omega_g \quad (7)$$

Where p represent the pole pairs of the generator.

The resultant of the PMSG mathematical model is the driving force, which is described by the following electromagnetic torque equation [3].

$$\tau_e = 1.5p((L_{ds} - L_{ls}) i_d\, i_q + i_q \Psi_f \quad (8)$$

The PMSG modelling has been simulated in Simulink is shown in Figure 6.

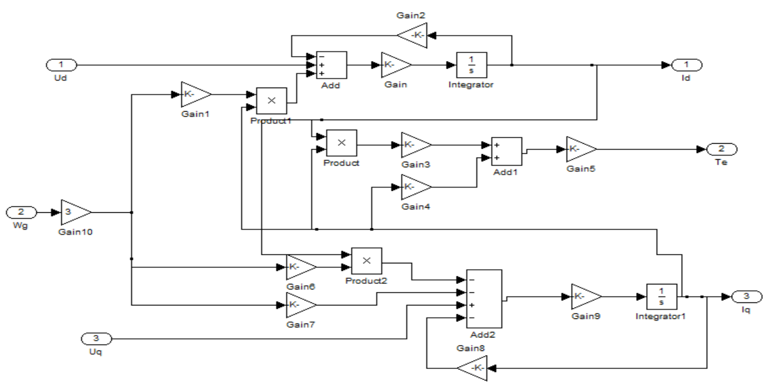

Figure 6. Simulink Model of PMSG

The basic parameters used for modelling PMSG are given in Table 1.

Table 1

Parameter	Symbol	Value	Unit
Power	P_n	2	[MW]
Phase Voltage	V_n	3000	[V]
Rated current	I_n	400	[A]
Rated speed	n_n	25	[rpm]
Stator resistance	R_s	0.08	[Ω]
Synchronous inductance	L_d	0.334	[H]
Synchronous inductance	L_q	0.217	[H]
Permanent magnet flux linkage	λ_m	0.4832	[Wb]
Rotor moment of inertia	J	0.3	[$mKgm^2$]
Nr.of pole pairs	*npp*	3	-

6. Results and Discussion

The study is carried out for wind speed 12 m/s. The output torque of the turbine is shown in Figure 7. The turbine works at rated conditions when is operating at wind speed of 12 m\s. Beyond the rated value pitch angle mechanism is activated, so that the power and speed are limited to their rated values.

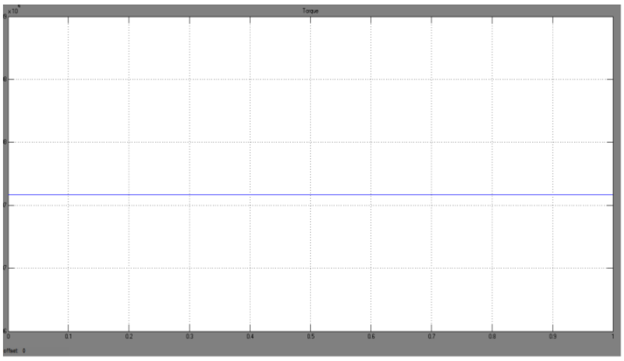

Figure 7. Output Waveform of Wind Turbine

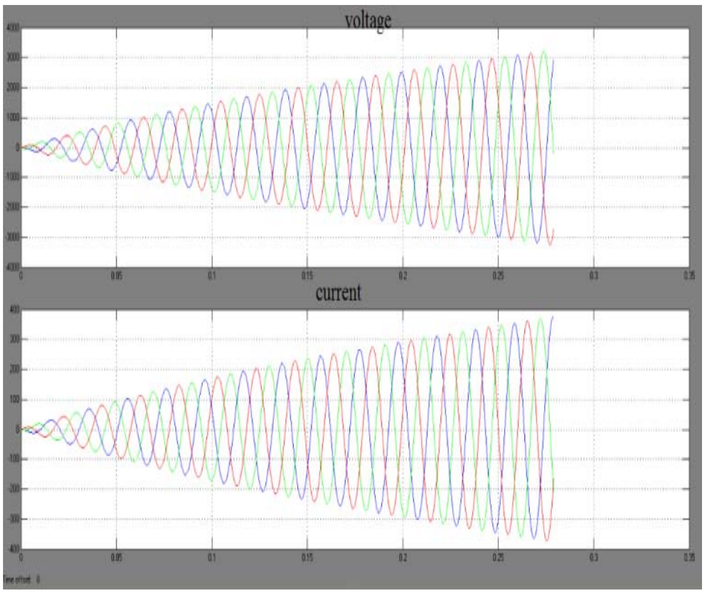

Figure 8. Output Waveform of voltages and current of generator

7. Conclusion

This paper presented the complete mathematical model of wind turbine based PMSG and also it analyzed that if the wind speed decreases below the rated value of the generator speed, current and voltage decreases but as the wind speed increases beyond the rated value the control mechanism like pitch angle mechanism is activated thus it limits the power and the speed to their rated values and also the observation is done that there is no variation in voltage and current at the generator terminal. Here a control strategy for variable speed wind energy system is proposed which allows the PMSG to operate at different wind speeds to generate maximum power from the wind turbine and also used for real and reactive power control. Thus by using new control strategy known as perturb and observation controller better results are proved in system stability. In future this paper is extended for MPPT using hybrid optimization technique.

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