Volume : 3 | Issue : 3 | March 2014 • ISSN No 2277 - 8160

Research Paper ENGINEERING

Modeling and Simulation of Wind Turbine Connected to Pmsg for Wind Mill Application

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ABSTRACT

The aim of this work is to analyze a typical configuration of The Variable Speed Wind Turbine (VSWT) configuration is the dominant wind turbine topology available at this moment on the market. Moreover, the Permanent Magnet Synchronous Generator (PMSG) offers better performance than other generators because of its higher efficiency and of less maintenance since they don't have rotor current and can be used without a gearbox, which also implies a reduction of the weight of the nacelle and a reduction of costs. VSWT wind turbine generator consists of another three parts: wind speed, wind turbine and drive train. These elements have been modeled and the equations that explain their behaviour have been introduced. What is more, the whole WTGS has been implemented in MATLAB. Therefore, in this paper the modeling of a 2 MW VSWT equipped with PMSG is presented.

KEYWORDS : wind speed, wind turbine ,drive train, PMSG and MPPT

INTRODUCTION

Wind energy is available and clean source of energy that has been used to generate electrical power. The focus on electrical power generated from wind energy has been increased due to the environmental problems that fossil fuels make. Global warming and green house emissions are the main harmful results of fossil fuel consumption. The first wind turbines appeared at the beginning of the last century and technology was improved step by step from the early 1970s. By the end of the 1990s, wind energy has re-emerged as one of the most important sustainable energy resources. Currently, five countries (Germany, USA, Denmark, India and Spain) concentrate more than 83% of worldwide wind energy capacity in their countries [1].The wind farm are located on land and due to scarcity of land and wind energy extraction wind turbine site are located offshore. The electrical wind turbine generators are an interface connection between the mechanical part of the system and the electrical part. The main function of the electrical generator is to convert the mechanical energy coming from the wind turbine which act as a prime mover to electrical energy that is transferred to the electrical grid. Wind turbines are different types and generally categorized in two types according the wind speed, variable wind speed turbines and fixed wind speed turbines.

Wind turbines electrical generators commonly used are:

1. Squirrel-Cage rotor Induction Generator (SCIG).**2**-Wound-Rotor Induction Generator (WRIG).**3**-Doubly-Fed Induction Generator (DFIG).**4**-Synchronous Generator (SG) with external field excitation.**5**- Permanent Magnet Synchronous Generator (PMSG).

Moreover, the Permanent Magnet Synchronous Generator (PMSG) offers better performance than other generators because of its higher efficiency and of less maintenance since they don't have rotor current and can be used without a gearbox, which also implies a reduction of the weight of the nacelle and a reduction of costs. Therefore, in this paper the modeling of a 2 MW VSWT equipped with PMSG is presented and modeling of converter and inverter and control system are does not included.

SYSTEM AND MODEL DESCRIPTION

The system in Fig.1 analyzed is a variable speed wind turbine based on a multi-pole PMSG. Due to the low generator speed, the rotor shaft is coupled directly to the generator, which means that no gearbox is needed. The generator is connected to the grid via an *AC/DC/AC* converter, which consists of an uncontrolled diode rectifier, boost chopper circuit and a PWM voltage-source inverter. For this topology of converter, operation at relatively low wind speeds is possible due to the inclusion of the boost circuit. The boost circuit can maintain the DC bus link voltage at a constant value. A transformer is located between the inverter and the Point of Common Connection (PCC) in order to raise the voltage by avoiding losses in the transport of the current. The layout of the electrical part is depicted in Fig. 1. It must be noted that this study is dedicated to analyze and implement the model from the wind turbine to the PMSG. For this reason, transformer, grid, rectifier and inverter models and their controls will not be considered.

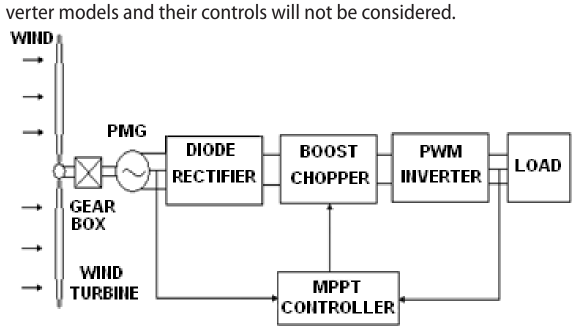

Fig. 1: Block diagram of wind electric generator system with diode rectifier and boost circuit.

A.WIND MODEL

Simulations concepts concerning wind modeling that the wind speed is characterized by the sum of the four following components [1]:

1. The average value; 2. A ramp component, which describes a steady increase in wind speed; 3.A gust component, representing a sudden wind gust; 4.A turbulence component;

The equation below describes the whole concept:

$$V_w(t)=V_{wa}+V_{wr}(t)+V_{wg}(t)+V_{wt}(t) \qquad (1)$$

where Vw(t) is the wind speed at time t, Vwa is the average wind speed, Vwr (t) is the ramp component, Vwg (t)is the gust component and Vwt(t) is the turbulence. All the wind speed components are in "meters per second" and time t is "in seconds". The model does not include the tower shadowing effect. The present work considers a constant wind speed equal to12 m/s. Consequently, the model implementation of the wind speed in Simulink implies the consideration of the base wind speed component.

B. ROTOR MODEL

The rotor aerodynamics are presented by the well-known static relations [l] , [2], [4].

The mechanical power available from a wind turbine

$$Pwt = \frac{1}{2}\delta\ Awt\ Cp(\lambda,\theta)V_w^3 \qquad (2)$$

where is the power coming from wind in watts, is the air density (*kg/* m3), cp is the power coefficient , is the tip speed ratio Vt /Vw - between the blade tip speed and wind speed, is the pitch angle and is the area covered by the wind turbine rotor. The amount of aerodynamic torque () in Nrn is given by the ratio between the power extracted from the wind () in Watt, and the turbine rotor speed () in rad/s, as in eq. (3).It should be noted that the mechanical torque transmitted to the generator () is the same as the aerodynamic torque, since there is no gearbox. It implies that the gearbox ratio is ng = 1. Therefore .

$$\tau_W = \tau_{W-G} \qquad \tau_W = \frac{P_W}{\omega_W} \qquad (3)$$

As stated in [1] most of the individual wind turbines have very similar power curves. Therefore an individual approximation of a power curve for each wind turbine is not necessary. Instead a general approximation of will be used. The general equation describing the fixed speed and variable speed wind turbines is presented below.

$$Cp(\lambda,\theta) = C_1\left(\frac{C_2}{\lambda_i} - C_{3\theta} - C_4\theta^{C_5} - C_6\right)\exp\left(\frac{-C_7}{\lambda_i}\right)(4)$$

Where

$$\lambda_i = [\left(\frac{1}{\lambda + C_8\theta}\right) - \left(\frac{C_9}{\theta^3+1}\right)^{-1} \qquad (5)$$

The constant coefficients from to are presented in table .

variable speed	0.73	151	0.58	0.0002	2.14	13.2	18.4	-0.02	-0.003

Table 1: Approximation of power curves.

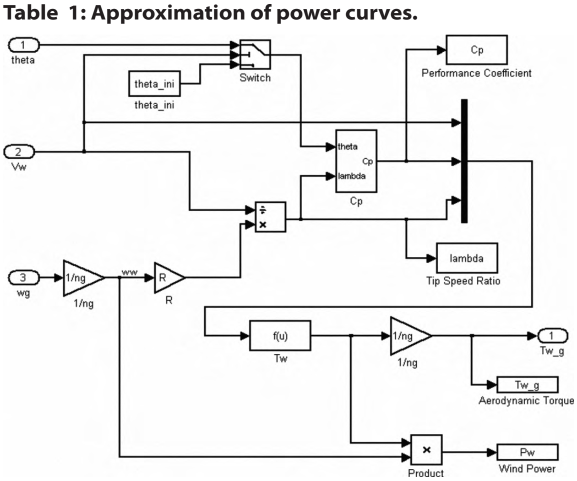

Fig. 2. Wind Turbine modeled with Simulink.

Above model was implemented in MATLAB Simulink software and it is presented in Figure 3.Parameter of wind turbine are shown in table 2.

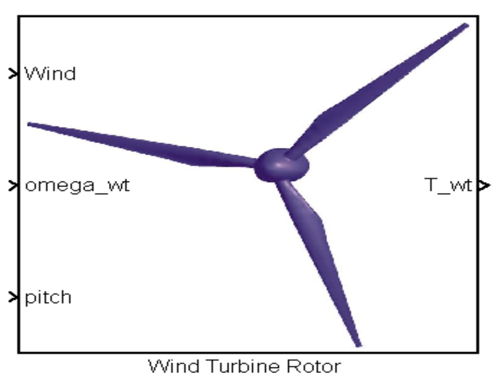

Figure .3: Implemented rotor model.

C. DRIVE TRAIN MODEL

The drive train of a wind turbine generator system consists of the following elements: a blade-pitching mechanism with a spinner, a hub with blades, a rotor shaft and a gearbox with breaker and generator. The simulated wind turbine uses a drive train with a single stage gearbox. To analyze the behaviour of the wind rotor during transients, a mechanical model for the wind turbine drive train was used The drive train behaviour can be analyzed by the simplified two-mass model, if the following assumptions are made [2]:

1. The moments of inertia for the low speed shaft, high speed shaft, and gearbox wheels are neglected, being small quantities when compared to wind wheel and generator inertias

2. The shaft torsional stiffness and the damping coefficient of the low-speed shaft and high speed shaft are combined together and moved on either side of the gearbox. The stiffness of the low speed shaft is about 100 times less than the generator shaft.

The diagram for the drive train with its parameters is shown in Figure 4.

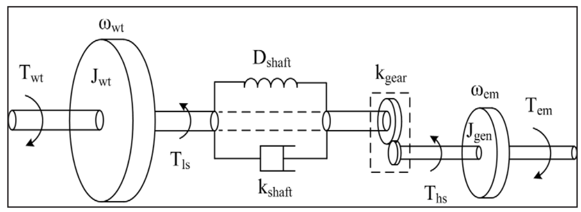

Figure 4: The drive train diagram.

The equations shown below are forming the two-mass model of the drive train:

$$J_{\omega t}\frac{d\omega_{wt}}{dt} = T_{wt} - T_{ls} \qquad (6)$$

$$T_{ls} = K_{shaft}(\theta_{wt} - \theta_{ls}) + D_{shaft}(\omega_{wt} - \omega_{ls}) \qquad (7)$$

$$J_{gen}\frac{d\omega_m}{dt} = T_{hs} - T_{em} \qquad (8)$$

$$\frac{d\theta_{wt}}{dt} = \omega_{wt} \qquad (9)$$

$$\frac{d\theta_m}{dt} = \omega_m \qquad (10)$$

$$\omega l_s K_{gear} = \omega_{hs} \qquad (11)$$

Above model was implemented in MATLAB Simulink software and it is presented in Figure 5.The detailed model, showing the implemented differential equations, is presented in Table 3, and it is based on [2].

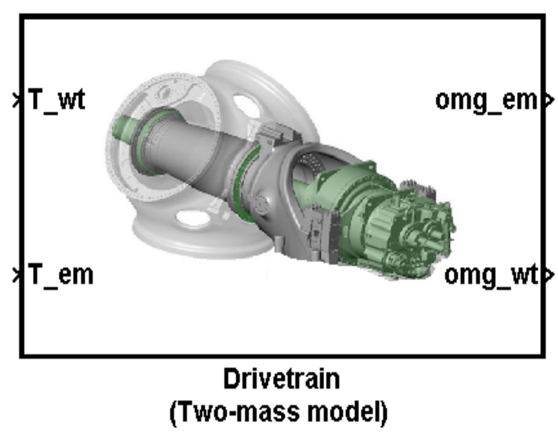

Figure 5: drive train model .

D.WIND TURBINE GENERATOR PMSG MODEL

The Wind Turbine Generator (WTG) is the most important component in a wind energy conversion system. It converts the mechanical energy from the rotor shaft into electrical energy, with the use of electromagnetic induction principle. The Permanent Magnet Synchronous Generator (PMSG) is a synchronous generator which has permanent magnets

(PM's) mounted on the rotor. The model of the PMSG was developed in the dq synchronous reference frame, where the q-axis is 90_ phase shifted ahead of the d-axis with respect to the direction of rotation. In order to simplify the system, the generator was assumed to be a PMSG with surface-mounted magnets. Thus, the model of the PMSG in the dq synchronous reference frame is given by the voltage equations (12) and (13), the torque equation (14) and the mechanical equation (6).

$$u_{sd} = R_s i_{sd} + L_d \frac{di_{sd}}{dt} - \omega_e L_q i_{sq} \quad (12)$$

$$u_{sq} = R_s i_{sq} + L_q \frac{di_{sq}}{dt} - \omega_e L_d i_{sd} \quad (13)$$

$$T_{em} = \frac{3}{2} n_{pp} \Psi P_M i_{sq} \quad (14)$$

Where, usd , usq represent the direct and quadrature components of the stator voltages, isd , isq represent the direct and quadrature components of the stator currents, Ld , Lq represent the direct and quadrature components of the stator inductances Rs represents the stator resistance, ωm represents the mechanical speed of the rotor, ωe represents the electrical speed of the rotor, ΨPM - represents the permanent magnet flux linkage, Tem represents the electromagnetical torque, npp represents the number of the pole pairs.

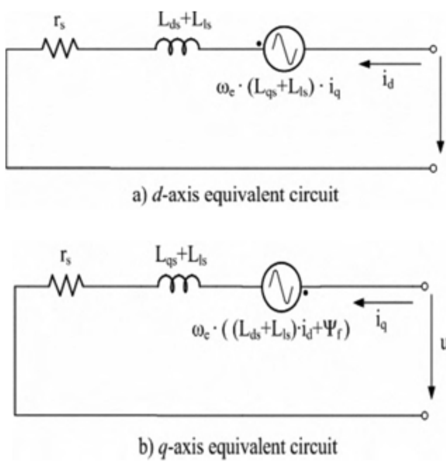

Fig. 6. Equivalent circuit of the PMSG in the synchronous frame.

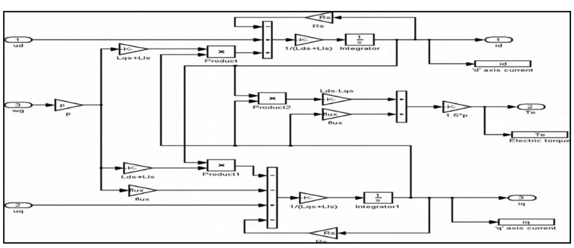

Fig. 7. PMSG modeled with Simulink.

The input/output signals of the generator modeled in Simulink are shown in Figure .8. The values for the generator parameters are presented Table 4.

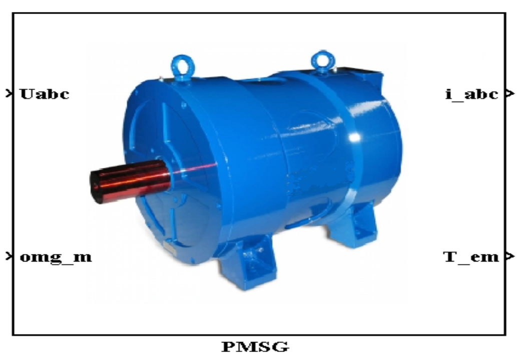

Figure 8: PMSG block diagram.

In variable speed WTGS, generated active power depends on the power coefficient, Cp, which is related to the proportion of power extracted from the wind. From eq.(4), the optimum values of tip speed ratio and power coefficient are chosen 5.9 and 0.44 respectively. For each instantaneous wind speed of VSWT, there is a specific turbine rotational speed, ωr, which corresponds to the maximum active power, Pmax, from the wind generator. In this study, power coefficient curve with maximum power point tracking (MPPT) line is shown in Fig. 9. When the wind speed changes, the rotational speed of wind turbine is controlled to follow the maximum power point trajectory. Since the precise measurement of the wind speed is difficult, it is better to calculate the maximum power, Pmax, without the measurement of wind speed as shown below.

$$Pmax = \frac{1}{2} \delta \pi R^2 \left(\frac{\omega_r R}{\lambda_{opt}}\right) C_{p\_}opt \quad (15)$$

Equation (15) shows that the maximum generated power is proportional to the cube of rotational speed.

During the control of boost converter, the maximum power, Pmax, is calculated using MPPT, which works as the reference power, Pref, of the converter.Therefore, the reference power will not exceed the rated power of the PMSG.

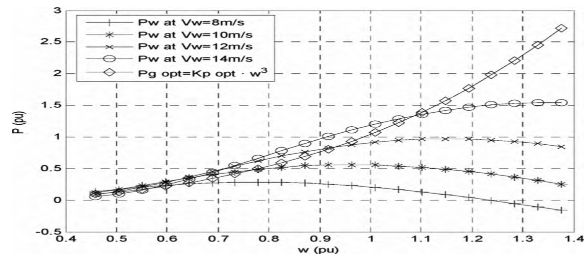

Fig. 9. Power vs. speed curves for different wind speeds and optimum power generated as a function of generator speed and wind speed.

Parameter	Simbol	Value	Unit
Rated voltage	V	690	$[V]$
Rated power	P	2	$[MW]$
Stator resistance	R_s	2	$[m\Omega]$
d-axis stator inductance	L_d	0.11	$[mH]$
q-axis stator inductance	L_q	0.11	$[mH]$
No. of pole pairs	n_{pp}	4	[-]
Permanent magnet flux linkage	ψ_m	2.91	$[mWb]$

PMSG parameter Table 2.

Drive train parameter Table 3.

Parameter	Simbol	Value	Unit
Inertia of the wind turbine rotor	J_{wt}	$9.0 \cdot 10^4$	$[kg \cdot m^2]$
Inertia of the generator	J_{gen}	70	$[kg \cdot m^2]$
Shaft stiffness	k_{shaft}	$1.64 \cdot 10^8$	$[Nm/rad]$
Damping factor	D_{shaft}	$7.4 \cdot 10^5$	$[Nmsec/rad]$
Gearbox ratio	k_{gear}	46	[-]

Wind Turbine Parameters Table 4.

Parameter	Simbol	Value	Unit
Rotor blade radius	R	40	$[m]$
Air density	ρ	1.225	$[kg/m_3]$
Cut-in speed	v_{cut-in}	3	$[m/s]$
Cut-out speed	$v_{cut-out}$	20	$[m/s]$
Rated speed	v_{rated}	12	$[m/s]$
Rated rotor speed	ω_{rated}	1.71	$[rad/s]$
Optimum TSR	λ_{opt}	5.7	[-]

CONCLUSION

The modeling of a variable speed wind turbine with a permanent magnet synchronous generator has been treated. The model has been implemented in MATLAB/Simulink in order to validate it. Cl' curves and power-speed characteristics have been obtained.

The generator has been modeled in the d-q synchronous rotating reference frame, taking into account different simplifications. Moreover, the concept of the maximum power point tracking has been presented in terms of the adjustment of the generator rotor speed according to instantaneous wind speed.

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