MODELING OF A SMALL PERMANENT MAGNET SYNCRONOUS GENERATOR WIND ENERGY CONVERSION SYSTEM FOR A SMART BUILDING

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REZUMAT. În acestă lucrare modelarea unui generator sincron cu magneţi permanenţi (PMSG) bazat pe o turbină eoliană va fi dezvoltată. Scopul principal al lucrării este de a combina o turbină eoliană, un PMSG, un convertor de putere şi controlul sistemului pentru a construi un sistem complet a unei turbine eoliene pentru o clădire inteligentă. Folosind acest model ca punct de pornire, inginerii pot nu doar să dezvolte topologii noi pentru convertorul de putere sau a metodelor de control care au eficienţe şi controlabilitate ridicată, dar şi verificarea performanţelor lor prin simulare.

Cuvinte cheie: clădire inteligentă, generator cu magneți permanenți, sistem de turbină eoliană, metodă de control

ABSTRACT. In this paper, a modeling of a permanent magnet synchronous generator (PMSG) based wind turbine system will be developed. The main purpose of this paper is to combine a wind turbine, a PMSG, a power converter, and a control system together to build a complete set of a wind turbine system for a residential smart building. Utilizing this model as a starting point, engineers can not only develop new topologies of the power converter or control methods which have better efficiency and controllability, but also verify their performance through simulation.

Keywords: smart building, permanent magnet sincronus generator, wind turbine system, control method

1. INTRODUCTION

Smart Grids and the integration of intermittent renewable, like wind and solar power, are proposed as costs-effective options for reducing the dependency on fossil fuels and reducing environmental impacts from the energy sector [1].

This development relies on successfully increasing energy system flexibility. However, while current research in Smart Grids and Microgrids focuses on electro-chemical and mechanical storage options [2], other have pointed towards options for cost-effective integration of end-use appliances, like high-efficiency compression heat pumps with thermal storages [3].

Over the last years, global wind energy capacity has increased rapidly and became one of the fastest developing renewable energy technologies. At the end of 2006, the global wind electricity-generating capacity has increased to 74 223 MW from 59 091 MW a year before. The early technology used in wind turbines was based on squirrel-cage induction generators (SCIGs) directly connected to the grid. Recently, the technology has developed toward variable speed. The controllability of the wind turbines becomes more and more important as the power level of the turbines continuously increases [4].

In this paper, a modelling of a permanent magnet synchronous generator (PMSG) based wind turbine system will be developed for a Smart Building. The main purpose of this paper is to combine a wind turbine, a PMSG, a power converter, and a control system together to build a complete set of a wind turbine system for a flexible and independent energy system.

Together with thermal storage technologies, heat pumps, photovoltaic or solar panels, and intelligent control system this technology may come to play a key role in the development of Smart Buildings in future energy systems.

The structure of the paper is: description of the system, an overall modeling of a PMSG wind energy conversion system (WECS), the maximum power point tracking (MPPT) controller, simulation results, and conclusion.

2. SYSTEM DESCRIPTION

Wind turbine systems can be classified into three dominant types: One is a constant speed squirrel-cage induction generator (SCIG) based wind turbine system, the second one is a variable speed doubly fed induction generator (DFIG) based wind turbine system, and third one is a variable speed permanent magnet synchronous generator (PMSG) based wind turbine system [5].

With the development of permanent magnetic materials in recent years, the performance of the PMSG based wind turbine systems are improved and widely used. This system requires neither slip rings nor an additional power supply for the magnetic field excitation. It can also operate in a relatively wide range of the wind speed. Therefore, efficiency is known to be higher than any other wind turbine systems mentioned above.

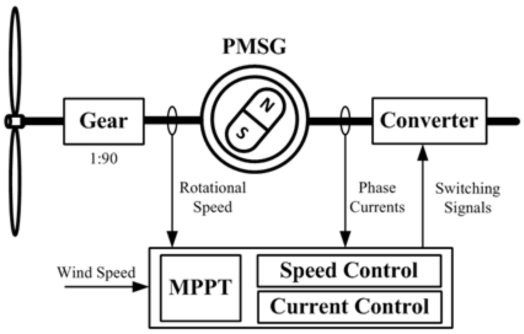

Fig. 1 PMSG based wind turbine system.

Fig. 1 shows the basic concept of a PMSG based wind turbine system. The wind turbine is connected to the PMSG through a gearbox (1:90) and the rotational speed of the PMSG is measured to control the speed of the turbine. The wind speed is also measured using an anemometer. The speed of turbine should be controlled according to the wind speeds in order to extract the maximum power from the wind stream. This control is called maximum power point tracking (MPPT).

The power captured from the wind turbine can be expressed as:

$$P_m = T_m \omega_T = \frac{1}{2}\pi\rho C_p(\lambda,\beta) R^2 V^3 \qquad (1)$$

where ωT is the rotational speed of the turbine, ρ is the air density (typically 1.25 kg/m3), Cp(λ, β) is the power coefficient, λ is the tip-speed ratio, β is the pitch angle, R is the blade radius, and V is the wind speed [6].

Wind turbines can achieve their own maximum power coefficients if they are controlled to maintain an optimal tip-speed ratio, λopt, at various wind speeds. Fig. 2 shows the mechanical output power of a wind turbine at various wind speeds. The value of the tip-speed ratio is constant for all maximum power points (MPPs), while the rotational speed of the turbine is related to the wind speed as:

$$\omega_T^* = \frac{1}{90}\cdot\omega_r^* = \lambda_{opt}\frac{V}{R} \qquad (2)$$

where ωT* is the optimal rotational speed of the wind turbine at a certain wind speed and ωr* is the reference rotational speed of the PMSG [7].

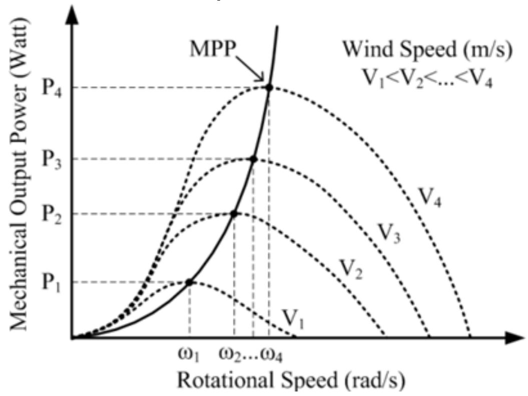

Fig. 2 Output power curves of the wind turbine.

The speed controller controls the speed of the PMSG to track the reference rotational speed using a proportional integral (PI) controller. The speed controller produces the q-axis reference current with which the PMSG can produce proper torque to follow the optimal rotational speed. The d-axis reference current is kept at zero so that no additional energy is used for the magnetic field excitation [8].

The current controller can be implemented with different modulation strategies such as sinusoidal pulse width modulation (SPWM), space vector pulse width modulation (SVPWM), and hysteresis modulation [9]. In this project, the hysteresis modulation strategy will be used for the sake of simplicity. To control the phase current of the PMSG, the three phase currents are measured using current sensors. The reference dq-axis currents are transformed into the normal three phase currents using Park transformation and compared with measured phase currents to perform the hysteresis modulation. Fig. 3 shows the block diagram of the overall control scheme.

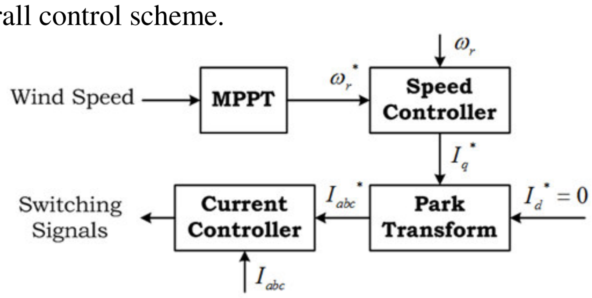

Fig. 3 Block diagram of the overall control scheme.

3. MODEL DESCRIPTION

Overall modeling of PMSG WESC:

Fig. 4 shows the overall schematic of a Permanent Magnet Synchronous Generator (PMSG) Wind Energy Conversion System (WECS).

As it can be seen from the figure, a permanent magnet synchronous machine block from the Simulink/Sim Power Systems library is used to simulate the PMSG. A universal bridge block of three-phase IGBT/Diodes is used as a power converter. It is assumed that the power converter is connected to a 520V ideal dc network which is represented by a dc battery block in this schematic. To simulate the wind turbine, a wind turbine block from the Simulink/Sim Power Systems library is used. The wind turbine block takes the wind speed in m/s, the pitch angle in degrees, and the generator speed in per unit as inputs and produces the mechanical torque in per unit as an output. Two controllers are implemented to control the power conversion system: one is the maximum power point tracking controller and the other is the controller which controls the speed and the phase current of the PMSG. These controllers will be explained in detail in the next subsection. The overall parameters for the simulation are summarized in Table 1.

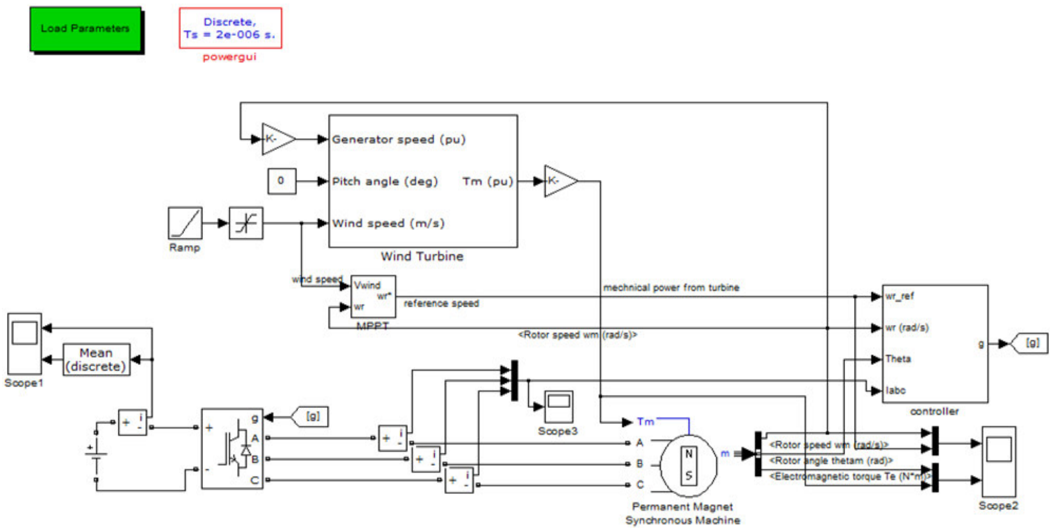

Fig. 4 Overall schematic of PMSG WESC.

Table 1

Summarized parameters for the simulation model

Blocks	Parameters	Values
Wind turbine	Nominal mechanical output power	10 kW
	Base power of the electrical generator	10 kVA
	Base wind speed	12 m/s
	Maximum power at base speed	1 p.u.
	Base rotational speed	1 p.u.
	Pitch angle	0□
Permanent magnet synchronous machine	Rated electrical power	10 kW
	Rated speed	1800 rpm
	Stator phase resistance	0.2 Ω
	Inductance Ld, Lq	8.5 mH
	Flux linkage established by magnets	0.175 V·s
	Inertia	0.0089 kg·m2
	Viscous damping	0.005 N·m·s
	pole	4
IGBT/Diodes	On resistance	1 mΩ
	Snubber resistance	100 kΩ
	Snubber capacitance	infinite

MPPT Controller: Referring to (2), the optimal rotational speed of the turbine is linearly proportional to the speed of wind. In order to implement this relationship, a linear function with the coefficient of 5π is used, so that the reference speed will be 1800 rpm (60π rad/s), which is the optimal rotational speed in this model, at the base wind speed of 12 m/s. Furthermore, a switch is used to restrict the reference rotational speed. When the wind speed is lower than 4 m/s, the reference rotational speed is set to the current rotational speed so that the turbine can accelerate or decelerate solely by the wind and no power is generated from the PMSG. On the other hand, when the wind speed is higher than 4 m/s, the MPPT controller gives the calculated optimal rotational speed as a reference speed. Fig. 5 shows the modelling of the MPPT Control.

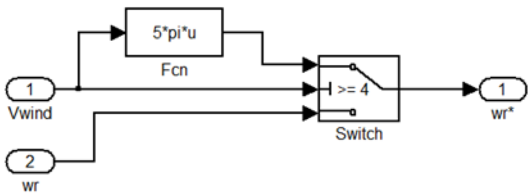

Fig. 5 MPPT Control

As it can be seen from Fig. 6, the speed controller is implemented with a simple PI controller. Two zero-order hold blocks are inserted to the inputs and a unit delay block is inserted to the output to lower the sampling rate of the speed controller. The sampling period of the controller is set to 140 μs. A rate limiter block with the slew rate of 1000 is also used at the input to avoid the abrupt change in the reference rotational speed. The rate limiter can lower the stress in the system when the wind speed changes abruptly. In addition, the gains in the PI controller can be tuned more roughly. The proportional gain is set to 10 and the integral gain is set to 300 in this model.

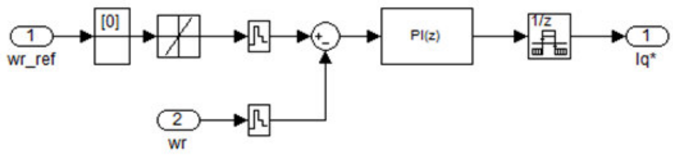

Fig. 6 Speed Control

Fig. 7 shows the current controller implemented in this model. The zero-order hold blocks and unit delay block is also used to lower the sampling rate of the controller. The sampling period is set to 20 μs for the current controller. The reference dq-axis currents are first transformed into the three phase currents using Park transformation and compared with the measured phase currents. The error of each phase current is used as an input to the hysteresis block. The hysteresis (Δh) is set to 1 A in this model. When the error is bigger than Δh, the switch is turned on to increase the phase current and when the error is smaller than –Δh, the switch is turned off to decrease the phase current. After determining the switching signals in this manner for the upper switches in the three-phase bridge converter, the switching signals for the lower switches can be easily obtained by complementing the upper switching signals.

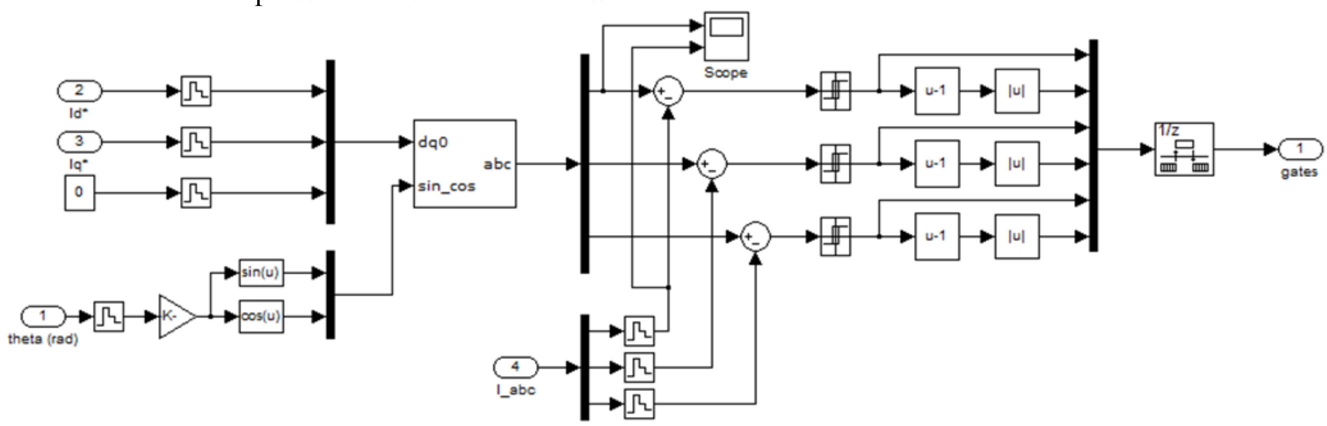

Fig. 7 Current Control

4. RESULTS

Fig. 8 shows the simulation result of the implemented model in this project. The input wind speed is changed from 0 to 12 m/s in a ramp manner during first 1 s and kept constant afterwards. When the wind speed reaches 4 m/s, the reference rotational speed of the PMSG is set to the optimal speed to track the maximum power points. As it can be seen from the middle graph, the PMSG is controlled by the speed controller and follows the reference speed very well. The bottom graph shows the mechanical torque from the turbine and the electromechanical torque produced by the PMSG. The measured rotational speed of the generator at the base wind speed is 188.5 rad/s and the measured electromechanical torque is 53 Nm. Therefore, neglecting the losses in the converter, the calculated power produced by the PMSG is 9.991 kW.

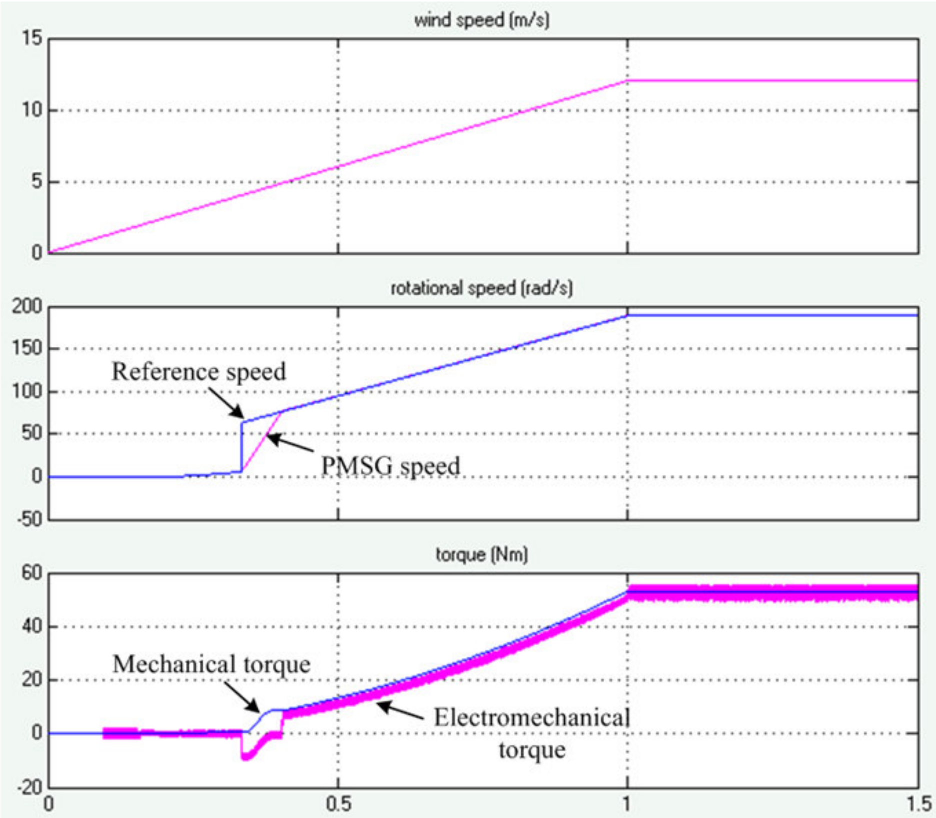

Fig. 8 Simulation results when input wind speed varied from 0 to 12 m/s: wind speed (top), rotational speed (middle), and torque (bottom).

5. CONCLUSIONS

✓ In this project, the PMSG based wind energy conversion system has been modelled using Matlab/Simulink.

✓ The basic description of each part of the system has been given and the basic concepts of MPPT control, speed control, and current control have been explained briefly. The mechanical and electrical parts of the system were modelled using the wind turbine, PMSG, and converter blocks from the Simulink/Sim Power Systems library.

✓ The control methods were implemented solely with the basic blocks from the Simulink library. The simulation has been performed to verify the implemented model and the simulation result showed the reasonable speed and torque characteristics of the controlled wind turbine system.

✓ This model can be used to check a wind turbine performance and behaviour at different wind speeds with various new circuit topologies and/or control methods.

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