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ELECTRICAL ENERGY CONTROL SYSTEM FOR SMALL POWER WIND TURBINES

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ABSTRACT

Electrical energy control systems for energy storage devices are required for power quality and balance within wind systems. In the context of rapidly expanding of distributed energy sources, the wind energy turbines are in the center of interest. This paper presents a control system for small power wind turbines of 3kW. As practical results are depicted modeling and simulation waveforms for the main parts of the system obtained with a dSPACE system DS1103.

Keywords: wind energy, control system, modeling and simulation, electrical energy storage.

1. INTRODUCTION

The renewable resources named also “green resources” are theoretically inexhaustible all over the world, free to use, and do not cause pollution. Since, they represent a great alternative to fossil fuel resources, some European countries, made the political choice to promote renewable energy and to supply electricity using a mix of traditional fossil fuels and “green resources” (such as wind, solar or biomass energy). Among these resources, wind is the cheapest on a large scale to transform into electrical energy. That is why much attention is paid nowadays to wind energy conversion systems.

The use of renewable energies will continue to grow, and such plants will become cheaper and more readily accepted by the market.

2. WIND SYSTEM DESCRIPTION

The wind turbine studied is a small power one with a rated power of 3kW and the blade diameter of 4m. It contains a permanent magnet synchronous generator (PMSG), buck-boost converter, transformer, inverter, ac load, and lead acid batteries (LAB) and supplies single-phase consumers, at 230V and 50Hz, as shown in Fig.1.

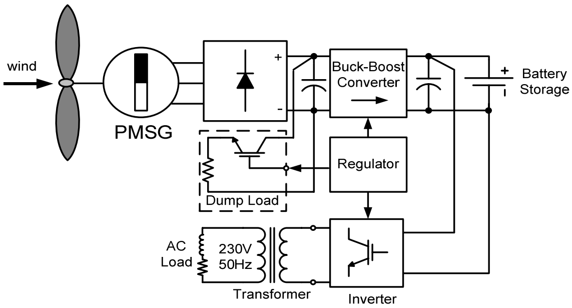


Figure 1. Wind turbine system configuration.

This topology is built in order to obtain a maximum efficiency for the system.

The regulator measures the main system's parameters – wind speed, battery voltage and current, PMSG's rotor speed – and controls the buck-boost duty-cycle, commands the dump load and gives the inverter's modulation index. The main advantage of variable speed operation is that more energy can be generated for a specific wind speed regime. Although the electrical efficiency decreases, due to the losses in the power electronics and are essential for variable speed operation. There is also a gain in aerodynamic efficiency due to variable speed operation. The aerodynamic efficiency gain exceeds the electrical efficiency loss, overall resulting in a higher energy yield. There is also less mechanical stress, and noise problems are reduced as well, because the turbine runs at low speed when there is little wind.

2.1. Wind turbine power characteristic and model

The wind speed dependence is best described by the Weibull probability distribution function [4,5,7]. The equation expressing the power wind is characterized by the following expression [4,7]:

$$P_{wind} = \frac{\Delta E}{\Delta t} = \frac{1}{2}\rho \cdot v^3 \cdot A \ . \tag{1}$$

where ρ is the air density, v is the wind speed and A is the turbine swept air area.
This relationship is usually shown graphically in a power curve, as shown in the Fig.2.

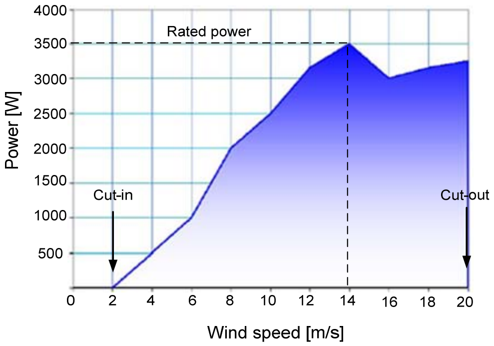


Figure 2. Wind turbine power characteristic for 3kW.

The wind turbine's power curve is an important parameter in the wind plant energy yield prediction and the wind model is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine. The output power of the turbine is given by the following equation:

$$P_m = c_p(\lambda, \beta) \cdot \frac{\rho \cdot A}{2} \cdot v^3{}_{wind} \ , \tag{2}$$

where P_m is the mechanical output power of turbine, c_p is the performance coefficient of turbine, ρ is the air density, A is the turbine swept area, λ is the tip speed ratio of the rotor blade tip speed to wind speed; and β is the blade pitch angle. To model the turbine coefficient $c_p(\lambda, \beta)$, a universal equations based on the modelling turbine characteristics are used [1,4], as follows:

$$c_p(\lambda,\beta) = c_1 \cdot \left(\frac{c_2}{\lambda_i} - c_3 \cdot \beta - c_4\right) \cdot e^{\frac{-c_5}{\lambda_i}} + c_6 \cdot \lambda \ , \tag{3}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \ . \tag{4}$$

The coefficients c_1 to c_6 are: $c_1 = 0.5176$, $c_2 = 116$, $c_3 = 0.4$, $c_4 = 5$, $c_5 = 21$ and $c_6 = 0.0068$.

The c_p-λ characteristics, for different values of the pitch angle β, are illustrated in the Fig.3.

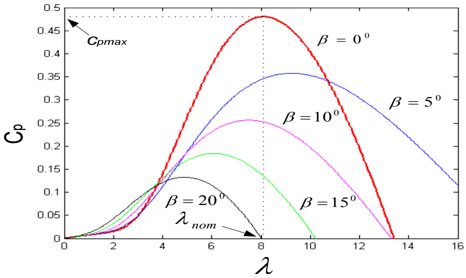


Figure 3. Wind turbine $C_p(\lambda, \beta)$ *curves.*

The maximum value of c_p ($c_{pmax} = 0.48$) is achieved for $\beta = 0$ degree and for $\lambda = 8.1$. This particular value of λ is defined as the nominal value ($\lambda_{\_nom}$). It is clear from this figure that there is a value of λ for which c_p is maximized thus maximizing the power for a given wind speed. Because of the relationship between c_p and λ, as the turbine speed changes for a given wind velocity, there is a turbine speed that gives a maximum output power. The Simulink model of the turbine is illustrated in the Fig.4.

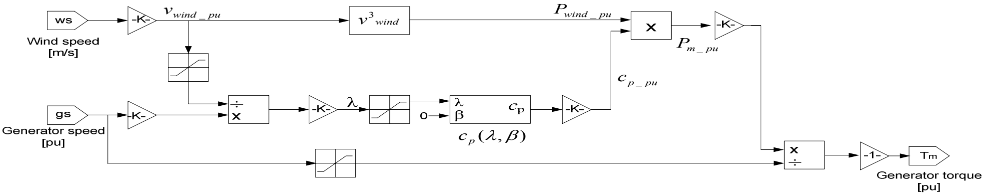
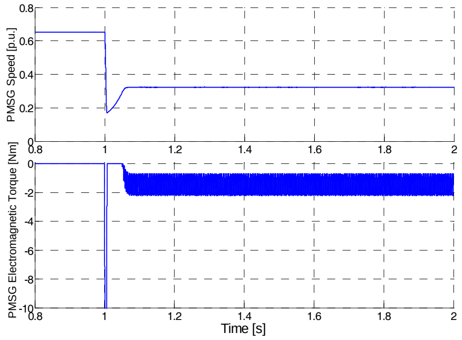


Figure 4. Simulink model of the wind turbine.

The tip speed ratio λ in pu of $\lambda_{\_nom}$ is obtained by the division of the rotational speed in pu of the base rotational speed and the wind speed in pu of the base wind speed. The output power is 3kW, base wind speed is 12 m/s, maximum power at base wind speed is 0.9 pu ($k_p = 0.9$) and the base rotational speed is 1 pu. For the PMSG, diode bridge rectifier, buck-boost converter and the inverter, the control method is based on MPPT (maximum power point tracking) control which is depending on the wind speed and adjusts the power transferred to bring the turbine operating points onto the ”maximum power curve”[1,2,3,4,5,6,7].

3. DYNAMIC BEHAVIOUR SIMULATIONS

Simulations were carried out for the start-up process, variable wind speed behavior and variable load behavior. The ***start-up process*** takes place at a wind speed of 4m/s. The PMSG is considered connected at t =1s, when the generator operates under steady-state condition. In the Fig. 5 are shown the PMSG rotor speed and the electromagnetic torque.



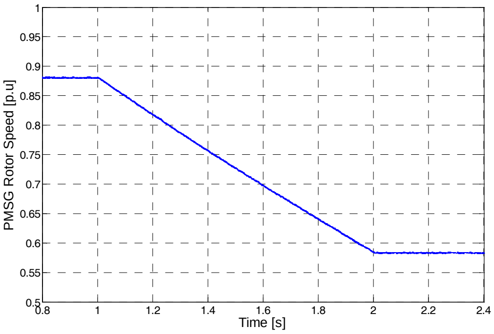


Figure 5. PMSG speed and electromagnetic torque. *Figure 6. The PMSG rotor speed.*

For the ***variable wind speed behaviour***, is considered a wind speed decrease from 10 m/s to 7 m/s at the moment t = 1s, which affects the system's power balance. In the Fig.6, the rotor speed is shown.
At ***variable load behavior***, the wind velocity is assumed constant at 10 m/s, the initial load has P = 500W and Q = 100VAR and the PMSG is operating in steady state conditions.
At the moment t = 2s an initial load is suddenly connected..Then, after t = 3s, this load is disconnected. In this case, in Fig 7, the ac voltage's shape is depicted.

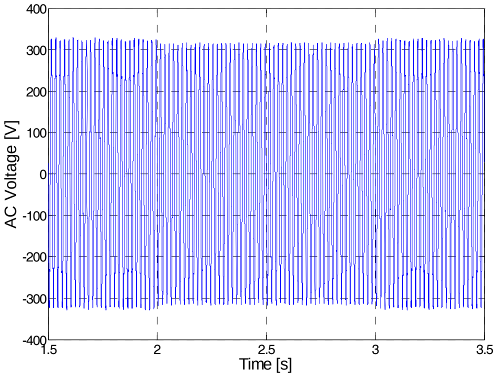


Figure 7. The ac link voltage.

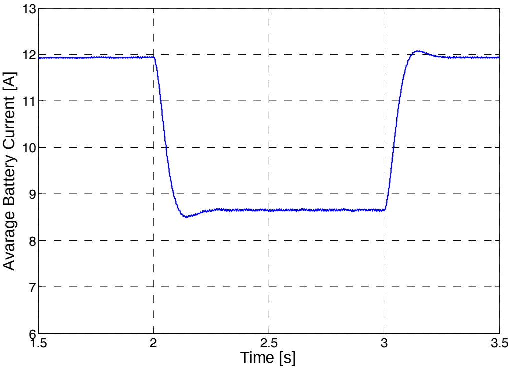


Figure 8. The average battery current.

During the transitory time, the voltage shape presents small sags. Because the mechanical power delivered to the PMSG is constant, the power balance is maintained by varying the battery's charging current, as shown in Fig.8. While an additional load is connected, the average battery current decreases from 12A to about 8.5A.

4. CONCLUSIONS

The proposed wind stand-alone system for a residential location is a 3kW wind turbine system with PMSG generator, rectifier bridge, buck-boost converter, bidirectional charge controller, and LAB storage device, inverter, transformer and loads. It is able to supply single-phase consumers, at 230V and 50Hz. The control of a variable speed PMSG for wind generation system is based on the MPPT method and has been presented in this paper. The start-up process begins when the wind velocity exceeds the threshold value of 4m/s. The turbine-generator speed is controlled by the buck-boost converter, which acts as a maximum power point tracker. The balance between the generated power and the consumed power is maintained by an electrical battery or by the dump load. The load variations are well managed and the dynamic performance is good.

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