MODELING AND SIMULATION OF A SMALL WIND TURBINE USING MATLAB SIMULINK

Dumitru **POP**, Radu **TÎRNOVAN**, Liviu **NEAMȚ**, Dorin **SABOU**

Technical University of Cluj Napoca.

dan.pop@enm.utcluj.ro

Keywords: Wind energy, Modeling, Simulation, Matlab

Abstract*:* *In this paper, a small wind turbine is analyzed. Because usually the manufactures don't provide enough information about the turbine (especially for small turbines), the steps for obtaining this parameters are presented. A Matlab program was written to fulfill this steps and then the whole turbine was simulated in Simulink. The resulted performance curve from simulation was compared with the performance curve from the manufacture's datasheet for validation*

1. INTRODUCTION

In recent years, the demand for renewable energy increased due to environmental problems, high conventional fuels prices and shortage of traditional energy sources in the near future. [1] [2] Of all available renewable resources, solar and wind energy are attracting the most attention due to its abundant, inexhaustible potential and its increasingly competitive cost. Wind technologies have been developing rapidly over the last few decades being considered one of the most important sustainable energy resources and one of the best technologies today to provide a sustainable electrical energy supply to the world development. [3] [4]

The utilization of wind energy has a very long tradition, being used first to move ships. Later, the Persians invented the windmill to pump water and grind crops. Nowadays, wind turbines are used to convert wind energy into electricity. The main problem of wind energy is that its availability depends on climate conditions and terrain. Also, the "quality" of the wind is very important because even if the speed it's good, turbulences produced by trees or hills (in cities by buildings) will affect the energy production and can damage the turbine. [5] [6]

In terms of the generators for wind-power application, there are two big concepts: fixed-speed and variable-speed wind turbine generators. Permanent magnet synchronous generators (PMSG) are increasingly popular due to their advantages of small size, high energy density, low maintenance cost, and ease of control. [2] [3] Large wind turbines are complex in operation, deploy multitude of control methods and operate in grid-connected mode. On the other hand, small wind turbines can be used for grid-connected system as well as stand-alone system for remote places where grid based electricity is not available. [7] [8]

In order to simulate a wind turbine, some information about it must be known. Unfortunately, the manufactures don't provide enough specifications in their data sheets, especially for small scale turbines. Usually, they provide only the power curve (with respect to wind speed) and some information about rotor diameter and weight. This paper will present a method to obtain the parameters needed for simulations using Matlab Simulink.

2. WIND ENERGY CONVERSION

The kinetic energy of the wind is given by the following equation:

$$E = \frac{m \cdot v^2}{2} \text{ [Nm]} \tag{1}$$

where v is the wind speed (m/s) and m is the air mass determined by air density ρ and volume that crosses a certain surface A in time t:

$$m = \rho \cdot A \cdot v \cdot t \text{[kg/s]} \tag{2}$$

The wind power P_w has the following expressions:

$$P_w = \frac{\rho \cdot A \cdot v^3}{2} \text{ [W]} \tag{3}$$

The power extracted from the wind by a wind turbine is given by:

$$P = C_p \cdot P_v = C_p \cdot \frac{\rho \cdot A \cdot v^3}{2} \text{ [W]} \tag{4}$$

where C_p is the power coefficient and it's given as a function of the tip speed ratio λ and the blade pitch angle. The pitch angle is the angle between the plane of rotation and the blade cross section chord. [9] The tip speed ratio of a wind turbine is defined as:

$$\lambda = \frac{u}{v} = \frac{\omega R}{v} \tag{5}$$

where: u is the tangential velocity of the blade pitch, ω is the angular velocity of the rotor (rad/s), R is the rotor radius (m), and v the wind speed (m/s).

In Fig. 1 the approximation of the real rotor power curve by various theoretical approaches is presented. [1]. Usually three-blade airflow wind turbines are used for electric energy generation because, they have the highest power coefficient.

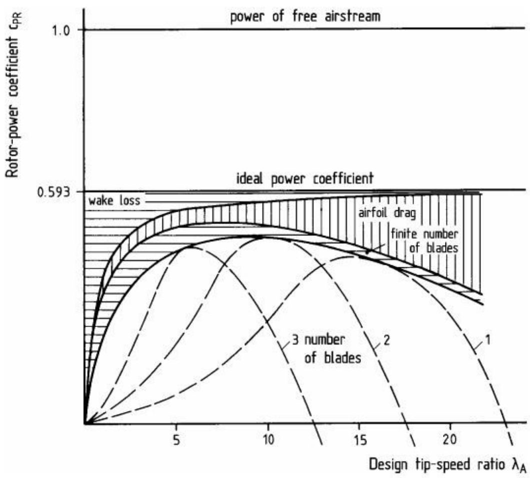


Fig. 1 – Approximation of the real rotor power curve by various theoretical approaches [1]

3. SIMULATION AND RESULTS

In this paper a wind turbine fabricated by Southwest Windpower Inc. is analyzed. Table1 presents the specifications of the wind turbine, model AirX 400, and in Fig. 2 the power curve with respect to wind speed.

Table1. Parameters of wind turbine AirX 400

Power	400 W
Voltage	24V
Rotor diameter	1.15 m
Cut in wind speed	2.5 m/s
Cut out speed	13 m/s
Weight	5.85 kg
Blades	3

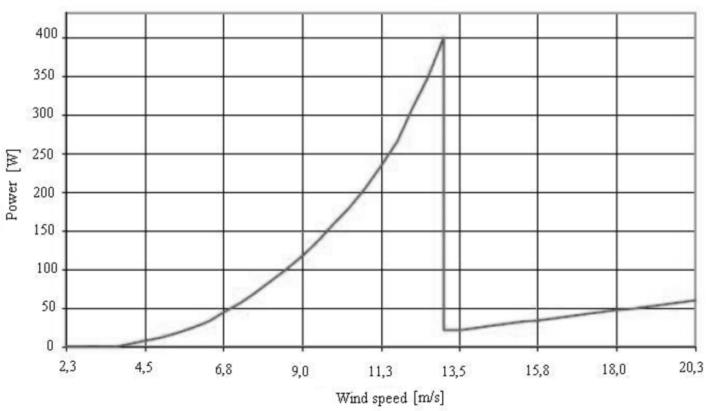


Fig. 2 – AirX 400 performance curve

This wind turbine was analyzed using Matlab. It must be specified that the analyze was made for the interval between no wind speed and cut-out wind speed, i.e. for wind speed ranging between 0 to 13 m/s. In order to find the parameters needed for simulations these steps were made:

- the values of power in respect with wind speed were extracted from Fig. 2;
- the *Cp* values in respect with λ were extracted from Fig. 1 (for a 3 blade wind turbine);
- from eq. (4), Cp was computed for every value of power;
- with eq. (3) we computed the power of the wind;
- with eq. (4) we computed the power of the wind turbine.

In order to fulfill these steps, a Matlab program was written. A screenshot with a part of this program is presented in Fig. 3.

```
% Read curve's point from Cp(TSR) curve:
dataCpTSR = xlsread('Cp-TSR.xlsx', 'Valori', 'A:B');
Cp=dataCpTSR(:,1);
Cp=Cp'; % Cp values from Cp(TSR) curve
TSR=dataCpTSR(:,2);
TSR=TSR'; % TSR values from Cp(TSR) curve
clear dataCpTSR

Area=1.0381625; % area of blades
AirDensity=1.29; % air density
BladesRadius=0.575; % blades radius

% Computation:
CpMatlab=PowerAirX./(0.5*AirDensity*Area*WindSpeedAirX_mps.^3);
CpMatlab(isnan(CpMatlab))=0;
TSRMatlab=interp1(Cp,TSR,CpMatlab);
OmegaMatlab=WindSpeedAirX_mps.*TSRMatlab/BladesRadius;
OmegaMatlab1rpm=OmegaMatlab.*(30/3.14);%convert from rad/s to rpm
WindPower=(0.5*AirDensity*Area*WindSpeedAirX_mps.^3);
TurbinePower=WindPower'*CpMatlab;
```

Fig. 3 – Screen shoot with a part of the program written in Matlab

After running the Matlab program, the parameters needed for the simulation are loaded in Matlab's workspace. In Fig. 4 is presented the differences between the theoretical *Cp(λ)* and the obtained curve after simulation. Also, from Fig. 4 we can see that the power coefficient is ranging from 0 to 0.27 for this wind turbine. In Fig. 5 we can see the output power of the wind generator in respect with wind speed and angular speed of the rotor.

In Fig. 6 is presented the wind turbine system implemented in Matlab Simulink. This model has as input parameter the wind speed (the "Ramp" block from Simulink library). The permanent magnet synchronous machine block has a negative input in order to act as a generator (positive for motor and negative for generator).

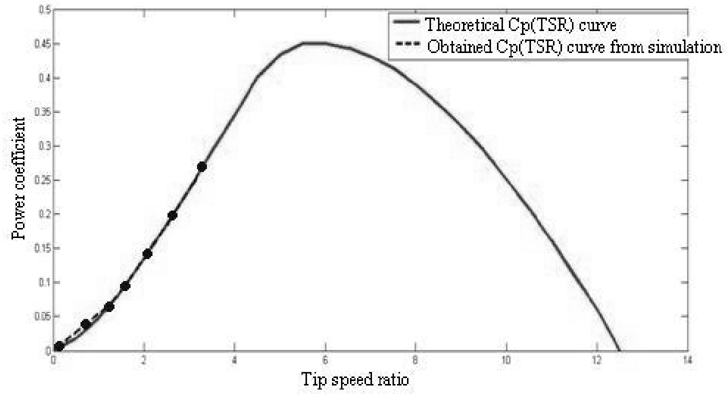


Fig. 4 – Differences between the theoretical Cp(λ) and the obtained curve after simulation

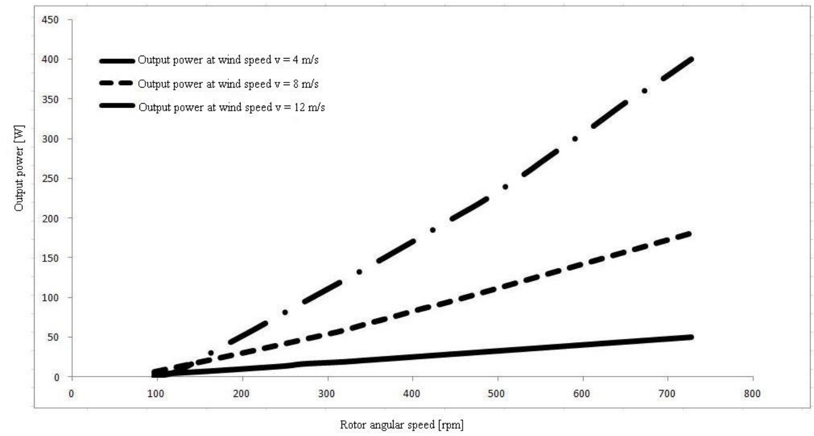


Fig. 5 – Output power of the wind generator in respect with wind speed and angular speed of the rotor

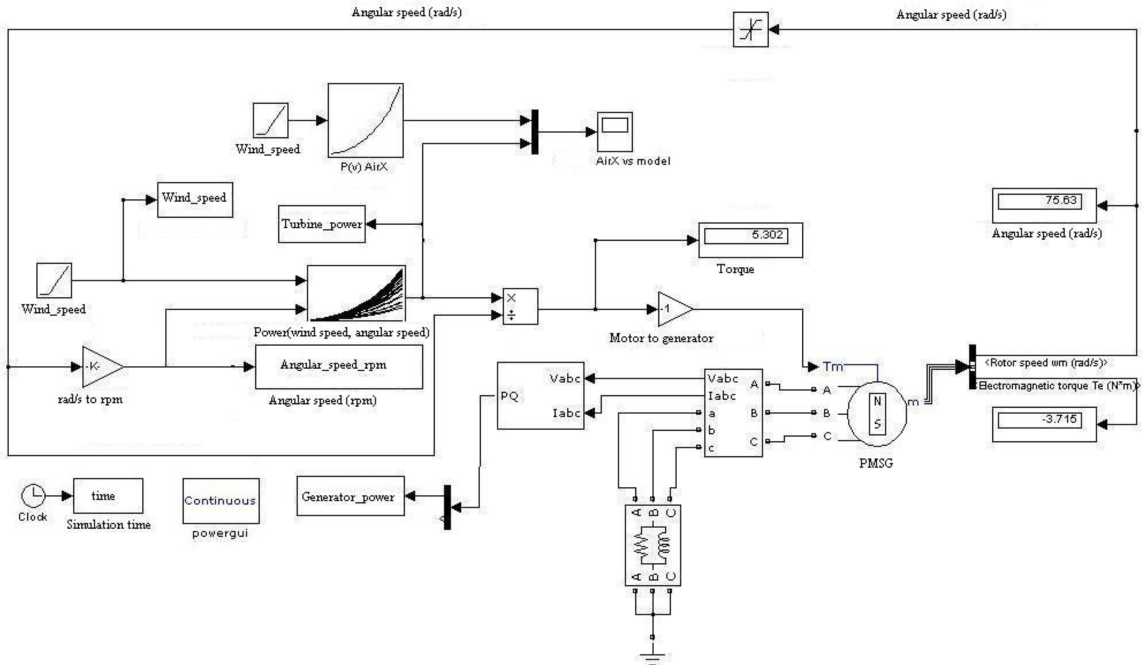
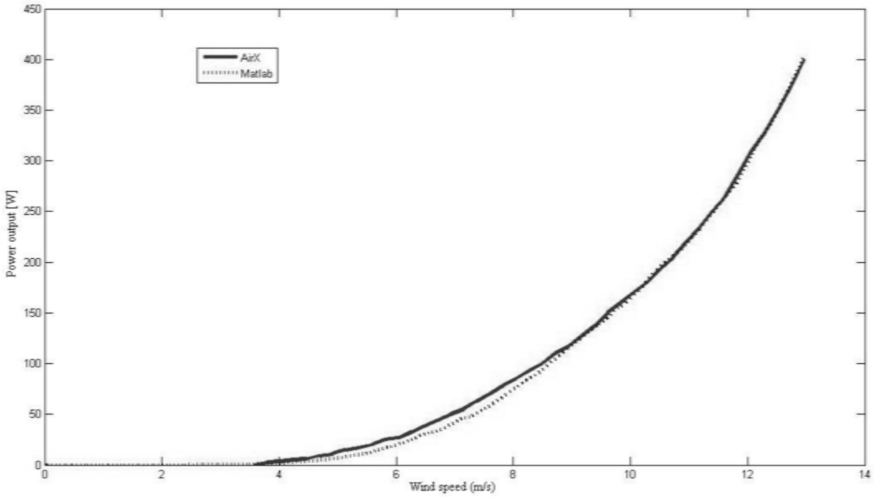


Fig. 6 – The wind turbine system implemented in Matlab Simulink

The “Power (wind speed, angular speed)” block (“Lookup2D” in Simulink library) outputs a power value using interpolation-extrapolation method with respect to the input values of wind speed and angular speed. The data needed for this block were obtained after running the Matlab program presented in Fig. 3.

For the validation, the power curve obtained after simulations was compared with the curve from the manufacturer (Fig. 7). As it can be seen, there is a good match between those two curves.



3. CONCLUSIONS

In this paper, a small wind turbine was analyzed. Because usually manufactures don’t provide enough information about the wind turbine, a Matlab program was written in order to find out some parameters needed for simulation. Then, using blocks from Matlab Simulink library, a wind turbine was implemented. The resulted performance curve from the model was compared with the curve from the manufacture’s datasheet for validation.

ACKNOWLEDGMENT: This paper was supported by the project "Improvement of the doctoral studies quality in engineering science for development of the knowledge based society-QDOC” contract no. POSDRU/107/1.5/S/78534, project co-funded by the European Social Fund through the Sectorial Operational Program Human Resources 2007-2013.

REFERENCES

1. H. Erich, *Wind turbines: Fundamentals, Technologies, Application, Economics*, 2nd Edition, Springer, 2005.

2. M. Yin, G. Li ; M. Zhou, C. Zhao, *Modeling of the Wind Turbine with a Permanent Magnet Synchronous Generator for Integration*, Power Engineering Society General Meeting, 2007. IEEE, pp.

1 - 6, Tampa, FL, 2007.

3. Z.M. Dalala, Z.U. Zahid, et. al., *Design and Analysis of an MPPT Technique for Small-Scale Wind Energy Conversion Systems*, IEEE Transactions on Energy Conversion, pp. 756 - 767, 2013.

4. A. Rolan, A. Luna, G. Vazquez, D. Aguilar, G. Azevedo, „*Modeling of a variable speed wind turbine with a Permanent Magnet Synchronous Generator*, IEEE International Symposium on Industrial Electronics, pp. 734 - 739, Seoul, 2009.

5. A. Luque, P*erformance of a Small Scale Turbine in an Urban Environment*, Master thesis, University of Strathclyde, Glasgow, 2009

6. A. Soetedjo, A. Lomi, W.P. Mulayanto, *Modeling of Wind Energy System with MPPT Control*, International Conference on Electrical Engineering and Informatics (ICEEI), pp. 1 - 6, Bandung, 2011

7. M. Arifujjaman, M.T. Iqbal, J.E. Ouaicoe, M.J. Khan, *Modeling and control of a small wind turbine*, Canadian Conference on Electrical and Computer Engineering, pp. 778 - 781, Saskatoon, 2005.

8. M. Örs, *Maximum Power Point Tracking for Small Scale Wind Turbine With Self-Excited Induction Generator*, Control engineering and applied informatics (CEAI), vol.11, pp. 30-34,2009

9. M. Sarvi, S. Azarbara, *A Novel Maximum Power Point Tracking Method Based on Extension Theory for Wind Energy Conversion System*, International Journal of Computer Science & Engineering Technology (IJCSET), Vol. 3, 2012