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Modeling of renewable hybrid energy sources

Dumitru Cristian Dragoş , Gligor Adrian
"Petru Maior" University of Tîrgu Mureş
cdumitru@engineering.upm.ro, agligor@engineering.upm.ro

Abstract

Recent developments and trends in the electric power consumption indicate an increasing use of renewable energy. Renewable energy technologies offer the promise of clean, abundant energy gathered from self-renewing resources such as the sun, wind, earth and plants. Virtually all regions of the world have renewable resources of one type or another. By this point of view studies on renewable energies focuses more and more attention. The present paper intends to present different mathematical models related to different types of renewable energy sources such as: solar energy and wind energy. It is also presented the validation and adaptation of such models to hybrid systems working in geographical and meteorological conditions specific to central part of Transylvania region. The conclusions based on validation of such models are also shown.

1. Introduction

The importance of hybrid systems has grown as they appeared to be the right solution for a clean and distributed energy production. It has to be mentioned that new implementations of hybrid systems require special attention on analysis and modeling. One issue is determined by the variable and unpredictable character of energy supply from renewable sources.

A major importance for the theoretical study of hybrid systems, based on renewable energy (photovoltaic, wind, hydroelectric systems), is the availability of models, which can be used to study the behavior of hybrid systems, and most important, software simulation environments.

As available tools are quite limited, this chapter intends to present several models which can be used for the simulation purposes of hybrid power systems as well as in educational purposes.

The modeling of renewable energy hybrid systems has to be made by knowing all types of renewable energy used in the model. For a good understanding of the system, equivalent models, based on large scale used components, should be considered.

2. Modeling the Solar Photovoltaic System

A photovoltaic PV generator consists of an assembly of solar cells, connections, protective parts, supports etc.

Solar cells are made of semiconductor materials (usually silicon), which are specially treated to form an electric field, positive on one side (backside) and negative on the other (towards the sun). When solar energy (photons) hits the solar cell, electrons are knocked loose from the atoms in the semiconductor material, creating electron-hole pairs [1]. If electrical conductors are then attached to the positive and negative sides, forming an electrical circuit, the electrons are captured in the form of electric current (photocurrent).

The model of the solar cell can be realized by an equivalent circuit that consists of a current source in parallel with a diode (Figure 1) [2], [3].

In Figure 1 R_S, R_P and C components can be neglected for the ideal model.

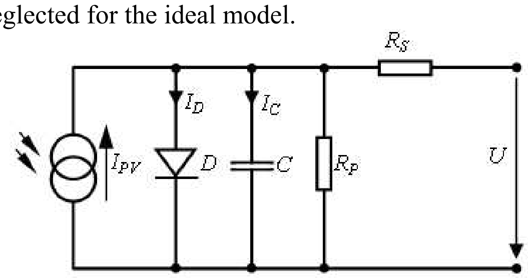

Figure 1. Equivalent circuit diagram of a solar cell

The p-n junction has a certain depletion layer capacitance, which is typically neglected for modeling solar cells.

At increased inverse voltage the depletion layer becomes wider so that the capacitance is reduced similar to stretching the electrodes of a plate capacitor. Thus solar cells represent variable capacitance whose magnitude depends on the present voltage. This effect is considered by the capacitor C located in parallel to the diode.

Series resistance R_S consists of the contact resistance of the cables as well as of the resistance of the semiconductor material itself.

Keywords: *wind energy system, renewable hybrid energy sources, solar photovoltaic system*

Parallel or shunt resistance R_P includes the "leakage currents" at the photovoltaic cell edges at which the ideal shunt reaction of the p-n junction may be reduced. This is usually within the kΩ region and consequently has almost no effect on the current-voltage characteristic [2].

The diode is the one which determines the current-voltage characteristic of the cell. The output of the current source is directly proportional to the light falling on the cell. The open circuit voltage increases logarithmically according to the Shockley equation which describes the interdependence of current and voltage in a solar cell [2], [4].

$$I = I_{PV} - I_0\left(e^{\frac{qU}{kT}} - 1\right) \quad (1)$$

$$U = \frac{kT}{q}\ln\left(1 - \frac{I - I_{PV}}{I_0}\right) \quad (2)$$

where:
- k - Boltzmann constant (1.3806 10^{-23} J/K);
- T – reference temperature of solar cell;
- q – elementary charge (1.6021 10^{-19} As);
- U – solar cell voltage (V);
- I_0 – saturation current of the diode (A);
- I_{PV} – photovoltaic current (A).

3. Modeling the Wind Energy System

Modeling the wind energy converter is made considering the following assumptions
- friction is neglected;
- stationary wind flow;
- constant, shear-free wind flow;
- rotation-free flow;
- incompressible flow (ρ=1.22 kg/m^3);
- free wind flow around the wind energy converter.

On the above condition the maximum physical achievable wind energy conversion can be derived using a theoretical model that is independent of the technical construction of a wind energy converter.

The flow air mass has certain energy. This energy is obtained from the air movement on the earth's surface determined by the difference in speed and pressure. This is the main source of energy used by the wind turbines to obtain electric power. The kinetic energy W taken from the air mass flow m at speed v_1 in front of the wind turbine's pales and at the back of the pales at speed v_2 is illustrated by equation (3).

$$W = \frac{1}{2}m\left(v_1^2 - v_2^2\right) \quad (4)$$

The resulted theoretical medium power P is determined as the ratio between the kinetic energy and the unit of time and is expressed by equation (4):

$$P = \frac{W}{t} = \frac{1}{2}\frac{m}{t}\left(v_1^2 - v_2^2\right) = \frac{1}{2}\frac{V\rho}{t}\left(v_1^2 - v_2^2\right) \quad (4)$$

where:
- V- air mass volume;
- t - time;
- ρ - air density.

Assuming the expression of the mean air speed $v_{med} = \frac{1}{2}\left(v_1 + v_2\right)$ the mean air volume transferred per unit time can be determined as follows:

$$V_{med} = \frac{V}{t} = Av_{med} \quad (5).$$

The equation for the mean theoretical power is determined using equation (5) (Figure 2):

$$P = \frac{1}{4}A\rho\left(v_1^2 - v_2^2\right)\left(v_1 + v_2\right) = \frac{A\rho v_1^3}{4}\left(1 - \frac{v_2^2}{v_1^2}\right)\left(1 + \frac{v_2}{v_1}\right) \quad (6)$$

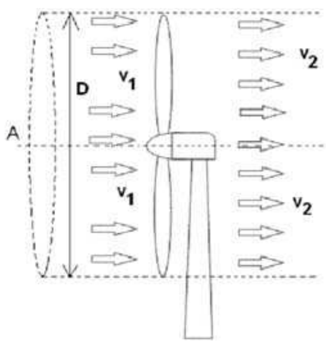

Figure 2. Flow through a wind energy converter

We can conclude that an adequate choice of ratio v_2 / v_1 leads to a maximum power value taken by the wind converter from the kinetic energy of the air masses, as shown by equation (7):

$$P_{max} = \frac{8}{27}A\rho v_1^3 \quad (7).$$

This power represents only a fraction of the incident air flow theoretical power given by:

$$P_{wind} = \frac{1}{2}\rho A v_1^3 \quad (8).$$

Equations (7) and (8) lead to:

$$P_{max} = \frac{8}{27}A\rho v_1^3 = \frac{1}{2}A\rho v_1^3 \cdot 0{,}59 = P_{wind} \cdot C_p \quad (9)$$

where: C_P represents the mechanical power coefficient which expresses that the wind kinetic energy cannot be totally converted in useful energy. This coefficient, meaning the maximum theoretical efficiency of wind power, was introduced by Betz [5].

The electrical power obtained under the assumptions of a wind generator's electrical and mechanical part efficiency is given by:

$$P_{el} = \frac{1}{2} C_e \rho A v_1^3 \tag{10}$$

where: C_e represents the total net efficiency coefficient at the transformer terminals [6].

The wind energy generator model was implemented by a module having configurable parameters based on equation (10) and using the equivalent model of a generator. This model takes the following form and is shown in Figure 3.

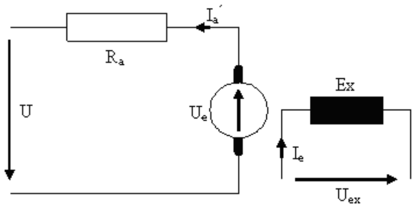

Figure 3. Equivalent circuit diagram of a small wind generator

In the equivalent circuit diagram of a small wind generator the notations are:

- R_a – rotor winding resistance;
- E_x – generator separate excitation winding; current I_e through this winding generates the main field;
- U_e – induced voltage in the rotor (armature);
- U – terminal voltage $U = U_e - R_a I_a$

4. Models Verification and Validation

Generally, to a complex physical system, a mathematical model can be built and associated, and such model is used in its study. But those mathematical models are frequently approximate models due to modeling uncertainties which establish the possibility of using them on a smaller or on a larger scale. It is recognized that nonlinear systems bring such issues.

Thus, a verification and validation of developed models is required to identify their scope and precision. In the present paper the verification and validation of solar photovoltaic and wind power system were obtained by using a comparative analysis between real systems and mathematical models deducted. For this purpose, in Matlab/Simulink environment, were developed validation and verification models of solar photovoltaic and wind power system as shown in Figure 4 and Figure 5.

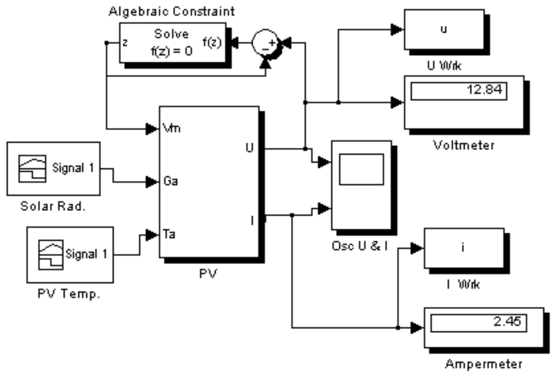

Figure 4. Matlab-Simulink model used for PV mathematical model validation

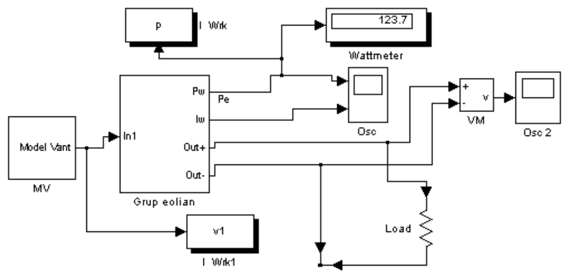

Figure 5. Matlab-Simulink model used for wind mathematical model validation

The models validation was realized by comparing theoretical model system solutions with real system solutions. For this analyze specific characteristics for photovoltaic solar system and wind power systems were considered.

In the case of photovoltaic solar system it can be noticed that the current-voltage theoretical characteristic (Figure 6), the current-voltage experimental characteristic (Figure 7) and the characteristic obtained with the Matlab/Simulink validation model (Figure 8) have the same allure.

In Figure 6 is presented a typical current-voltage "I-V" characteristic for a solar photovoltaic module. If the module terminals are connected to a variable resistance R, the operating point is determined by the intersection of the "I-V" characteristic of the solar photovoltaic module with the load "I-V" characteristic. It should be pointed out that the power delivered to a load depends on the value of the resistance only. For a small load R, the solar photovoltaic module operation is in the MN region of the "I-V" characteristic, where the module behaves as a constant current source, almost equal to the short-circuit current. For a large load R, the solar photovoltaic module operation is in the region PS of the "I-V" characteristic, where the module behaves as a constant voltage source, almost equal to the open-circuit voltage.

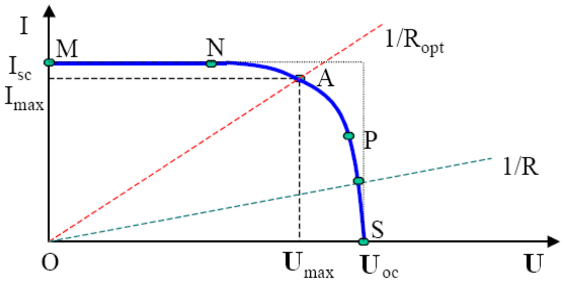

Figure 6. Current-voltage (I-V) theoretical characteristic for a PV solar module [7]

In Figure 7 is presented the experimental current-voltage „I-V" characteristic of a photovoltaic solar panel on different constant solar radiation at different loads. The experimental laboratory stand contains a photovoltaic solar panel of ET-M53620 type (4 x 9 photovoltaic solar cells) . The photovoltaic solar panel is characterised by following parameters:

- Peak power (P_{max}) 20 W;
- Maximum power point voltage (V_{mpp}) 17.82 V;
- Maximum power point current (I_{mpp}) 1.15 A;
- Open circuit voltage (V_{oc}) 21.96 V;
- Short circuit current (I_{sc}) 1.27 A;

The photovoltaic solar panel is equipped with 12V DC-230V AC inverter, a solar charge controller SOLSUM 5.6 and a 12 V accumulator.

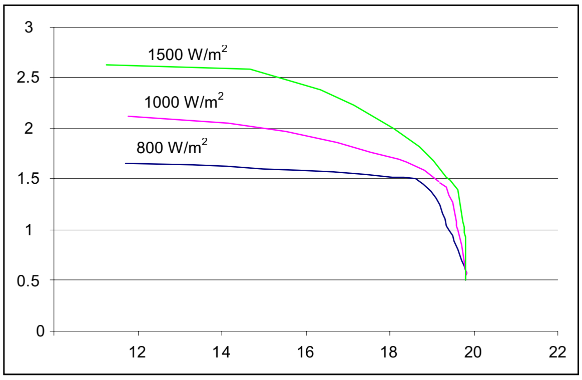

Figure 7. Experimental current-voltage characteristic of a photovoltaic solar panel on different constant solar radiation at different loads

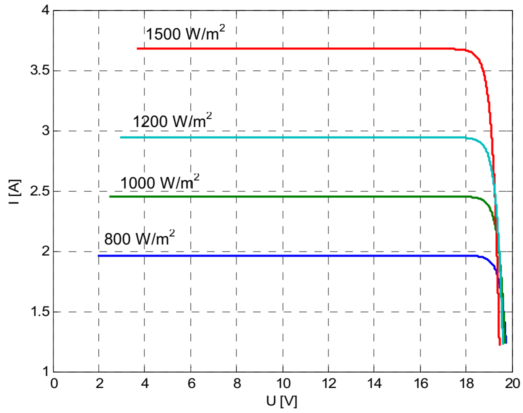

Figure 8. Current-voltage characteristic of PV solar module obtained with the Matlab/Simulink validation model

In the case of wind power system it can be noticed that the wind speed – electrical power theoretical characteristic (Figure 9) and the wind speed – electrical power characteristic obtained with the Matlab/Simulink validation model (Figure 10) have almost the same allure.

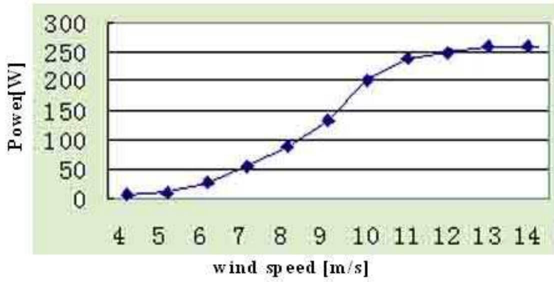

Figure 9. Wind speed - power theoretical characteristic for a small wind turbine [8]

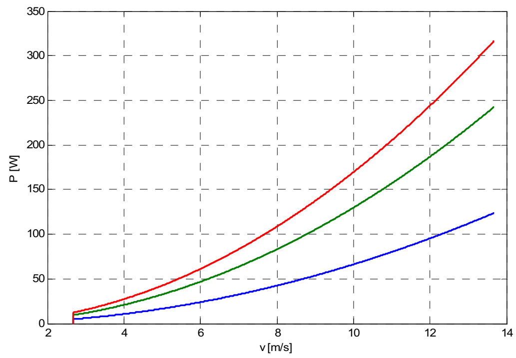

Figure 10 . Wind speed - power characteristic of a small wind turbine with constant pales area obtained with the Matlab/Simulink validation model

The analised wind turbine type is Air Breeze by Southwest Windpower U.S.A., with rotor diameter 1,17 m and P_N=200W.

5. Conclusions

The present paper intends to present and validate the mathematical models used in a renewable energy solar-wind hybrid system. Considering the importance of developing these models for study of renewable energy systems it is necessary to identify their scope and precision. In this paper was presented the set of renewable energy sources models from a solar-wind hybrid system but also the methodology of their verification. This implies experimental studies on laboratory equipments but also the developing of Matlab/Simulink applications for model testing.

By analyzing the comparative results it can be seen that, on a large scale of model parameters, a similarity between real systems behavior and theoretical model behavior was found.

The adaptation of models to specific environmental and climatic conditions from Transylvania was also necessary in order to find an equivalence between real (experimental) models and theoretical ones.

Some differences between real models characteristics and theoretical models characteristics can also be noticed, but those differences are predictable and caused especially by measure errors during experimentation and due to impossibility of conceiving a theoretical model by taking into consideration all conditions of a real model.

6. References

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