Isolated hybrid solar-wind-hydro renewable energy systems

Dorin Bică, Cristian Dragoş Dumitru, Adrian Gligor, Adrian-Vasile Duka
"Petru Maior" University of Tg. Mureş, Electrical Engineering Department
Romania

1. Introduction

Renewable energy technologies offer the promise of clean, abundant energy gathered from self-renewing resources such as the sun, wind, water, earth, and plants. Virtually all regions of the world have renewable resources of one type or another.

Renewable energy technologies offer important benefits compared to those of conventional energy sources. Worldwide, 1000 times more energy reaches the surface of the earth from the sun than is released today by all fossil fuels consumed. Photovoltaics and wind generation are also an attractive source of energy because of their benign effect on the environment.

Increased population growth and economic development are accelerating the rate at which energy, and in particular electrical energy is being demanded. All methods of electricity generation have consequences for the environment, so meeting this growth in demand, while safeguarding the environment poses a growing challenge

Each of the renewable energy technologies is in a different stage of research, development, and commercialization and all have differences in current and future expected costs, current industrial base, resource availability, and potential impact on greenhouse gas emissions.

Hybrid power systems consist of a combination of renewable energy sources such as: photovoltaic (PV), wind generators, hydro, etc., to charge batteries and provide power to meet the energy demand, considering the local geography and other details of the place of installation.

These types of systems, which are not connected to the main utility grid, are also used in stand-alone applications and operate independently and reliably. The best applications for these systems are in remote places, such as rural villages, in telecommunications, etc.

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 modelling. 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 behaviour 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 modelling 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. Modelling the components of a hybrid power system

2.1 Modelling 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 (Lorenzo, 1994). 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 realised by an equivalent circuit that consists of a current source in parallel with a diode (Fig. 1) (Kaltschmitt et al., 2007) (Markvart & Castaner, 2003).
In Fig. 1 R_S, R_P and C components can be neglected for the ideal model.

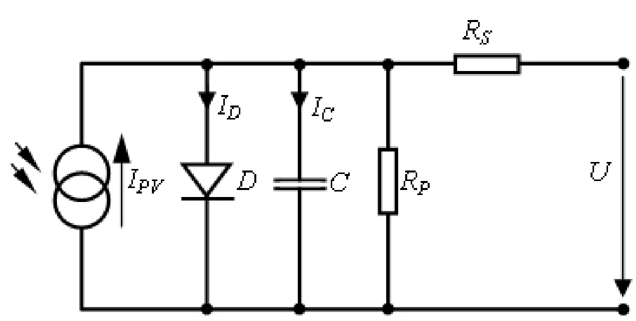

Fig. 1. Equivalent circuit diagram of a solar cell

The p-n junction has a certain depletion layer capacitance, which is typically neglected for modelling 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.
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 (Kaltschmitt et al., 2007).
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 (Kaltschmitt et al., 2007), (Patel, 1999).

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

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

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).

Equations (1) and (2) lead to the development of a Matlab Simulink model for the PV module presented in Fig. 2.

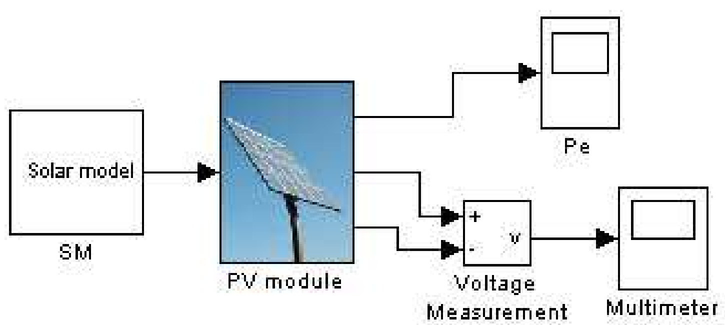

Fig. 2. Matlab Simulink Library PV module

The solar system model consists of three Simulink blocks: the solar model block, the PV model block and energy conversion modules.
The solar model block implements the mathematical model of the solar radiation. This is done by using standard Simulink and Matlab modules and functions. This block allows selecting different type of patterns for the solar radiation (Dumitru & Gligor, 2008a).
The PV module implements the equivalent circuit of a solar cell, shown in Fig. 1. Standard functions and blocks of Matlab and Simulink were used to obtain this model. Its structure is presented in Fig 3.
The output of the PV module is processed by an energy conversion block implemented with an PWM IGBT inverter block from standard Simulink/SimPowerSystems library.

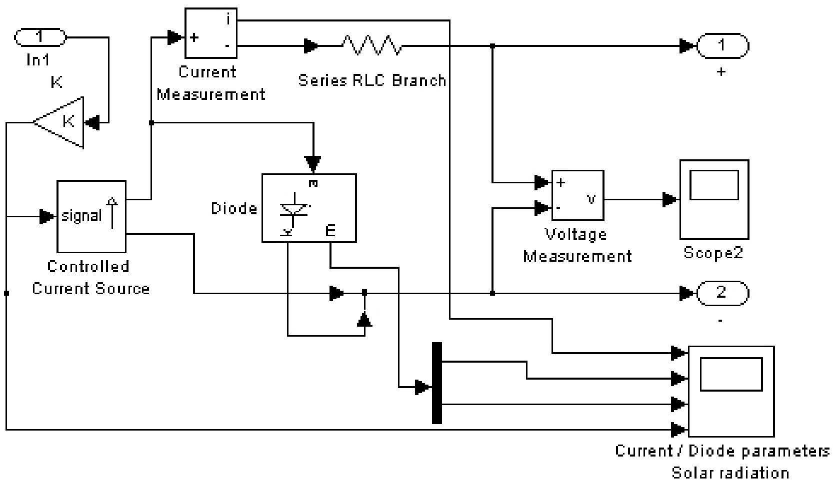

Fig. 3. Matlab Simulink implementation of the PV module.

2.2 Modelling the Wind Energy System

Modelling 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):

$$W = \frac{1}{2} m \left(v_1^2 - v_2^2\right) \quad (3)$$

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:

$$V_{med} = \frac{V}{t} = A v_{med} \tag{5}$$

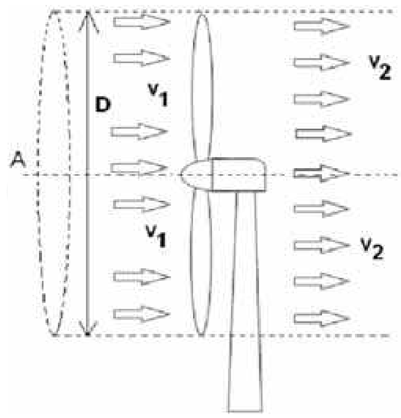

Fig. 4. Flow through a wind energy converter

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

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

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

$$P_{\max} = \frac{8}{27} A\rho v_1^3 \tag{7}$$

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

$$P_{wind} = \frac{1}{2}\rho A v_1^3 \tag{8}$$

Equations (7) and (8) lead to:

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

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 (Burton et al., 2004).
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 (Golovanov et al., 2007).
A Matlab Simulink model, based on the equations mentioned above, was developed for the wind generator module. This model is shown in Figure 5.

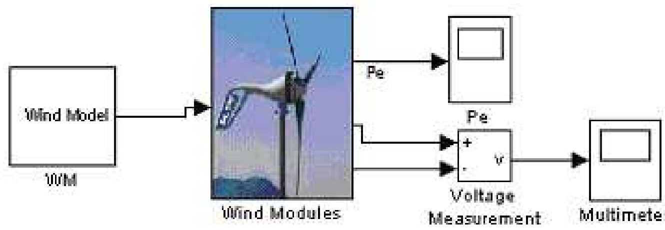

Fig. 5. The Matlab Simulink model of the wind generator module.

The wind system model consists of three Simulink blocks: the wind model block, the wind generator model block and energy conversion modules.
The wind model block implements the mathematical model of the air mass flow. This is done by using standard Simulink and Matlab modules and functions. This block allows the selection of different patterns for the air mass flow and the equations mentioned above were used in the design of this model.
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 6.

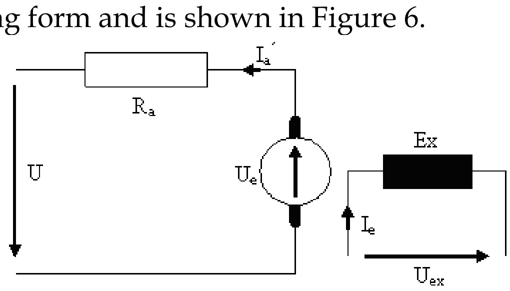

Fig. 6. Equivalent circuit diagram of a small wind generator

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

- R_a – rotor winding resistance
- Ex – 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 $U = U_e - R_a I_a$

The resulted Matlab-Simulink model for the wind generator is a particular case of the more general model of an electrical generator, which is presented in figure 7.

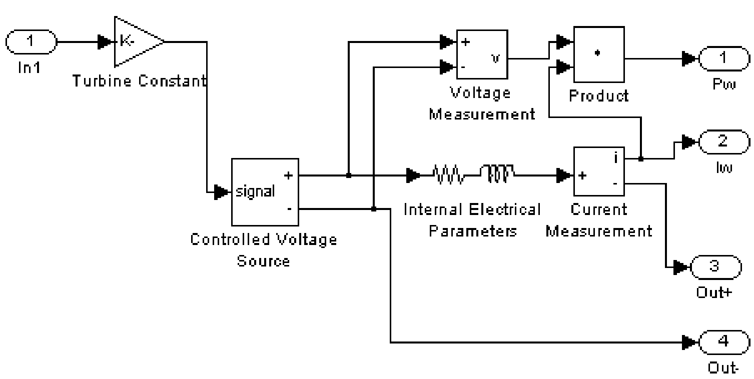

Fig. 7. Matlab-Simulink model of the generator

The output of the wind energy generator module is processed by an energy conversion block implemented with a PWM IGBT inverter block from the standard Simulink/ SimPowerSystems library.

2.3 Modelling the Hydroelectric System

Small hydroelectric power plants harness the falling water kinetic energy to generate electricity. Turbines transform falling water kinetic energy into mechanical rotation energy and then, the alternator transforms the mechanical energy into electricity. Water flows within a river from a higher geodesic site to a lower geodesic site due to gravitation. This is characterized by different particular kinetic and potential energy at both sites. The correct identification of the resulting energy differences of the out-flowing water can be assumed by considering a stationary and friction-free flow with incompressibility. The hydrodynamic Bernoulli pressure equation applied in such conditions is written according to equation (11)

$$p + \rho_{water} g h + \frac{1}{2}\rho_{water} v_{water}^2 = const. \tag{11}$$

where:

- p – hydrostatic pressure;
- ρ_{water} – water density;
- g – acceleration of gravity;
- h – the water height;
- v_{water} – velocity of the water flow.

Equation (11) can be transformed so that the first term expresses the pressure level, the second term the level of the site and the third term the water velocity level.

$$\frac{p}{\rho_{water} g} + h + \frac{1}{2}\frac{v_{water}^2}{g} = const. \tag{12}$$

The term $\frac{1}{2}\frac{v_{water}^2}{g}$ refers to the dynamic height and is defined as the height due to the speed of water flow and can be identified by the term of kinetic water energy.

The usable head h_{util} of a particular section of river can be determined by considering: the difference in pressure, the geodesic difference in height and the different flow velocities of the water, using equation (13). It must be mentioned that the equation is used to analyze an ideal case and does not consider the losses due to the friction of the individual water molecules among each other and the surrounding matter.

$$h_{util} = \frac{p_{up} - p_{down}}{\rho_{water} g} + (h_{up} - h_{down}) + \frac{v_{water,up}^2 - v_{water,down}^2}{2g} \tag{13}$$

where:

- p_{up} – upstream hydrostatic pressure;
- p_{down} – downstream hydrostatic pressure;
- h_{up} – upstream geodesic water height (headwater);
- h_{down} – downstream geodesic water height (tailwater);
- $v_{water,up}$ – upstream water velocity;
- $v_{water,down}$ – downstream water velocity;

Considering equation (13), the power of a water supply P_{water} can be determined using (14):

$$P_{water} = \rho_{water} g q_{water} h_{util} \tag{14}$$

where q_{water} is the volume-related flow rate.
According to equation (14), the power of a water supply is determined by the volume-related flow rate and usable head. The water flow assumes high values in lowland areas, while large heads can be achieved in mountain areas.
Considering two specific points of a river, the theoretical power of the water $P_{water,\ th}$, can be calculated based on:

$$P_{water,th} = \rho_{water} g \dot{q}_{water} (h_{up} - h_{down}) \tag{15}$$

where $\dot{q}_{water}$ is the volumetric flow rate through a hydroelectric power plant.
In the real case, considering the energy balance between two specific points of a river, and also the energy losses, the hydrodynamic Bernoulli pressure equation can be written according to equation (16).

$$\frac{p_{up}}{\rho_{water,up} g} + h_{up} + \frac{v^2_{water,up}}{2g} = \frac{p_{down}}{\rho_{water,down} g} + h_{av} + \frac{v^2_{water,down}}{2g} + \xi \frac{v^2_{water,down}}{2g} = const. \tag{16}$$

where:

- $\frac{p}{\rho_{water} g}$ - hydrodynamic pressure energy;
- h - potential energy of the water;
- $\frac{v^2_{water}}{2g}$ - kinetic energy of the water;
- $\xi \frac{v^2_{water}}{2g}$ - energy losses;
- ξ - loss coefficient.

The energy losses are represented by the part of the rated power which is converted into ambient heat by friction and cannot be used technically.
In the turbine, pressure energy is converted into mechanical energy. The conversion losses are described by the turbine efficiency $\eta_{turbine}$. Equation (17) describes the part of the usable water power that can be converted into mechanical energy at the turbine shaft $P_{turbine}$.

$$P_{turbine} = \eta_{turbine} \rho_{water} g \dot{q}_{water} h_{util} \tag{17}$$

h_{util} is the usable head at the turbine, and the term $(\rho_{water} g \dot{q}_{water} h_{util})$ represents the actual usable water power (Kaltschmitt et al., 2007).
The water model described by the equations mentioned above was introduced in a Matlab-Simulink model of the hydroelectric system. This model is shown in figure 8 and it encapsulates the model of the hydroelectric plant connected to the water model. Measurement of power and voltage is also provided by this model.
The model of the hydroelectric plant (generator) has the same form as the one presented in figure 7 and also an equivalent diagram as the one we considered for the wind generator can be assumed (Figure 6)

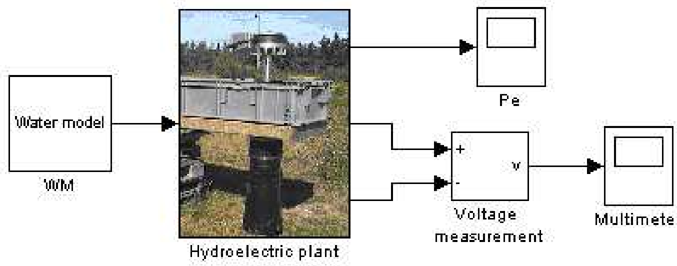

Fig. 8. The Matlab Simulink model of the hydroelectric system.

2.4 Modelling the Storage Device

The energy storage devices/equipments are used basically for three purposes: energy stabilization, ride through capability and dispatchability.

The energy stabilization permits the hybrid system to run at a constant stable output level with the help of the energy storage devices, even if the load fluctuates rapidly.

The ride through capability is the capability of the energy storage device which provides the proper amounts of energy to loads, when the hybrid system generator units are unavailable, (e.g. the solar supply system during the night time or when components of any type are being maintained or repaired). The hybrid system owner who needs power has two options during such periods. The first one is to use another backup or use the utility grid. The second way is to meet out the needs with energy stored when the source is unavailable (Willis & Scott, 2000).

For energy sources like photovoltaic or wind energy systems, the power production depends upon the availability of the resources like sunlight or wind. This makes the nature of power available to loads intermittent, thus making them non-dispatchable sources. However, the energy storage systems with non-dispatchable energy can be deployed as dispatchable energy sources. This only needs a proper design of the energy storage system, by looking into the load curve (Sahay & Dwivedi, 2009).

Batteries are the basic component of an energy storage system. A battery consists of one or more electrochemical cells that are electrically connected. The basic components of an electrolytic cell like a lead-acid cell are a positive electrode, a negative electrode, a porous separator and an electrolyte. During cell operation, ions are created and consumed at the two electrode/electrolyte interfaces by oxidation/reductions reactions. The electrolyte, which can either be a solid or liquid chemical, has high conductivity for ions but not for electrons, because if the electrolyte conducts electrons then the battery will self-discharge. The electrolyte completes the internal circuit between the electrodes.

The parameters associated with battery modelling are (Chan & Sutanto, 2000):

- internal resistance:
    - self discharge resistance: the resistance associated with the electrolysis of water at high voltage levels and slow leakage across the battery terminal at low voltage, inversely proportional to the temperature and very sensitive to it;
    - charge and discharge resistance (R_c / R_d): the resistances associated with the electrolyte resistance, plate resistance and fluid resistance, variable during charging and discharging;

  - overcharge and over discharge resistance: the resistances attributed to the electrolyte diffusion during over charging and over discharging.
- polarization capacitance: the capacitance due to the chemical diffusion within the battery which does not necessarily represent a purely electrical capacitance.
- discharge type:
  - continuous discharging: the battery continuously delivers energy to the load which leads to a continuous drop in the battery capacity;
  - intermittent discharging: the battery delivers energy to the load at regular or irregular intervals of time.
- discharge mode:
  - constant load mode: the battery delivers energy to a constant load and the load current decreases proportional to the decrease in the battery terminal voltage;
  - constant current mode: the battery supplies constant current to the load; this is achieved by continuously reducing the load resistance to match with the decreasing battery terminal voltage in order to maintain a constant current to the load;
  - constant power mode: the battery supplies constant electrical power to the load; the load current increases to compensate for the drop in voltage in order to maintain constant power to the load.
- rate of charge and discharge: the rate of charge and discharge should not be too high in order to extend service life of the battery; the frequency of charging and discharging cycles affects the battery life significantly.

In figure 9 the Thevenin equivalent battery model is presented.

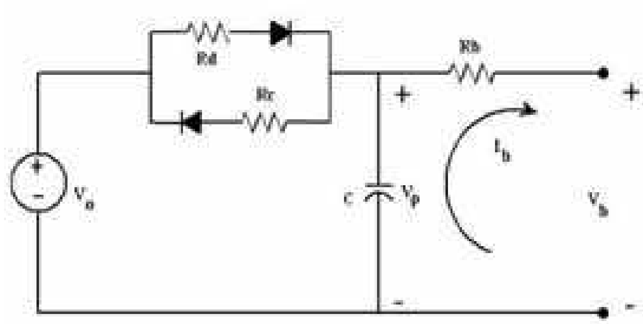

Fig. 9. Thevenin equivalent battery model.

The open circuit voltage, internal capacitor voltage and the terminal voltage are represented by V_0, V_p and V_b. The charging, discharging and the internal resistance of the battery are represented by R_c, R_d and R_b and the polarization capacitance of the battery is represented by C. The current I_b is taken as positive if discharging and negative otherwise (Vairamohan, 2002).

The equations for the circuit model are:

$$\dot{V}_p = \frac{1}{C}\left(\left(\frac{V_0 - V_p}{R_d}\right) - I_b\right) \tag{18}$$

$$V_b = V_p - I_b R_b \tag{19}$$

Based on this model and the equations above, a Matlab-Simulink model was developed for the battery storage device. This model is shown in Figure 10.

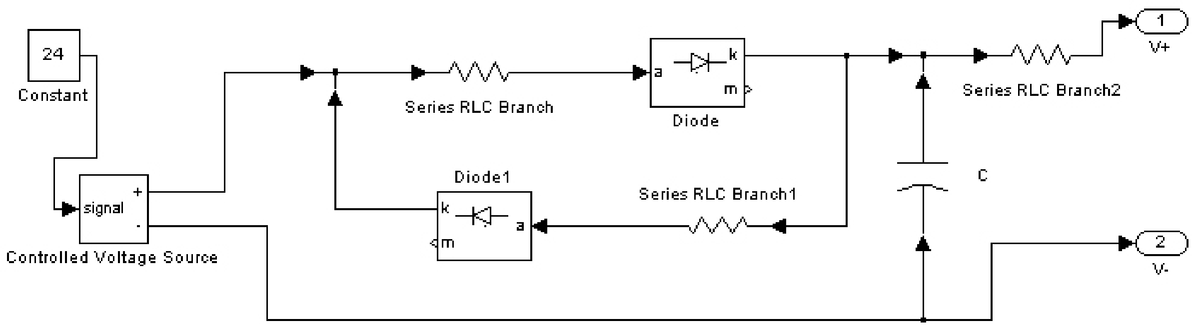

Fig. 10. The Matlab Simulink model of the battery storage device.

3. Distributed Generation in Hybrid Systems

3.1 Issues Regarding Distributed Generation

The problem of generating and using electrical energy by consumers is strictly connected to the study and modelling of local distribution electrical networks.

The distribution of electrical energy in local distribution systems is done by modular generation, using relatively small generation systems, ranging from less than 1kW to approx. 20 MW. These systems are located close to consumer areas. This type of energy production is called distributed generation (DG).

There are two types of distribution systems: interconnected and independent. The main purpose is to redefine the electrical networks, so that, instead of producing electrical energy in large plants and sending it in a single direction, the consumers should have a degree of energetic independence, and the system should be made available to large numbers of small producers in order to assure economic functioning for the electrical distribution network. This way, the electrical energy could be produced by photovoltaic solar systems, wind generation systems, biomass systems etc. The energy surplus could be sold /supplied to the distribution network, and the consumers could use the energy whenever they need it.

The reliability of the distribution system as well as the quality of the electrical energy can be improved by placing the sources close to the consumers, and the efficiency is improved by locally generating electrical and thermal energy. Thermal energy, resulting as side effect in the production of electrical energy, can also be used, and therefore a more efficient plant is obtained.

DG helps complete the traditional centralized production and distribution of electrical energy. Some of the characteristics of DG include the relatively low costs reported to the increase in energy demand meaning that the installation of newer transportation and distribution systems is no longer necessary. Also, energy generation can be placed where it is more needed and has the flexibility of delivering it in a network near the consumer. Another important aspect is represented by the demand of cheaper and less pollutant energy that is safe and reliable for all, including consumers, suppliers, producers and political partners (Bloem, 2006).

Several major influences that can be identified in the operation of distribution systems which are also reflected in DG are:

- according to the produced energy and the level of consumption, the voltage profile is changing across the network, leading to different behavior than usual;
- transitory signals appearing as result of connecting and disconnecting generators or during their operation;
- the increase of short circuit power;
- the variation of losses according to production and consumption levels;
- change in the quality of energy and the system's reliability;
- the distributor's protection systems need to be coordinated with those installed at the generator (Chindriş et al., 2008).

3.2 Case Study: Development of a Hybrid DG System in Mureş County

3.2.1 Solar Energy

The potential of solar radiation hitting the earth's surface is represented by the average energy density of horizontally direct solar radiation, which overcomes 1000 kWh/m²/year. Romania has five identified geographical areas with differences in solar energy flows, as can be revealed in the map provided by ANM (National Meteorology Agency) shown in Figure 11. The geographical distribution shows that Romania's surface benefits of an average solar energy flow higher than 1000 kWh/m²/year.

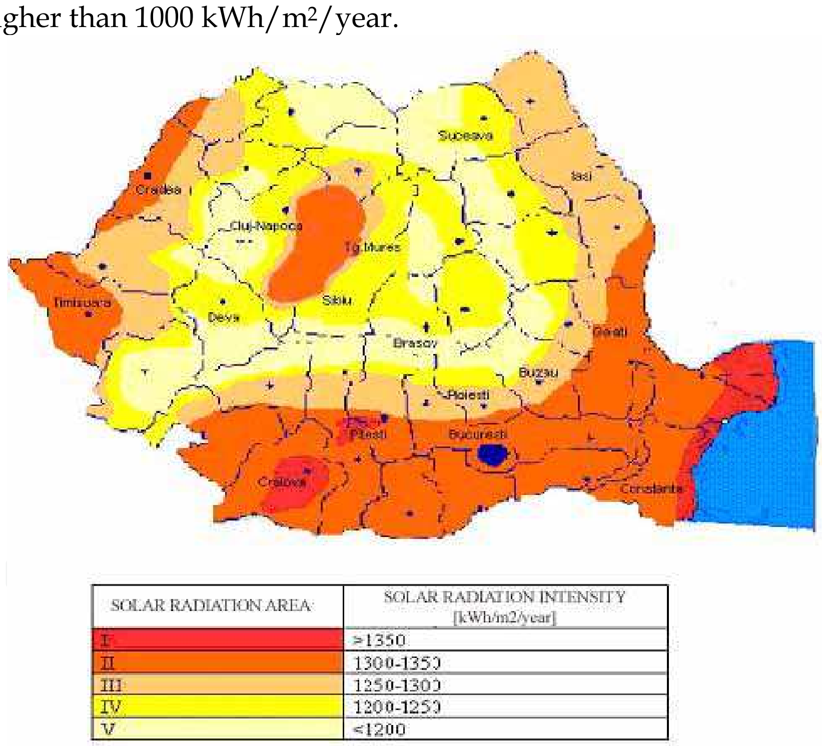

Fig. 11. Solar radiation intensity in Romania

The radiation hitting the earth's surface on a bright summer day contains of levels of approximate 1000 W/m² during the year, on average approximate 1000 kWh, which equates to approximate 100 liters of heating oil reaching every m² surface of our country's territory.
Considering the geographical position of Mureş County and analyzing its solar potential, we may affirm that two large areas with different incident solar radiation values are available. The first area, with incident solar radiation values between 1300 and 1350

kWh/m²/year presents a good solar potential, and is situated in the west of Mureş County (an area which includes the Transylvanian Plain bounded in the North by Bistriţa Năsăud County, in the West by Cluj County, in the South by Sibiu County and at the East by an imaginary line connecting the towns Târnăveni, Târgu Mureş and Reghin).
The second, more narrow, area with a moderate solar potential having incident solar radiation values between 1250 and 1300 kWh/m²/year is situated in the hill area of Mureş County which includes the Târnave Plateau and the Carpathian lower mountains.
There are also areas with different particularities such as the Mureş County mountain area, where the direct solar radiation has large variations, the negative relief forms (e.g. valleys) favoring the persistence of fog and even diminishing the sun light, while the positive relief forms (e.g. hills, mountains) favor the growth or the decrease of the value for the direct solar radiation, considering their orientation in relation to the sun and the dominant air mass circulation.
The study is based on data provided by ANM from weather stations in Târgu Mureş and Târnăveni. In 2006, ANM in cooperation with NASA, JRC and Meteotest produced a detailed map with solar radiation areas of Romania, which was presented in Figure 11.
A local detailed analysis can be made by accessing JRC website: http://re.jrc.ec.europa.eu (JRC Website, 2009), which offers data regarding solar irradiation on daily, monthly or yearly time base as values or as histogram. For example, for Târgu Mureş (46°32'59" North and 24°33'59" East), the recorded data is presented in Figure 12. JRC's website provides also other important information, such as: the estimated amount of daily, monthly or yearly power generated by a solar panel placed in a specified location. It also takes in consideration the panel type, its installed power and its position relative to the sun. This way, the optimum place for a solar photovoltaic panel in a certain area can be determined technically and economically based on this analysis.

Month	Irradiation at inclination: (Wh/m2/day) 0 deg.
Jan	1166
Feb	2024
Mar	3413
Apr	4553
May	5797
Jun	6068
Jul	6224
Aug	5563
Sep	3933
Oct	2738
Nov	1435
Dec	922
Year	3663

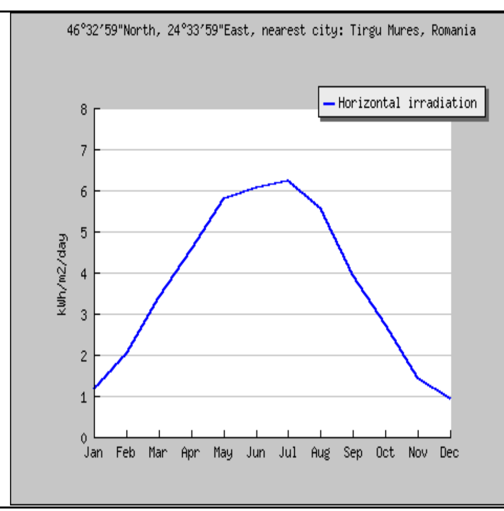

Fig. 12. Solar data for Târgu Mureş according to JRC's website

An alternative to JRC's website is represented by the "Calculator for a photovoltaic system estimation" provided by LP Electric (Alba Iulia, Romania) on their website: http://www.lpelectric.ro/ro/support/aplicatie_solar_ro.html. Depending on the consumer's required power, on the type of system and on the available solar data for a certain location, using the LP Electric application different photovoltaic panels can be chosen, an estimated cost of investment cost and its depreciation period can be calculated. Such an example is shown in Figure 13.

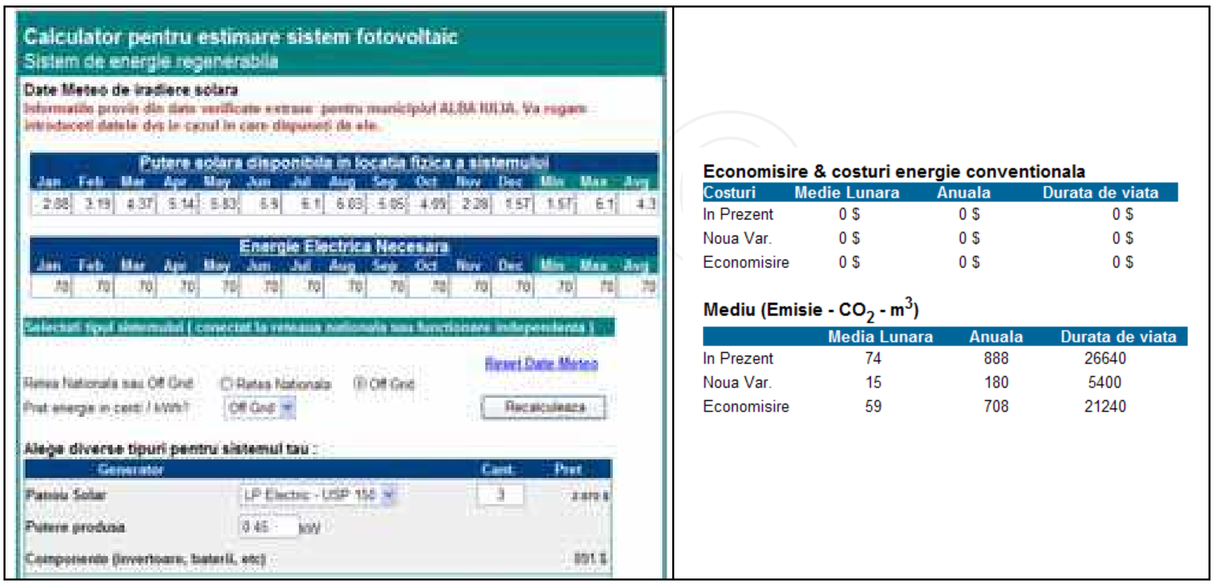

Fig. 13. Calculator for a photovoltaic system estimation provided by LP Electric (LP Electric Website, 2009).

3.2.2 Wind Energy

Assessing the wind potential in a certain areas encounters difficulties in measuring the wind components, especially the wind speed and direction. According to the recommendations, of the World Meteorological Organization, the wind speed and direction have to be measured at 10m above ground. However, the wind speed at which wind exploitation becomes feasible as a renewable energy resource has to be considered at the wind rotor's height, which is situated at 50 to 90 m above ground level for wind power turbines. Consequently, a reevaluation of Romania's wind power potential, by using dedicated software and devices, is necessary. In order to meet this necessity a wind map of Romania, containing the annual average wind speed measured at 50 m above ground, was elaborated by ANM (Figure 14).

According to a study performed by ANM based on the information provided by Weather Stations of Târgu Mureş and Târnăveni, three areas of different wind potential were identified in Mureş County.

The Transylvanian Plain is a region of low wind potential, with average wind speeds of 3-4 m/s and it is not of a great interest from the wind power turbines point of view. Still, there are areas where the relief allows the location of low and medium wind turbines that can give relatively high yield (e.g. Ernei village is suitable for wind turbines of 0,5 kW power).

An area having higher potential with an average wind speed of 4-6 m/s is represented by the hill area of Mureş County which includes the Târnave Plateau (the hill area between Târnava Mică and Târnava Mare rivers), the Carpathian lower mountains and the Gurghiu Mountains. This area is favorable for developing applications with medium and high power wind systems according to the particular structure of the relief.

However, the area with the highest wind potential is the region of the Călimani Mountains with an annual average wind speed of 8-10 m/s or more. Unfortunatelly, exploitation in this part is quite difficult because of the Călimani National Park and of some protected environmental areas. The installation of wind turbines in national parks or reservations is restricted. Presently, some studies are performed by an Austrian company to locate these turbines in the limitary areas of the Călimani National Park.

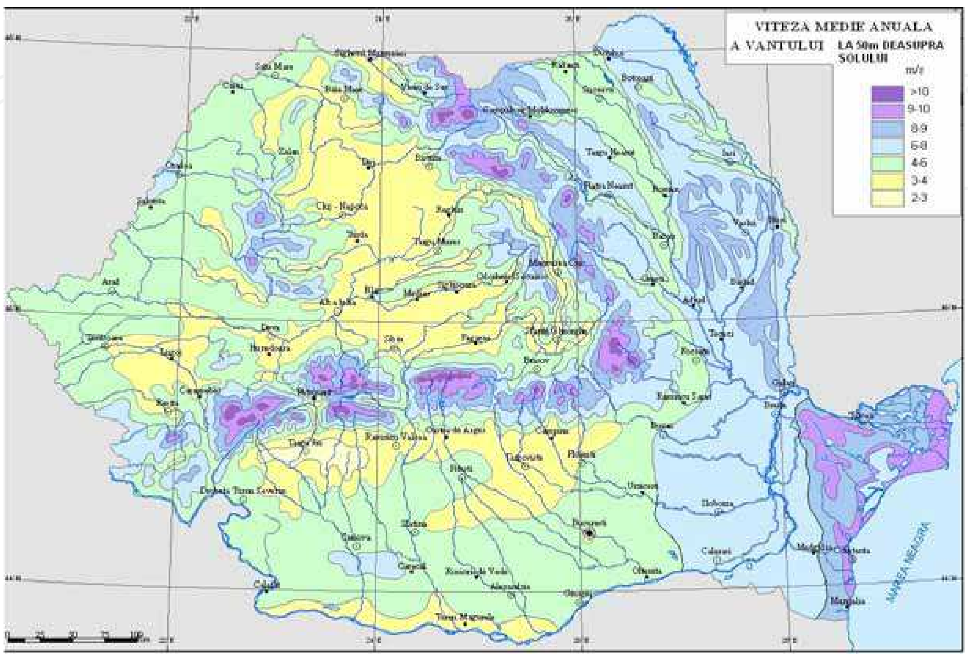

Fig. 14. Wind map of Romania containing the annual average wind speed measured at 50 m above ground [kWh/m²] (Electrica, 2007).

3.2.3 Hydroelectric Energy

Water represents the most important renewable energy resource of Romania. An inventory of micro-hydropotential is required for the studies concerning the location of future micro-hydro power plants.

This can be done in areas where the watercourse is present permanently all year long with a volume of at least 50 l/s and a slope greater than 10 m/km on rivers that are not included in the great hydroelectric energy locations.

The technical feasible micro-hydropotential is represented by the power or electric energy that can be produced using the water courses mentioned above.

The linear theoretical micro-hydropotential can be calculated to highlight the river sectors with the highest hydroelectrical potential. These sectors can be determined based on the following hypothesis:

- the use of all drained water volume;
- the use of all available fall;
- the total yield of hydraulic energy conversion into electric power equals 1 (losses are ignored).

The hydrographic basin of River Mureş is located in the center and west of Romania, between the Eastern, Southern and Western Carpathians and its lower sector is located in the middle of Tisa Plain. River Mureş is an affluent of River Tisa and collects its main waters from the volcanic chain of the Eastern Carpathians, from the Transylvanian Plateau, from

east and south of the Western Carpathians and from the northern slopes of the Southern Carpathians located at the west of River Olt. The dividing crest of River Mureş crosses over different units and sub-units of relief with specific physic-geographical characteristics that separates it from other important hydrographic basins. River Mureş collects a large number of affluents with hydrographic basins between 100 and 1900 km^2. These affluent rivers are: Toplița, Răstolița, Gurghiu, Arieş, Pârâul de Câmpie, Târnava, Sebeş, Cugir, Râul Mare, Strei, Cerna. The surface of the hydrographic basins inventoried in the River Mureş hydrographic basin sums to 15340 km^2 and the proper lenght of 3050 km.
The linear theoretical microhydropotential of river sectors studied in the River Mureş hydrographic basin sums 300994 kW and has a share of 31% with an average specific potential p = 74,6 kW/km. Technical feasible micro-hydropotential studied for rivers with p > 150 kW/km sums to P_i = 76.340 kW with a calculated share of 32% and E_m = 443 GWh/an situates the hydrographic basin of River Mureş among the hydrographic basins of Romania with a good hydroelectric potential to be asserted.
The River Mureş hydrographic basin includes the counties Mureş and Alba and part of Sibiu, Harghita, Cluj, Arad and Hunedoara counties and a very small part of Bistrița Năsăud country. According to a study performed by ISPH based on data provided by A.N. Apele Române Mureş the location for future micro-hydro power plants is synthesized in Table 1.

Nr.	Name of the power plant	Water course	County	Basin	Brute fall [m]	Installed flow [m³/s]	Installed power [MW]	Mean energy [GWh/yr.]
1	Duşa	Mureş	Mureş	Mureş	10	11.62	0.8	4.2
2	Zebrac	Mureş	Mureş	Mureş	10	12.19	0.8	4.4
3	Stânceni	Mureş	Mureş	Mureş	10	12.19	0.8	4.4
4	L. Bradului	Mureş	Mureş	Mureş	20	14.05	1.9	10.2
5	Jirca	Mureş	Mureş	Mureş	20	14.17	1.9	10.2
6	Beleiu	Mureş	Mureş	Mureş	10	16.12	1.1	5.8
7	Ferigilor	Mureş	Mureş	Mureş	10	16.24	1.1	5.9
8	Bradului	Mureş	Mureş	Mureş	15	16.35	1.7	8.9
9	Iodului	Mureş	Mureş	Mureş	7	16.41	0.8	4.2
10	Sărățeni	Târnava Mică	Mureş	Mureş	11	4.5	0.3	2.1
11	Sălard	Sălard	Mureş	Mureş	78	1.65	0.9	5.4

Table 1. Future hydroelectric developments

Among the main affluents of River Mureş are Toplița, Răstolița, Gurghiu, the lower course of River Arieş which crosses Mureş county, and also Rivers Târnava Mică and part of Târnava Mare. All of these affluents have a good hydroelectric potential.
At the moment, there are five functional micro-hydro power plants in Mureş County: three are placed on the Iod Valley in Răstolița and two near the Town of Sovata. A development project planned for the upper sector of River Mureş intends to locate a series of micro-hydro power plants to regulate the water-course starting with Răstolița dam.

3.2.4 Hybrid DG System

In order to implement a real hybrid system a theoretical preliminary study is required. Such study can be performed on simulation models. A simulation model is presented in Fig. 15.

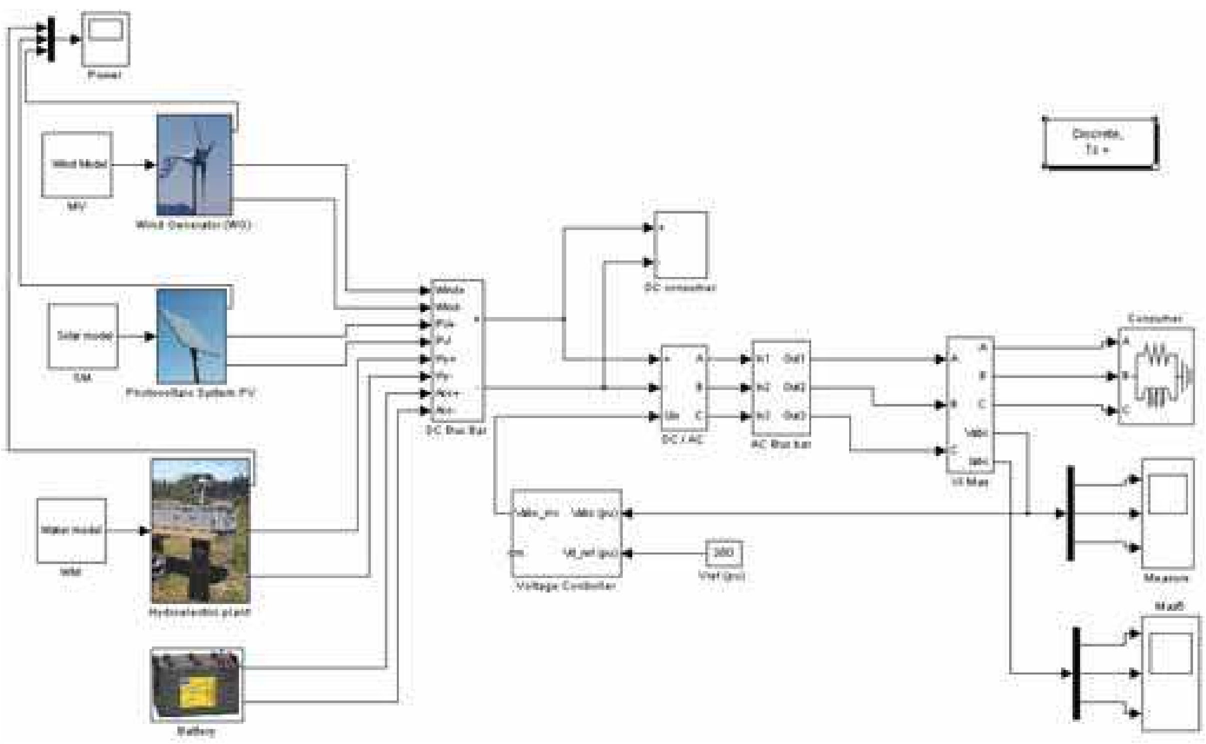

Fig. 15. Simulation model of a hybrid renewable energy system

The simulation model basically consists of the models presented above connected together to form an isolated hybrid system. The proposed model allows studies of modelled DC and AC consumers.

The simulation model allows studies such as:

- renewable energy sources electrical parameters (powers, voltages, currents, etc.);
- renewable energy sources constructive parameters (blades length and number of wind turbine, PV panels number and dimensions, number of hydroelectric turbines, batteries number, etc.);
- voltage and frequency control (control algorithms);
- electrical energy conversion (type of DC/AC conversion methods);
- consumer modelling and control
- power quality distortion phenomena and analysis
- renewable energy availability

Some examples of simulation results are presented below.

Fig. 16 illustrates the voltage waveform measured at the AC bus bar. It can be seen a voltage waveform distortion caused by electronic devices – inverters - used for energy conversion in DC/AC module.

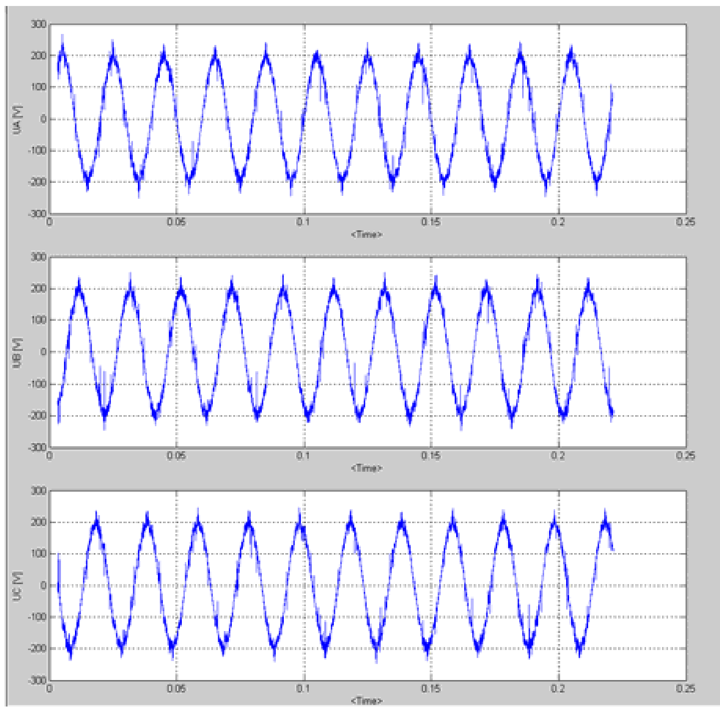

Fig. 16. Voltage waveform at the AC three-phased bus bar

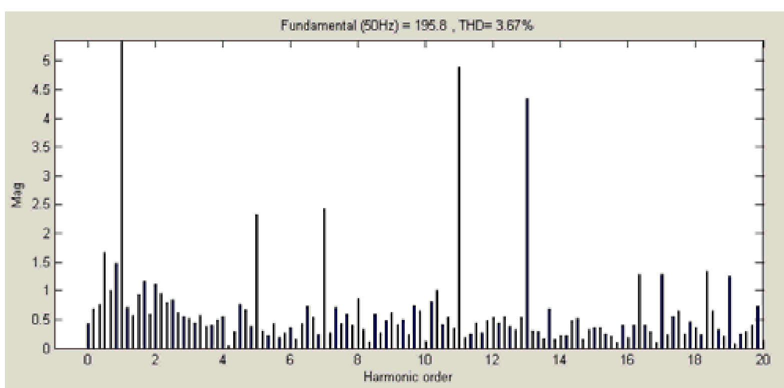

Fig. 17a. Harmonic analysis of the voltage waveform corresponding to phase A

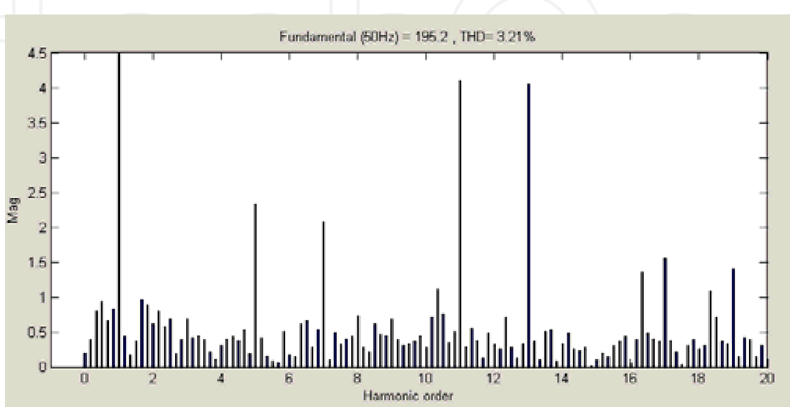

Fig. 17b. Harmonic analysis of the voltage waveform corresponding to phase B

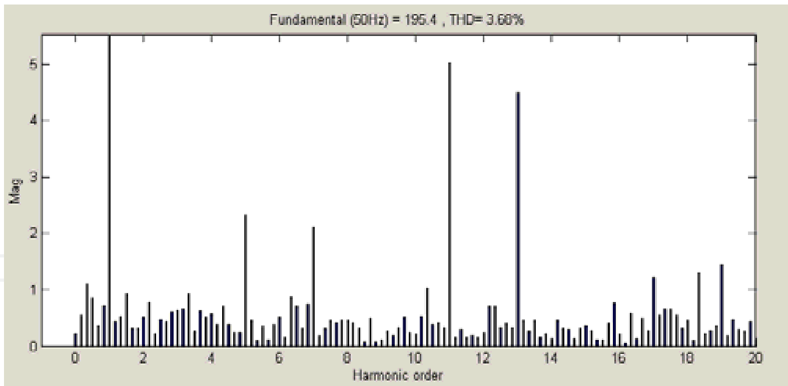

Fig. 17c. Harmonic analysis of the voltage waveform corresponding to phase C

The above simulation results are provided by a hybrid system with installed PV power of 1kW, wind power of 1kW and a hydroelectric turbine of 1kW. It has to be mentioned that the output voltage of hybrid power system generators is 12V and the consumer uses 60% of the available power the rest being used for battery charging. It can be also notified the presence of harmonics caused by consumer but also by the power electronics from electric energy conversion modules. If necessary, on AC side, the power quality can be raised up by using power active filtering devices (Dumitru & Gligor, 2008b).

4. Conclusion

In the conditions of an accelerated economic development in Romania, by a good energy policy it might be assured an increasing level of power supply safety and the reduction of energetic resources import. This demand can be accomplished by implementing a sustained policy of energy conservation, by increasing energy efficiency concurrent with a better capitalization of renewable resources.

The capitalization of renewable resources potential confers real premises to achieve some strategic aims c, but also the durable development of energy sector and the protection of the environment. In order to exploit the economic potential of renewable resources in competitive conditions on the energy market, it is necessary to adopt and implement some energy policies and specific resources. The promotion of energy production from renewable resources (E-SRE) represents an imperative objective in present times justified by environment protection, the increase of energetic independence by supplying sources diversity and, of course, economic and social cohesion reasons. The reasons to promote energy production from renewable resources (E-SRE) were accumulated in time, from economic nature reasons which appeared after the oil crisis in the 70's, to environmental, reasons, especially after signing the Kyoto Protocol in December 1997 and nowadays social cohesion reasons.

Depending on the methods or technologies, rational use of energy can have a positive or a negative impact on power quality. The cause of power quality problems is mainly the improper use of local loads and equipments. But, even if efficient loads are connected to a local grid or bus by a power electronics interface, the power quality might deteriorate. There are also devices with malfunction when the power quality becomes too poor.

5. References

Bloem, J., (2006). *Distributed Generation and Renewables - Integration & Interconnection*, Power Quality and Utilization Guide – LPQI Program, Issue Winter 2006

Burton, T., Sharpe, D., Jenkins, N., Bossanyi, E. (2004). *Handbook of Wind Energy*, John Wiley & Sons Ltd, ISBN: ISBN 0-471-48997-2, The Atrium, Southern Gate, Chichester, England

Chan, H.L., Sutanto, L., (2000). A New Battery Model for Use with Battery Energy Storage Systems and Electric Vehicles Power Systems, In: *IEEE Power Engineering Society Winter Meeting Conference,* Vol.1, pp. 470-475, NJ, USA

Chindriş, M., Cziker, A., Miron, A., (2008). Conectarea la rețea a generatoarelor distribuite. Legislația din România, In: *Forumul Național al Energiei – Foren 2008,* 15-19 iun. 2008, Neptun, România, on CD

Dumitru, C.D., Gligor, A. (2008a). Power Quality Analysis Of A System Based On Renewable Energy Supplying A Local Distribution Network, *Acta Electrotehnica,* Special Issue: Proceedings of the 2nd International Conference on Modern Power Systems MPS 2008, 12-14 nov. 2008, pag. 224-226, ISSN 1841-3323

Dumitru, C.D., Gligor, A. (2008b). Software Development For Analysis Of Solar-Wind Hybrid Systems Supplying Local Distribution Networks, *Acta Electrotehnica,* Special Issue: Proceedings of the 2nd International Conference on Modern Power Systems MPS 2008, 12-14 nov. 2008, pp. 220-223, ISSN 1841-3323

ELECTRICA S.A., (2007). Preocupările SC. ELECTRICA S.A în domeniul energiei verzi, In: Conferința Energiile regenerabile şi actorii principali. O provocare pe termen lung, 30 august 2007, Bucureşti, România

Golovanov, N., Postolache, P., Toader, C. (2007). *Eficiența şi calitatea energiei electrice*, Ed. AGIR, ISBN: 978-973-720-151-5, Bucureşti, Romania

JRC Website (2009). http://re.jrc.ec.europa.eu/pvgis/apps/pvest.php?lang=en&map

Kaltschmitt, M., Streicher, W., Wise A. (Eds.) (2007). *Renewable energy. Technology, economics and environment*, Springer Berlin Heidelberg New York, ISBN 978-3-540-70947-3

Lorenzo, E. (1994). *Solar Electricity Engineering of Photovoltaic Systems*. Artes Graficas Gala, S.L., ISBN: 84-86505-55-0, Spain

LP Electric Website (2009). http://www.lpelectric.ro/ro/support/aplicatie_solar_ro.html

Markvart, T., Castaner, L. (2003). *Practical Handbook of Photovoltaics, Fundamentals and Applications*, Ed. Elsevier, ISBN 1-85617-390-9, Oxford, UK

Patel, M. R. (1999). *Wind and solar power systems*, CRC Press LLC, ISBN 0-8493-1605-7, Boca Raton, Florida

Sahay, K., Dwivedi, B. (2009). Energy Storage Technology for Performance Enhancement of Power Systems, *Electrical Power Quality & Utilization Magazine,* Volume 4, Issue 1, Available online March 2009

Vairamohan, B., (2002). *State of Charge Estimation of Batteries*, A Thesis Presented for the Master of Science Degree, The University of Tennessee, Knoxville

Willis, H. L., Scott, W. G. (2000). *Distributed Generation Planning and Evaluation*, Marcel Dekker Inc., ISBN: 0-8247-0336-7, New York

Renewable Energy
Edited by T J Hammons

ISBN 978-953-7619-52-7
Hard cover, 580 pages
Publisher InTech
Published online 01, December, 2009
Published in print edition December, 2009

Renewable Energy is energy generated from natural resources-such as sunlight, wind, rain, tides and geothermal heat-which are naturally replenished. In 2008, about 18% of global final energy consumption came from renewables, with 13% coming from traditional biomass, such as wood burning. Hydroelectricity was the next largest renewable source, providing 3% (15% of global electricity generation), followed by solar hot water/heating, which contributed with 1.3%. Modern technologies, such as geothermal energy, wind power, solar power, and ocean energy together provided some 0.8% of final energy consumption. The book provides a forum for dissemination and exchange of up-to-date scientific information on theoretical, generic and applied areas of knowledge. The topics deal with new devices and circuits for energy systems, photovoltaic and solar thermal, wind energy systems, tidal and wave energy, fuel cell systems, bio energy and geo-energy, sustainable energy resources and systems, energy storage systems, energy market management and economics, off-grid isolated energy systems, energy in transportation systems, energy resources for portable electronics, intelligent energy power transmission, distribution and inter-connectors, energy efficient utilization, environmental issues, energy harvesting, nanotechnology in energy, policy issues on renewable energy, building design, power electronics in energy conversion, new materials for energy resources, and RF and magnetic field energy devices.

How to reference
In order to correctly reference this scholarly work, feel free to copy and paste the following:

Dorin Bica, Cristian Dragos Dumitru, Adrian Gligor and Adrian-Vasile Duka (2009). Isolated Hybrid Solar-Wind-Hydro Renewable Energy Systems, Renewable Energy, T J Hammons (Ed.), ISBN: 978-953-7619-52-7, InTech, Available from: http://www.intechopen.com/books/renewable-energy/isolated-hybrid-solar-wind-hydro-renewable-energy-systems

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821