2ème conférence Internationale des énergies renouvelables CIER-2014
Proceedings of Engineering and Technology - PET

Modeling and Simulation of a Hybrid Energy Source based on Solar Energy and Battery

Asma MESKANI[#1], Ali HADDI[#2], Mohamed BECHERIF [*3]

[#]*Innovative Technologies Laboratory*
ABDELMALEK ESSAÄDI University, (ENSA) Tangier, Morocco
*FCLAB FR CNRS 3539, FEMTO-ST UMR CNRS 6174,
University of Technology of Belfort-Montbéliard, France,

[1]meskani.asma@gmail.com
[2]haddi.ensat@gmail.com
[3]mohamed.becherif@utbm.fr

***Abstract*— With the increasingly prominent energy crisis and environmental pollution caused by automobiles, the solar energy, as a new and clean energy, has attracted much attention. In this paper, a novel topology of hybrid generator with a PV energy conversion system with a battery in a DC-coupled structure is adopted to solve the problem and replace Fuel Cells, which have important diesel fuel consumption and high energy costs.**
In the proposed system, the PV Source represents the main source, the DC link and battery the transient power source. This latter can absorb or supply power peaks.
Finally, the proposed system is verified by the results of simulation.

***Keywords*— Solar Energy, Hybrid generator, PV, Battery, DC-coupled structure**

I. INTRODUCTION

More likely than not, getting a vehicle from point "A" to point "B" involves combustion of a fossil fuel, a process that emits gasses and affects the environment. According to the U.S. Environmental Protection Agency, more than half of the air pollution in the world is caused by mobile sources, primarily automobiles. Further contributing to the pollution potential of cars is the fact that they are filled with numerous fluids, which can harm the environment in the cases of leakage or improper disposal.

One solution to the current emissions problems that we face is the Hybrid vehicles, as they offer lower emissions than gasoline automobiles.

Fuel cell (FC) technologies are expected to become a suitable substitution for conventional power generators and grid utility for residential applications, as they are more efficient and environmentally friendly in comparison with other conventional power generators. However, in order to provide power demand of a residential load, it may be required to over design fuel cell power module which is not economically advisable. Furthermore, due to the sluggish dynamic response of fuel cell in transient events, there will be load following problem. [1] Not to mention diesel fuel consumption and energy costs that makes FC less effective.

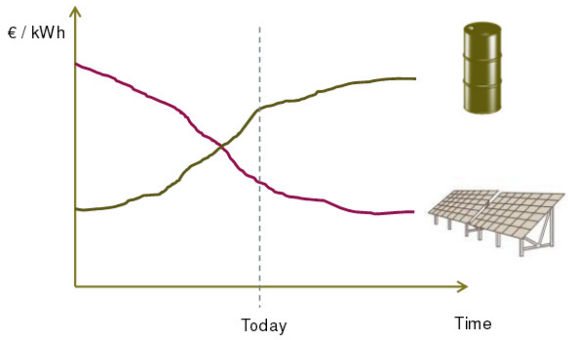


Fig. 1 The price for PV systems has decreased by more than 60% in the last 3 years. Fuel costs for diesel generators are constantly rising. Source: Juwi Group ASIA Pacific: Quantifying Commercial Benefits of Fuel Saver Systems

In such cases, a renewable energy, such as PV Panel, has been incorporated in order to overcome these problems. [2]

In an electric vehicle using a single energy source, the necessary power is transferred from the permanent source, the PV Panel for example, to the load.

The permanent source must frequently supply or absorb the picks of power resulting from the accelerations and the braking. This double uses of the permanent source, as energy source and as power source, is strongly penalizing: the losses and the weight are increased and the lifetime of the energy source is reduced. [3]

One solution to this problem is the hybridizing of the source with a battery which manages the power picks. Hence the permanent source can only supply the average power which insures the vehicle's energetic autonomy.

The battery system provides power to the vehicle during periods of peak power demand such as vehicle acceleration or traveling at a high constant speed.

Hybrid sources allow dissociating mean power sizing from peak transient power sizing, the aim being to reduce in volume and weight. [4] [5]

In this paper a hybrid power source using PV Panel and battery supplying a load is proposed to make the system highly efficient and reliable.

In a first step, a dynamic modeling of the overall system is given. Secondly, a description of the components of the proposed system is provided. Finally, simulation results in presence of DC Bus voltage changes and load resistor disturbances, using Matlab-Simulink, are presented.

II. DYNAMIC MODELING

The converter topology for the renewable hybrid system is depicted in Fig. 2.

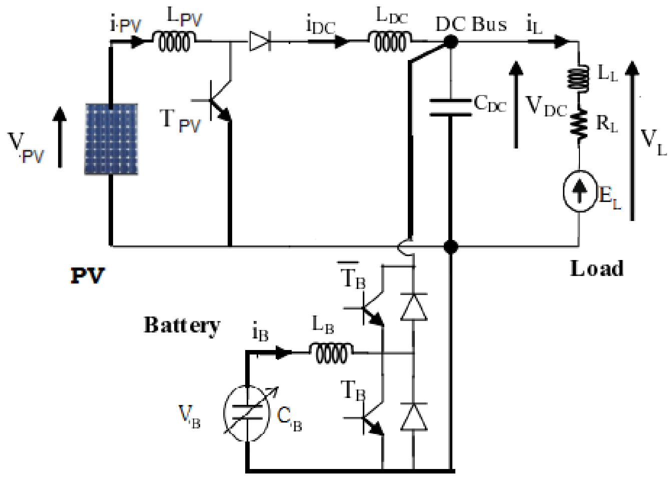


Fig. 2 PV/Battery hybrid system configuration

A. MODELING OF PV PANEL

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. 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 (Fig. 3).

In Fig. 3, R_S, R_P and C components can be neglected for the ideal model. [6]

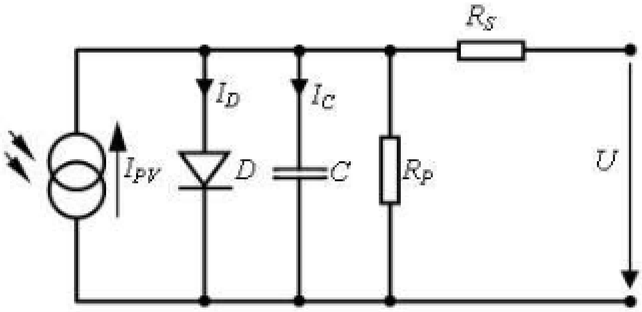


Fig. 3 Equivalent circuit diagram of a solar cell

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

Parallel or shunt resistance RP 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 [7].

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 [7] [8].

$$I = I_{PV} - I0\,(e^{\frac{qU}{kT}} - 1) \quad (1)$$

$$U = \frac{kT}{q} \ln\left(1 - \frac{I - IPV}{I0}\right) \quad (2)$$

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).

The model of solar photovoltaic power system has been developed in Matlab/Simulink as shown in Fig. 4.

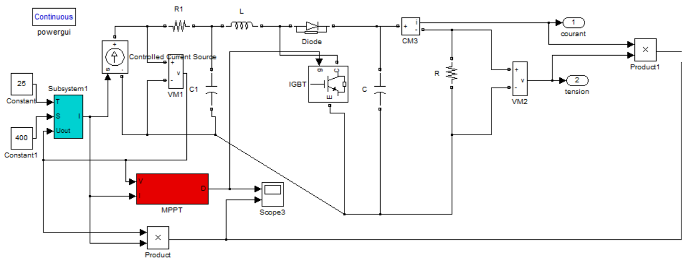


Fig. 4 Matlab-Simulink model used for PV mathematical model validation

B. BATTERY

The battery has the characteristics of high energy density and relatively low power density. The internal resistance is the major factor for the limited discharging and charging current capability. The internal equivalent series resistance has different values under charging and discharging operating conditions. The charging and discharging efficiency are nonlinear functions of current and state of charge (SOC). The battery can be modeled as an equivalent circuit such as a voltage source and an internal resistor. [4] [9]

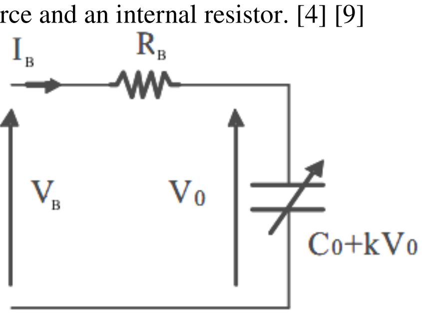


Fig. 5 Electrical model of the Battery

Because PV Panel and battery have advantages and disadvantages of their own, it should be beneficial to have hybrid energy-power sources, in which PV system supplies the base energy while battery supplies peak power for fast acceleration and captures the braking energy for regeneration.
Battery can carry out two main functions:

- the function \source of energy", since batteries are electrochemical accumulators,
- the function \source of power", for which battery comes in complement with the main source (FC) (or any other source limited in power), for a decrease in volume and weight of the whole system. [10]

The hybrid source studied in this paper concerns this second function.

III. COMMAND STRATEGY

A. PROPOSED HYBRID SYSTEM DESCRIPTION

The proposed hybrid structure given by Fig. 2 is composed by a PV array as a main source, a PV DC-DC boost converter, a DC bus, a Battery and its bidirectional DC-DC converter and a RLE load modeling the electric motor. The DC bus is powered by the PV system through its DC-DC boost converter that keeps the bus voltage to the value of its reference. The Battery is connected to the DC bus through its bidirectional DC-DC converter.
The role of the PV Panel is to provide power to the load; the Battery has the role to provide the extra power required by the load during transients and to recover the energy generated by braking.

To manage the exchange of energy between the DC bus and the storage element, three procedures may exist:

- Loading mode: where the main source (PV Panel) provides power to the Battery.
- Unloading mode: where the Battery and the main source supplies energy to the load.
- Recovery mode: where the load supplies energy to the Battery. [4] [9]

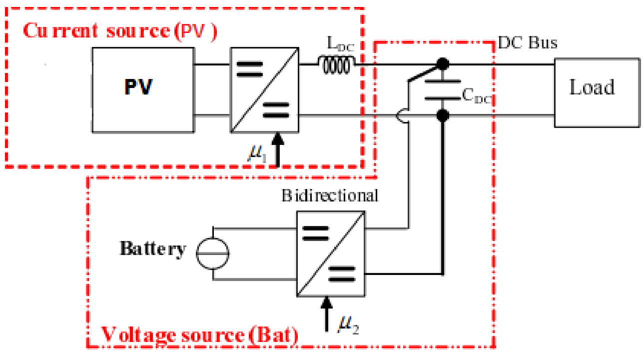


Fig. 6 Hybrid sources structure

Even with higher efficiency, the goal remains to maximize the power from the PV system under various lighting conditions.
Maximum Power Point Tracking (MPPT) is used to obtain the maximum power from this system. [11]

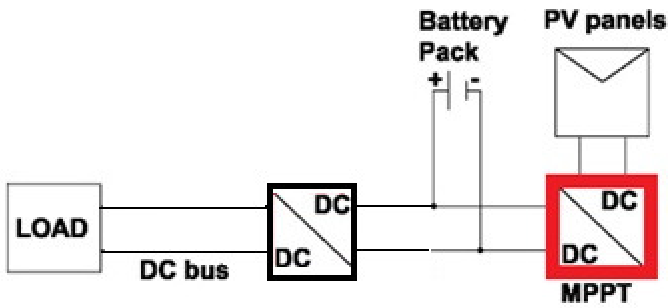


Fig. 7 Hybrid system for power generation from PV panels with an MPPT device

B. THE MAXIMUN POWER POINT TRACKING

In order to archive the maximum power point (MPP) of the PV array, it is necessary maintain it at their optimum point operating. The MPP varies with the solar radiation and the temperature. The characteristic curves specify a unique operating point at which maximum possible power is delivered. At the MPP, the PV system operates at its highest efficiency. [12]

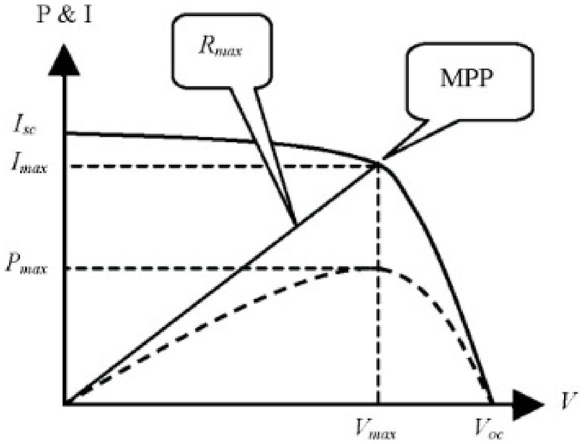


Fig. 8 V-I characteristic of a solar cell

There are many different approaches to maximizing the power from a PV system. The method that has been adopted is the Perturb and Observe (P&O) MPPT Algorithm.

The perturbation and observation method has been widely used because its simple feedback structure and fewer measured parameters which are required. It operates by periodically perturbing (incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. If the power is increasing the perturbation will continue in the same direction in the next cycle, otherwise the perturbation direction will be reversed. The flowchart of this method is represented by Fig. 9. [13] [14]

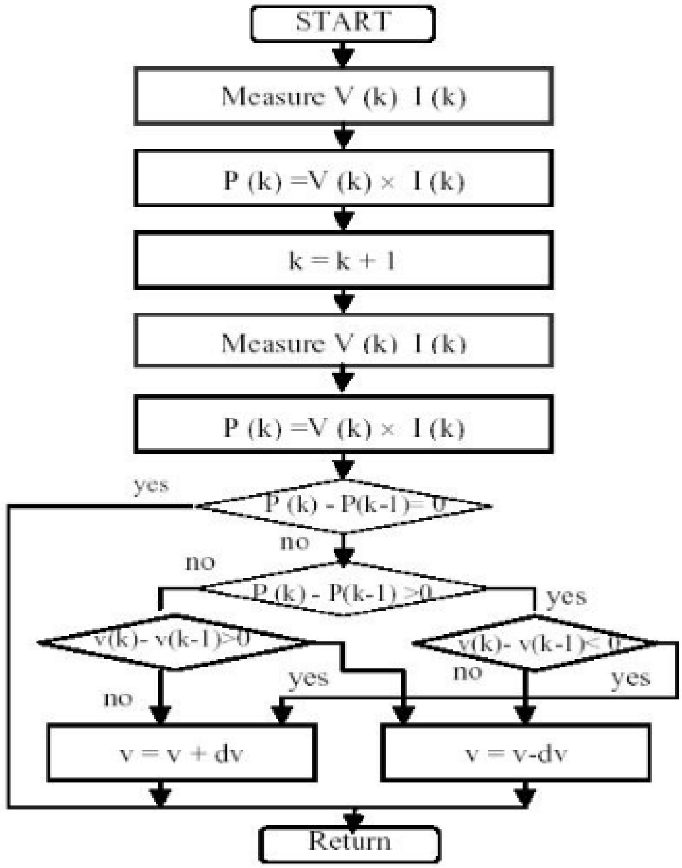


Fig. 9 The flowchart of the P&O algorithm. [15]

The output voltage and current with perturb and observe technique are shown by Fig. 10 (a) and Fig. 10 (b) respectively.

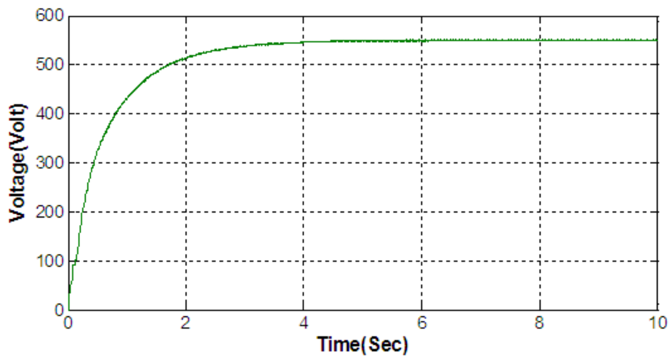


Fig. 10 (a) PV array output voltage for P&O MPPT technique

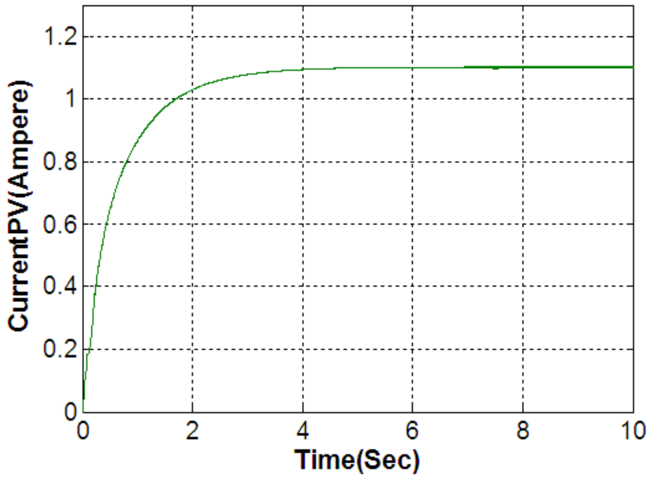


Fig. 10 (b) PV array output current for P&O MPPT technique

IV. Simulation Results

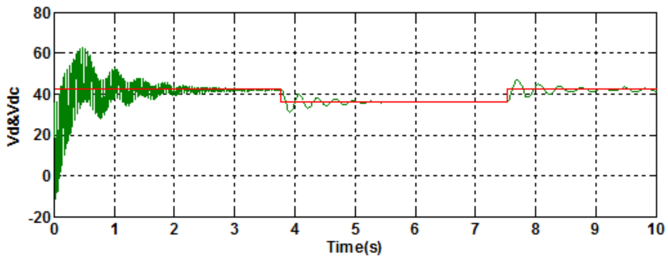


Fig. 11 DC Bus voltage and its reference.

Fig. 11 shows the response of the system to the DC Bus voltage reference changes V_D &V_{DC}. The DC Bus voltage tracks well the reference. A very low overshoot and no steady state error are observed.

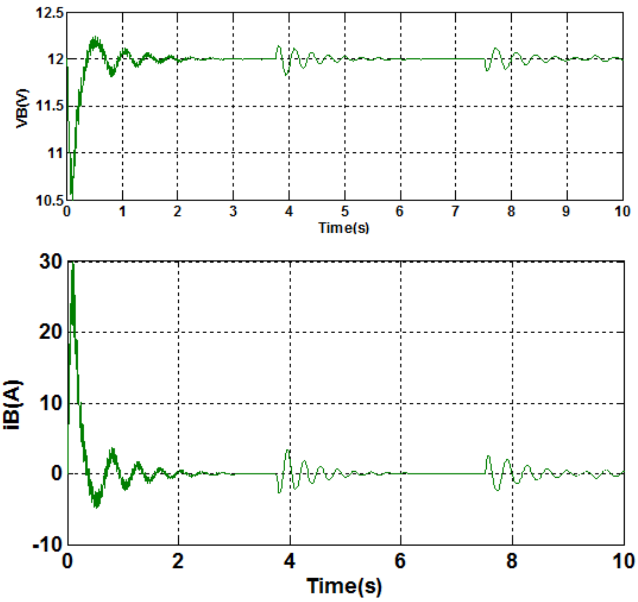
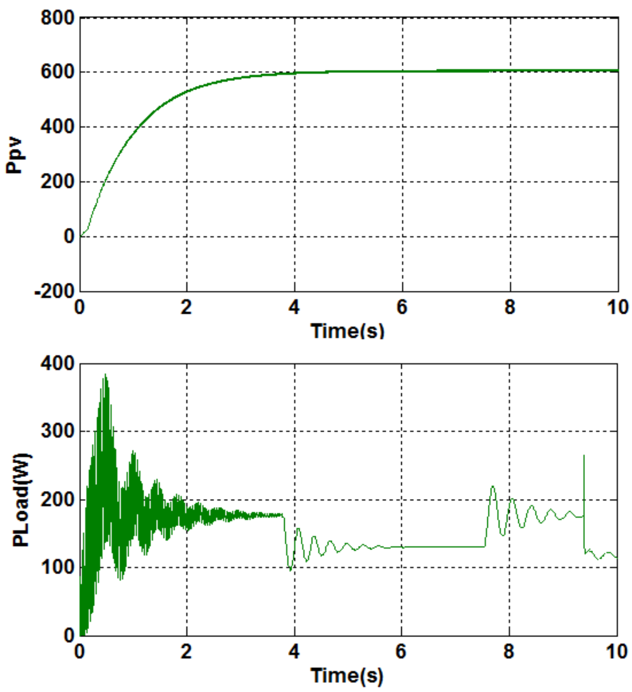


Fig. 12 (a) Battery voltage. (b) Battery current.

Fig. 12 shows the battery voltage and current V_B & I_B response in presence of the DC Bus voltage variation. The battery supplies power to the load in the transient and in the steady state no energy is extracted since the battery current is nul.

It can be seen from Fig. 13 that the battery supplies and absorbs the transient peak power.



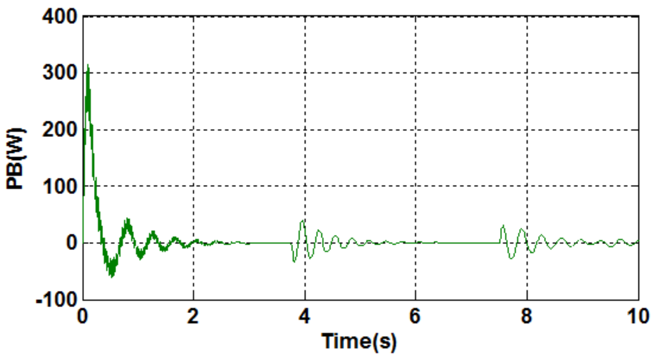


Fig. 12 PV Power, Load Power and Battery Power.

V. CONCLUSION

A dynamic modeling of a hybrid source system composed of a PV source and a battery source is presented.
An encouraging simulation results has been obtained exhibiting also the robustness of the proposed controllers towards load resistor variations.

Many benefits can be expected from the proposed structure such that supplying and absorbing the power peaks by using a battery which also allows recovering energy. At the same time, this can reduce significantly the harmonics on the line.

REFERENCES

[1] Power System Technology and IEEE Power India Conference, 2008.

[2] S. Chalise, J. Sternhagen, R. Tonkoski, Electr. Eng. & Comput. Sci. Dept., South Dakota State Univ., Brookings, Sd, Usa, Reducing Fuel Consumption in Microgrids using PV, Batteries, and Generator Cycling, Electro/Information Technology (EIT), IEEE International Conference on Bhandari 2013.

[3] Hicham Fakham, Di Lu, Bruno Francois, IEEE Transaction on Industrial Electronics, Power Control Design Of A Battery Charger In A Hybrid Active PV Generator For Load-Following Applications , Vol. 58, Iss. 1, Pp. 85-94, Jan. 2011, Tie-09-1370.

[4] M. Becherif, Passivity-Based Control of Hybrid Sources: Fuel Cell and Battery.

[5] M. Becherif, M.Y. Ayad, and A. Miraoui, Modeling and Passivity-Based Control of Hybrid Sources: Fuel Cell and Supercapacitors, 41st Ieee-Ias, 2006.

[6] Dumitru Cristian Drago, Gligor Adrian, Modeling of Renewable Hybrid Energy Sources, Scientific Bulletin Of The Petru Maior University Of Tirgu Mures 2009.

[7] A. Kaltschmitt, M. Streicher, W. Wiese, Renewable Energy, Technology, Economics and Environment, Springer-Verlag, Berlin Heidelberg, 2007.

[8] M. Patel, Wind and Solar Power Systems, Crc Press Llc, Boca Raton, Florida, 1999.

[9] M. Becherif, M.Y. Ayad, A. Henni, A. Aboubou, M. Wack, S. Laghrouche, Passivity-Based Control applied to DC Hybrid Power Source using Fuel Cell and Supercapacitors, Energy Conversion and Management, Volume 51, Issue 7, Pages 1468-1475, July 2010.

[10] H. Alloui, M. Becherif, K. Marouani., Modeling and Frequency Separation Energy Management of Fuel Cell-Battery Hybrid Sources System for Hybrid Electric Vehicle, Control & Automation (Med), 21st Mediterranean Conference, 2013.

[11] Giacomo Bruni, Stefano Cordiner, Matteo Galeotti, Vincenzo Mulone, Matteo Nobile, Vittorio Rocco, Control Strategy Influence on the Efficiency of a Hybrid Photovoltaic-Battery-Fuel Cell System Distributed Generation System For Domestic Applications, 68th Conference of The Italian Thermal Machines Engineering Association, Ati, 2013.

[12] M. I. Arteaga Orozco, J. R. Vázquez, P. Salmerón, S. P. Litrán, F. J. Alcántara, Maximum Power Point Tracker of a Photovoltaic System using Sliding Mode Control, International Conference on Renewable Energies and Power Quality (Icrepq'09) Valencia (Spain), 15th to 17th April, 2009.

[13] A. Yafaoui., B. Wu and R. Cheung, Implementation of Maximum Power Point Tracking Algorithm for Residential Photovoltaic Systems, 2nd Canadian Solar Buildings Conference Calgary, June 10 – 14, 2007.

[14] B. Amrouche, M. Belhamel and A. Guessoum, Artificial Intelligence Based P&O MPPT Method for Photovoltaic Systems, Revue des Energies Renouvelables, Icresd-07 Tlemcen (2007).

[15] Riad Kadri, Jean-Paul Gaubert and Gerard Champenois, An Improved Maximum Power Point Tracking for Photovoltaic Grid Connected Inverter Based on Voltage-Oriented Control, IEEE Transactions on Industrial Electronics, Vol. 58, No. 1, January 2011