

Modelling and Analysis of Hybrid PV-PEM Fuel Cell Power System

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ABSTRACT

Among the renewable energy sources, photovoltaics seems to be the most promising source. It has the advantage of being available everywhere, friend of the environment and easily maintainable. Nevertheless, the major disadvantages are high manufacturing cost, low energy conversion efficiency and non-linear characteristics. On the other hand, the fuel cell is undoubtedly the least polluting means of making electrical energy. Indeed, apart from electricity, the reaction between hydrogen and air produces only water vapour. As such, the process does not reject any greenhouse gases, unlike the combustion of fossil fuels. Whether in a transport-type application (bus or car, or stationary, energy systems including PV or Fuel Cell systems have a in such systems, several levels of control are to be studied, modelled and optimized; this last point, according to one or more criteria of the whole system, can intervene at several levels: optimization of the topology as well as optimization of component sizing. This paper addresses the modelling of hybrid PV-PEM fuel cell power system where the whole system components are implemented using Matlab/Simulink environment. The main parts (PV and PEM fuel cell) are analyzed and investigated alone and in hybrid mode using different scenarios tests. The simulation results show the advantages of using such hybrid system in providing electrical energy in different use cases.

1. INTRODUCTION

In view of the increasing technological development around the world, which in turn leads to the increasing consumption of electric power, traditional energies no longer meet the needs required, it is necessary to find alternative energies to cover this deficit. On other hand be environmentally friendly due to the dangers resulting from pollution which affects the earth as a result of the use of these traditional energies. In order to overcome these problems, it has become necessary to move towards the use of alternative energies such as solar energy, wind, fuel cell, tidal, hydrogen etc. [1].

The development of new energy technologies should be mandatory. Among them, fuel cells and solar cells are promising energy technologies. Electricity generation using a hybrid energy system combining this both sources of energy is of great interest due to its several of field applications and industrial. Solar systems that convert sunlight into electricity, it has many advantages we mention are silent, low-maintenance, eco-friendly, clean and efficient independent of the size of generator [2].

Fuel cells are electro chemical (mechanical) devices that convert chemical energy into electricity without generating carbon dioxide (promising power generation with high efficiency and low environmental impact) [3]. Among the many different fuel cell technologies, Proton Exchange Membrane (PEM) fuel cells are extensively used for mobile and portable applications. This is due to their compactness, low weight, high power density and clean, pollutant free operation. From the operational point of view, a relevant

aspect is their low temperature of operation (typically 60-80°C), which allows fast starting times [4, 5].

This paper deals with the modelling of hybrid PV-PEM fuel cell power system where the whole system components are implemented using Matlab/Simulink environment. The main parts (PV and PEM fuel cell) are analyzed and investigated alone and in hybrid mode using different scenarios tests. The simulation results show the advantages of using such hybrid system in providing electrical energy in different use cases. The remainder of this paper is organized as follows. Section 2 presents the PV modelling; while the PEM fuel cell modelling is presented is described in Section 3. The simulation results and discussions are presented in Section 4. Finally, Section 5 draws the main conclusions of this work.

2. PV MODELLING

The equivalent circuit of solar PV cell is shown in Figure 1, the cell consists of diode, a photo current and parallel/series resistor. The relation between the output current and voltage of PV module is given by [6]:

$$I = I_{ph} - I_s \left(e^{\frac{q(V+IR_s)}{NKT}} - 1 \right) - \frac{V + IR_s}{R_{sh}} \quad (1)$$

where, I is the output net current of PV cell; I_{ph} is the light-generated photocurrent; I_{sc} the short circuit current; I_s the reverse saturation current of the diode; V is the cell output voltage; R_s the series resistor of the PV cell; R_{sh} the shunt

resistor of the PV cell; q is the electron charge; A is the diode ideality factor; T is the working temperature of the p-n junction and K is the Boltzman's constant.

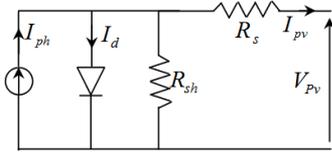


Figure 1. Model of photovoltaic cell

The photo-current I_{ph} is given by:

$$I_{ph} = \left(I_{sc} + K_i(T - T_{ref}) \right) \frac{G}{1000} \quad (2)$$

where, G is the sun irradiation; K_i the cell short circuit current temperature coefficient; and T_{ref} is the nominal reference temperature.

The saturation current I_s is described as follow:

$$I_s = I_{sref} \left(\frac{T}{T_{ref}} \right)^3 e^{\left[\frac{1}{T_{ref}} - \frac{1}{T} \right] \frac{qE_g}{NKT}} \quad (3)$$

where, E_g is the band gap energy of semiconductor; with:

$$I_{sref} = \frac{I_{scref}}{\left(e^{\left[\frac{V_{ocref}}{KAT} \right]} - 1 \right)} \quad (4)$$

The output simulation results of the I-V and P-V curves for different values of irradiation and temperature are presented in Figures 2 and 3.

3. PEM FUEL CELL MODELLING

Fuel Cell converts oxygen and hydrogen chemical energy to electrical energy during which heat and water is generated as well [7].

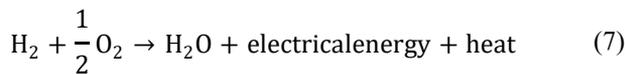
The half-reaction of oxidation of hydrogen will be as follows:



The half-reduction reduction of oxygen will be as follows:



The overall reaction taking place at the fuel cell can be summarized as:



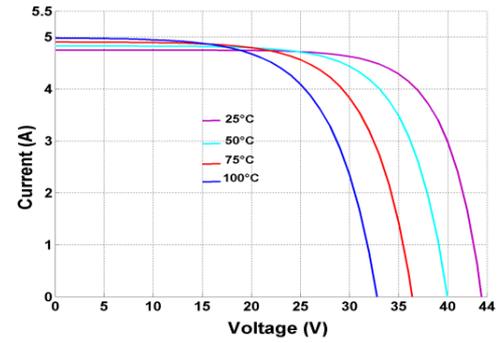
Each cell voltage can be defined by the well known expression given by:

$$V_{FC} = E_{nernst} - V_{act} - V_{ohmic} - V_{conc} \quad (8)$$

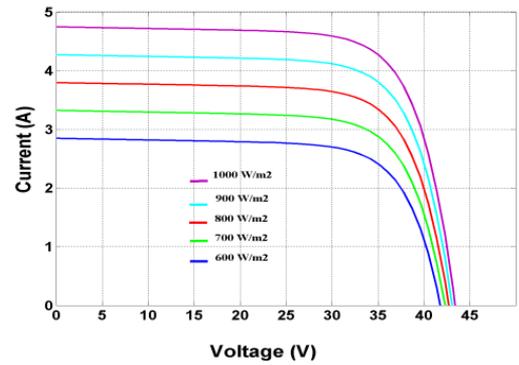
E_{nernst} is the reversible open circuit voltage approximated by [8-10]:

$$E_{nernst} = 1.229 - (8.5 \times 10^{-4})(T - 298.15) + (4.385 \times 10^{-5}T[\ln(P_{H_2}) + 0.5\ln(P_{O_2})]) \quad (9)$$

where, T is the temperature; P_{O_2} the oxygen pressure and P_{H_2} the hydrogen pressure.

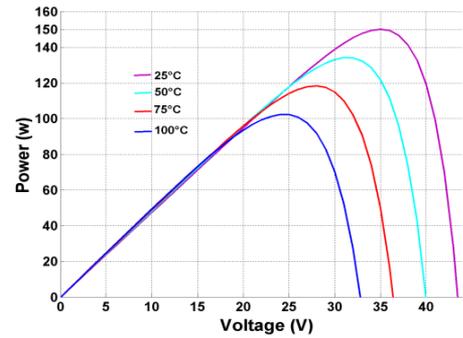


(a)

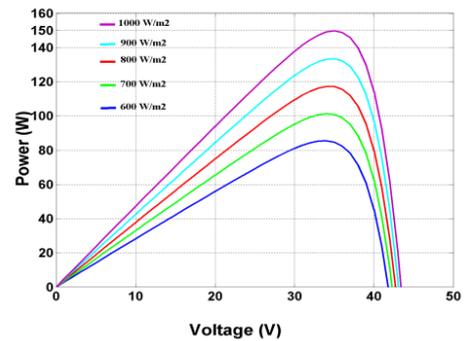


(b)

Figure 2. I-V Characteristics: a) In case of temperature variation, b) In case of irradiation variation



(a)



(b)

Figure 3. PV Characteristics: a) In case of temperature variation, b) In case of irradiation variation

V_{act} is the activation voltage drop approximated by:

$$V_{act} = \xi_1 + \xi_2 \cdot T + \xi_3 \cdot T \cdot \ln(C_{O_2}) + \xi_4 \cdot T \cdot \ln(i_{FC}) \quad (10)$$

where, ξ_i ($i = 1$ to 4) are parametric coefficients for each cell; i_{FC} is the cell current and C_{O_2} is the oxygen's concentration.

V_{ohmic} is the ohmic linear voltage drop proportional to electric current approximated by:

$$V_{ohmic} = R_{ohmic} \cdot i_{FC} \quad (11)$$

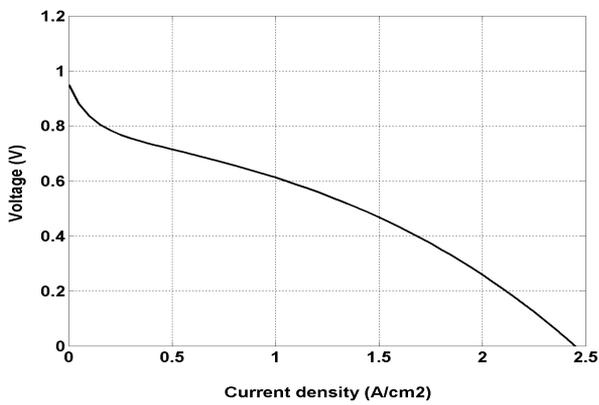
where, i_{FC} is the cell current; R_{ohmic} is the sum of the contact resistance R_c and the membrane resistance R_m .

V_{conc} is the concentration voltage drop approximated by:

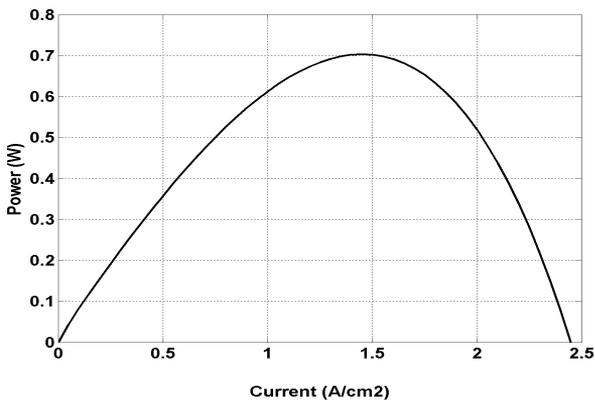
$$V_{conc} = -b \cdot \ln \left(1 - \frac{i_{FC}/A}{I_{max}} \right) \quad (12)$$

where, b is the concentration loss constant; i_{FC} is the cell current; A is the is cell active area; I_{max} is the maximum current density.

Thus, the FC voltage and power given in Figure 4 are nonlinear functions of the FC current, internal temperature and pressure of oxygen and hydrogen gasses.



(a)



(b)

Figure 4. FC Characteristic; a) V-I, b) P-I

4. RESULTS AND DISCUSSION

Results of the modeling of photovoltaic system, when apply the two profile of irradiance and temperature during one day, are illustrated in Figures 5 and 6.

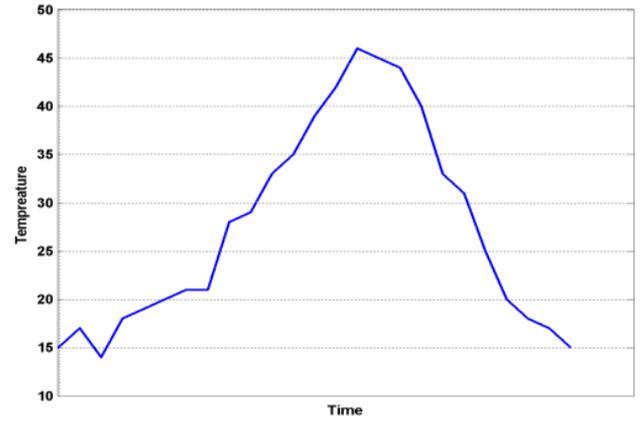


Figure 5. Temperature variation

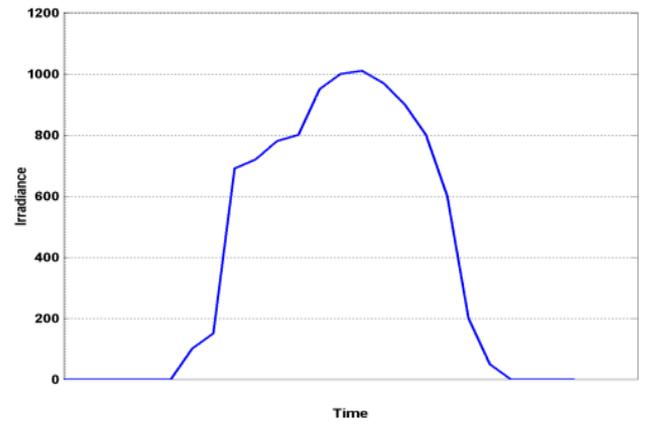


Figure 6. Temperature variationIrradiance variation

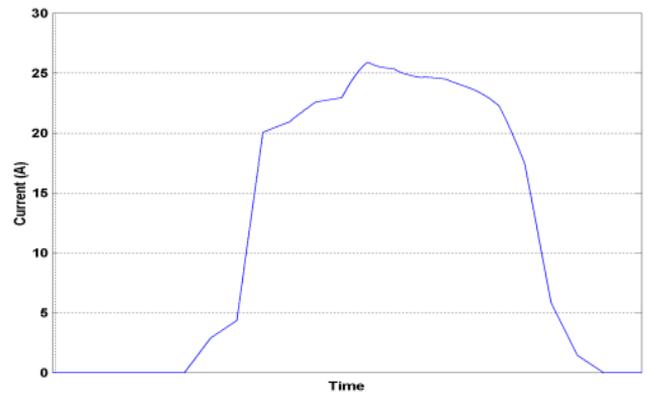


Figure 7. Hybrid system current curve

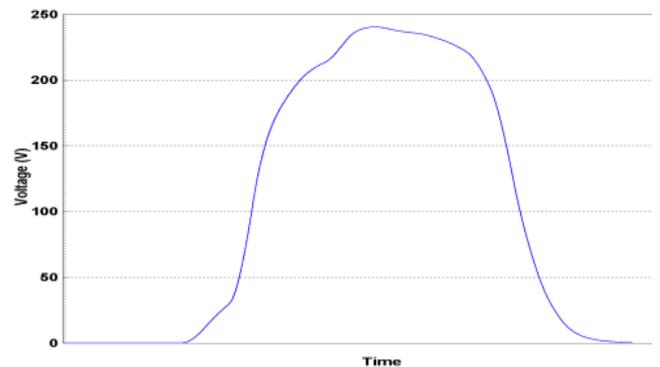


Figure 8. Hybrid system voltage curve

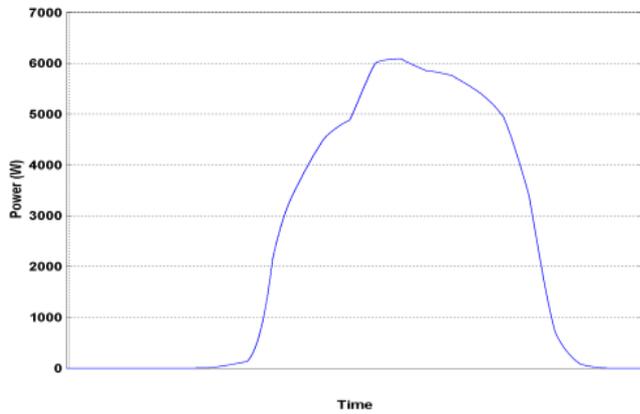


Figure 9. Hybrid system power curve

Figures 7 to 9 show the generated current, voltage and power through the solar cell over one days. As shown, when the irradiance and temperature becomes higher or lower, the values changes accordingly.

5. CONCLUSION

This paper addresses the modeling of hybrid PV-PEM fuel cell power system where the whole system components are implemented using Matlab/Simulink environment. The main parts (PV and PEM fuel cell) are analyzed and investigated alone and in hybrid mode using different scenarios tests. The simulation results using different test scenarios including temperature and irradiation profile for one day show the advantages of using such hybrid system in providing electrical energy in different use cases.

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NOMENCLATURE

I	The current of the PV cell (A).
I_{ph}	The light-generated photocurrent (A).
I_s	The reverse saturation current of the diode (A).
I_{sc}	The Short circuit current (A).
Q	The electron charge (C).
V	The voltage of the PV cell U (V).
V_{oc}	The Open-circuit voltage (V).
R_s	The series resistor of the PV cell (Ω).
R_{sh}	The shunt resistor of the PV cell (Ω).
N	The diode ideality factor.
K	The Boltzman's constant.
T	The temperature (K).
K_i	The cell short circuit-current temperature coefficient.
T_{ref}	The nominal reference temperature (K).
S	The irradiation (W/m^2).
E_g	The band-gap energy of semiconductor
ED	The new step size;
N	The Scaling factor.
v_{rev}	The reversible voltage (V).
v_{act}	The activation overvoltage (V).
v_{ohm}	The ohmic overvoltage (V).
ΔG	The Gibbs free energy change J/mol.
F	The faraday's constant C/mol.
Z	The number of electron.
η_F	The Faraday efficiency (%).
ϕ_{H_2}	The total hydrogen production (mole/s).
δ	The area of electrode (m^2).
S	The Coeff. for overvoltage on electrodes (V).
$K_{i=1,2,3}$	The Coeff. for overvoltage on electrodes.
ε_1	The Parameters related to ohmic (Ωm^2).
ε_2	The resistance of electrolyte (Ωm^2C).
PV	Photovoltaic.
FC	Fuel Cell.

MPPT Maximum Power Point Tracking.
MPP Maximum Power Point.
PEM Proton Exchange Membrane Electrolyzer.

DC Direct Current.
P&O Perturbation and Observation.
IC Incremental Conductance.