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Modeling, Design and Energy Management of a Residential Standalone Photovoltaic-Fuel Cell Power System

***Abstract**. The aim of this paper is to evaluate the potential of integrating photovoltaic and fuel cell technologies for standalone residential applications. The paper presents a detailed modelling of the photovoltaic (PV) array and maximum power tracking control, proton-exchange membrane (PEM) fuel cell stack, electrolyser and hydrogen storage tank. An energy management strategy is proposed to control the power flow in the system to satisfy the demand of typical residential load profiles under different operating conditions. In the proposed power management strategy, PV constitutes the primary energy source of the system, while the fuel cell represents the back-up supply when solar energy is unavailable. The overall model is simulated in Matlab/Simuink.The proposed model will provide qualitative information on the optimal rating and size of the PV array, fuel cell and storage devices characteristics to satisfy the energy/cost requirements for a residential application in rural/remote areas.*

Wznawianie.** Celem tego artykułu jest ocena potencjału integracji technologii fotowoltaicznej i ogniw paliwowych do zastosowań mieszkaniowych. W pracy przedstawiono szczegółowe modelowanie układu fotowoltaicznego (PV) i kontrolę śledzenia maksymalnej mocy, stos ogniw paliwowych z membraną wymiany protonów (PEM), elektrolizer i zbiornik wodoru. Zaproponowano strategię zarządzania energią w celu kontrolowania przepływu energii w systemie, aby zaspokoić zapotrzebowanie na typowe profile obciążeń mieszkaniowych w różnych warunkach pracy. W proponowanej strategii zarządzania energią ogniwo fotowoltaiczne stanowi podstawowe źródło energii systemu, a ogniwo paliwowe stanowi zapasowe źródło zasilania, gdy energia słoneczna jest niedostępna. Ogólny model jest symulowany w Matlab / Simulink. Proponowany model dostarczy informacji jakościowych na temat optymalnej oceny i wielkości tablicy fotowoltaicznej, ogniwa paliwowego i cech urządzeń magazynujących, aby spełnić wymagania dotyczące energii / kosztów dla zastosowań mieszkaniowych na obszarach wiejskich / odległych.* ***Projekt I modelowanie zarządzana energią w systemie hybrydowm: ogniwa słonezne I ogniwa paliwowe

Keywords: PV system, PEMFC system, Energy Management, fuzzy MPPT, P&O MPPT.
Słowa kluczowe: Fotowoltaika, system hybrydowy, zarządzanie energią

1. Introduction

The growing worldwide concerns about energy savings and less polluting forms of energy has led to an increased interest in the use of renewable energy sources in the residential sector.

Indeed, renewable energy sources have huge potential for residential remote areas as well as for agricultural industry and farming [5, 6].The Tiaret city is among the largest agricultural areas in Algeria and most of the remote farms in that region have no ready access to the electricity grid. The abundance of solar energy in these isolated areas makes photovoltaic (PV) systems an adequate solution for the supply electricity for domestic use and farming. Furthermore, PV systems offer the advantage of long lifetime with low maintenance [1].

However, due to its dependence on the environmental conditions such as the temperature and solar irradiance, the power generated from PV is intermittent.

The Hybrid renewable energy systems (HRES) produce power by combining two or more renewable energy sources, or alternatively by coupling renewable energy sources with conventional sources. HRES provide an economically viable and eco-friendly power generation solution for small-scale applications. HRES typically combine PV and wind turbines as renewable energy sources with diesel generators and fuel cells (FC) as controllable generators. Batteries, ultra-capacitors and hydrogen tanks are used as energy storage.

A PEMFC (proton exchange membrane fuel cell) is chosen in this work due to its high efficiency, low temperature operation, high power density, fast start up, and is very suitable for residential application [3].The PEMFC is fed by the hydrogen, which is produced by the electrolyser. Two types of electrolyzer exist, Alkaline and PEM. In this work, the PEM electrolyzer is used because of its advantages such as smaller dimension and mass, lower power consumption and lower operating temperature [4].

The aim of this paper is to present a comprehensive modeling of the HRES in order to evaluate the potential of integrating PV and FC technologies with electrolyser and storage devices to form a coordinated and hybrid energy system for residential applications in rural and remote areas.

PV and PEMFC are complex systems with highly nonlinear voltage- current characteristics [7, 8], which are required to operate at maximum power under variable load and operating conditions. Several maximum power tracking point (MPPT) algorithms exist to enable a PV panel or FC stack to extract the maximum power [9, 10]. In our work, a unified perturb & observe (P&O) technique and fuzzy logic control are proposed. The full system is simulated using Matlab/Simulink. We also discuss the results of each used technique.

The paper is organized as follows: in the section 2, we give a description of the overall system. In section 3, we present a detailed modeling and design of PV/FC hybrid system. In the section 4, the power management and control of PV/FC HRES is described. Finally, the simulation results are discussed in section 5. Section 6 summarises the conclusions of this work

2. Description of the HRES

The proposed HRES used in this study to supply the household, consists of a PV array generator (GPV), a PEM fuel cell (PEMFC), an electrolyzer (ELEC), a hydrogen storage tank and a power converter as depicted in Fig. 1. The GPV and PEMFC are connected to the DC bus whose voltage is regulated at 300V by the DC-DC boost converters. The maximum power point tracking (MPPT) controllers controls the duty cycles of the DC-DC converters.

Since all home appliances are AC loads, a DC-AC inverter regulated at 220 V with frequency of 60Hz is used.

The typical home appliances power ratings, estimated daily operation time and energy consumption are given in Table 1

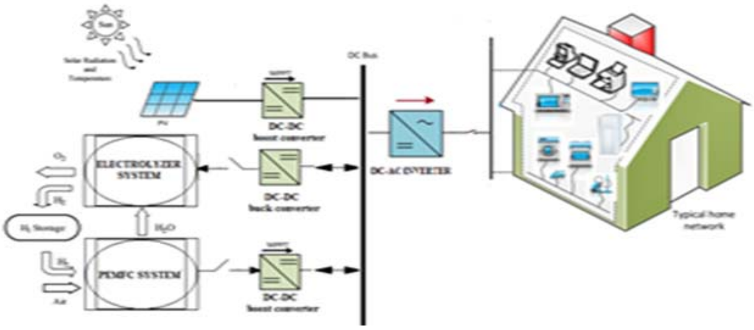


Fig.1. Structure of the HRES.

Table 1. Typical home appliances estimated daily power and energy consumption

Appliance	Power consumption [W]	Daily hours of Operation [h]	Energy Consumption [Wh
LCD television	200	4	800
Air conditioner	1000	3	3000
Washing machine	500	0.75	375
Iron	1000	0.25	250
Microwave	800	0.5	400
Refrigerator/freezer	700	24	16800
Laptop	30	3	90
Mobile phone charger	5	1	5
Light (7 lamps)	60x7	8x7	3360
Coffee maker	600	0.5	300
TAL	5255		25380

3. Modeling and design of the HRES

In this section, we present the models of the different component of the HRES.

3.1 PV array system model

A PV array is a group of PV panels interconnected in a parallel-series configuration. Each panel consists of several PV cells arranged in a series and parallel combination to obtain the desired voltage and current level. The single-diode equivalent circuit model shown in Fig. 2 is used in this simulation study.

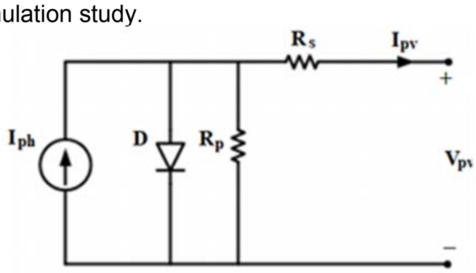


Fig.2. Single-diode equivalent circuit model of a PV cell.

where: D – inverted diode, I_{ph} – photocurrent, R_s, R_p – series and parallel resistances respectively.

The photocurrent I_{ph} and the output current I_{pv} are given by equations (1) and (3) [14]

(1) $$I_{pv} = N_p I_{ph} - N_p I_s[\exp(\frac{q(\frac{V_{pv}}{N_s} + \frac{I_{pv}R_s}{N_p})}{KT_cA}) - 1]$$

(2) $$I_{ph} = \frac{[I_{sc} + k_1(T_c - T_{ref})]}{1000}\lambda$$

(3) $$I_s = I_{rs}(\frac{T_c}{T_{ref}})^3 \exp[\frac{qE_g(\frac{1}{T_{ref}} - \frac{1}{T_c})}{KA})$$

where: I_s – current saturation of cell, V_{pv} – output voltage of PV system, N_s, N_p – number of series and parallel strings,
q – Electron charge, K – Boltzmann constant,
T_c, T_{ref} – temperatures of the *PV* surface and the reference temperature respectively, I_{rs}, I_{sc} – reverse saturation and short -circuit current at reference condition respectively, λ – irradiation level, E_g – band gap of the material , A – ideality factor, K_1 – short circuit temperature coefficient .

3.2 PEMFC system modeling

A fuel cell is a device which generates electricity through an electrochemical reaction between hydrogen (*H_2*) fuel and oxygen (O_2).Hydrogen enters the fuel cell stack from the anode side whereas oxygen enters the stack from the cathode side [2]. In this work, a proton exchange membrane fuel cell is used. Fig. 3 shows a chemical reaction for PEMFC and Fig. 4 shows a typical polarization curve of three regions for PEMFC [MATLAB Math Works].

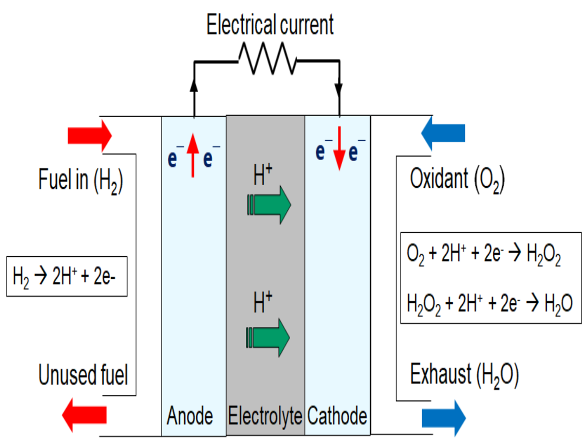


Fig.3. PEM fuel cell reaction

A dynamic model of the PEMFC is based on the relationship between the output voltage and potential pressure of hydrogen, oxygen and water. The overall output voltage of the fuel cell stack can be obtained as [13].

(4) $V_{cell} = E_{nerst} - V_{act} - V_{ohmic} - V_{con}$

where : E_{nerst} – Nernst voltage which is the thermodynamics voltage of the cells and depends on the temperatures and partial pressures of reactants and products inside the stack, E_0 – standard reversible cell potential (*V*), N_0 – number of cells in stack, R – universal gas constant (8.3145 *J·mol-1·K-1*), T – stack temperature (*K*), F - Faraday's constant (96485 *A·C·mol-1*), P_{H2}, P_{O2}, P_{H2O} – partial pressures of hydrogen, oxygen and water (*atm*) respectively.

(5)
$$\begin{cases} E_{nerst} = N_0[E_0 + \frac{RT}{2F}\log(\frac{P_{H2}p_{O_2}^{0.5}}{P_{H_2O}})] \\ V_{ohmic} = R_m I \end{cases}$$

where: $K_{H_2}, K_{O_2}, K_{H_2O}$ – valve molar constant for oxygen, hydrogen and water in (Kmol·s^{-1}·atm^{-1}) respectively.

(6)
$$\begin{cases} P_{O_2} = \frac{1/k_{O_2}}{1+\tau_{O_2}s}(q_{O_2}^{in} - 2k_r I) \\ p_{H_2} = \frac{1/K_{H_2}}{1+\tau_{H_2}s}(q_{H_2}^{in} - 2k_r I) \\ P_{H_2O} = \frac{1/K_{H_2O}}{1+\tau_{H_2O}s}(2K_r I_{fc}) \\ q_{H_2}^{in} = \frac{1}{1+T_f s}[\frac{2k_r}{U_{opt}} I_{fc}) \\ q_{O_2}^{in} = \frac{1}{r_{HO}} q_{H_2}^{in} \end{cases}$$

where: $q_{O_2}^{in}, q_{H_2}^{in}$ – hydrogen and oxygen input flow (kMol/s), *I* – stack current (A), $K_r = N/4F$ – modeling constant with *N* being the number of the series wound fuel cells in the stack, $\tau_{H_2}, \tau_{O_2}, \tau_{H_2O}$ – time constants for hydrogen , oxygen and water in (sec), U_{opt} – optimum fuel utilization, T_f – fuel time constant (sec), r_{HO} – ratio of hydrogen to oxygen [13,14], $V_{act}, V_{ohmic}, V_{con}$ – activation, Ohmic and concentration polarizations losses respectively.

(7) $V_{act} = [\xi_1 + \xi_2 T + \xi_{3T} \times \ln(C_{O_2}) + \xi_4 T \times \ln(I)]$

where: $\xi_i (i = 1,2,3,4)$ – parametric coefficients defined based on the kinetic, thermodynamic and electrochemical phenomena, C_{O_2} – concentration of oxygen dissolved in a water film interface in the catalytic of the cathode in (mol/m3). It is expressed as follows [12]:

(8) $C_{O_2} = \frac{P_{O_2}}{5.08 \times 10^6 e^{-\frac{498}{T}}}$

The Ohmic polarization loss is given as:

(9) $V_{ohmic} = IR_m$

where: R_m – ohmic resistance calculate in the paper [13].

A concentration polarization is expressed as:

(10) $V_{con} = -B \times \ln(1 - \frac{I}{I_{\lim}})$

With $I_{\lim}$ being the current density where fuel is used in a same rate as the maximum input rate (A/cm^2).to size the fuel cell, the amount of electric energy extracted from the *FC* should be calculated. Therefore, it is necessary to estimate the amount of energy generated from the FC per 1Kg of hydrogen, which can be obtained as follows [15]:

(11) $E_g^{FC} = H_2^{used} \xi_{fc} \frac{H_{2heatingvalue}}{H_{2density}}$

where: H_2^{used} – quantity of hydrogen input to the *FC* in Kg, ξ_{fc} – FC efficiency, $H_{2heatingvalue}$ – value is equal to $3.4\ kWh/m^3$ in the standard condition and H_2 densityis $0.09\ Kg/m^3$.

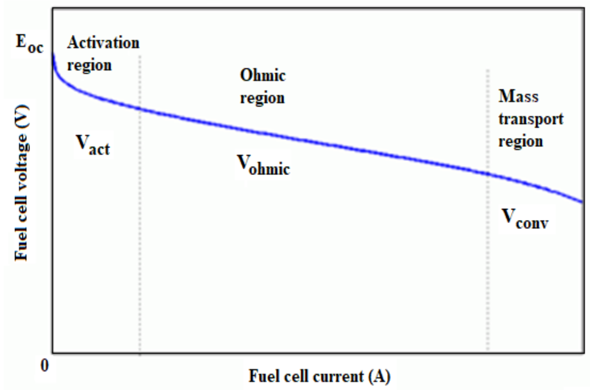


Fig.4. PEM fuel cell characteristics

3.3 PEM electrolyser system modeling

A PEM electrolyzer (*PEM-ELEC*) is an electrochemical device, which breaks down water into hydrogen and oxygen by passing a *DC* electrical current between two electrodes. These electrodes are separated by an aqueous electrolyte given a good ionic conductivity [16]. Fig. 5 shows the electrochemical reaction of water electrolysis in one cell. This last can be assembled into a stack to produce large quantity of hydrogen [17].

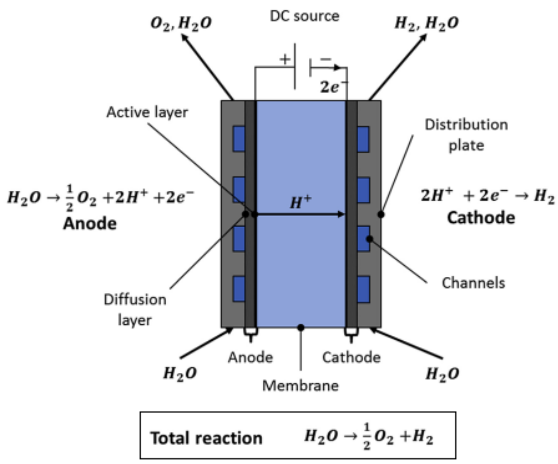


Fig.5. Structure of a PEM electrolyzer cell. [24]

The voltage-current characteristic is given by the follow relation:

(12) $$V_{elec}=V_{rev,elec}+\frac{r_1+r_2T}{A_{elec}}I_{elec}+(s_1+s_2T+s_3T^2)\log\left(\frac{t_1+\frac{t_2}{T}+\frac{t_3}{T^2}}{A_{elec}}I_{elec}+1\right)$$

where: $V_{elec}, V_{rev,elec}$ – operational cell voltage and the reversible voltage for the PEM-ELEC respectively, r_1, r_2 – parameters for the ohmic resistance of the electrolyte of the *PEM-ELEC* , $s_i\,(\mathrm{i}=1,2,3)$ – parameters for the overvoltage at the electrodes of the *PEM-ELEC,* $t_i\,(\mathrm{i}=1,2,3)$ – parameters for the overvoltage at the electrodes of the PEM-ELEC, T – temperature (°C), A_{elec} – area of the electrode (m²).

The size of the electrolyzer is determined by the amount of hydrogen produced. Therefore, the quantity of energy used to produce 1Kg hydrogen must be calculated. The mathematical formula is expressed as follows:

(13) $$Energy_{1KgH_2}=\xi_{elec}\frac{H_2heatingvalue}{H_2density}=\xi_{elec}\frac{3.4\left(\frac{kWh}{m^3}\right)}{0.09\left(\frac{Kg}{m^3}\right)}$$

(14) $$H_{2\,produced}\left(Kg\right)=\frac{P_{g,elec}}{Energy_{1\mathrm{KgH_2}}}$$

where: $\xi_{elec}=0.9$ – electrolyzer efficiency, $P_{g,elec}$ – power transferred from the DC bus to the electrolyzer [15],

From the calculation based on the given equations, the PV system power required to cover the consumption of the load is 7.9 *kW*, so 36 modules are used 4 connected in series and 9 connected in parallel each module consisting of 54 cells. The amount of hydrogen required by the system is 1.35 Kg that the *PEMFC* can produce 25.4 *kW/h* in the day of autonomy. In order to produce this quantity of hydrogen, the electrolyzer must work at the power of 6.55 kW which should produce 0.2*Kg/h* of hydrogen. Therefore, the electrolyzer must work 7hours/day or week to store 1.35 *Kg* of hydrogen in the tanks which is equivalent to 675 mol /day.

3.4 Modeling of hydrogen storage tank

The quantity of hydrogen produced by the PEM-ELEC is directly stored as compressed gas in tanks. The mathematical model for the hydrogen pressure in a storage tank is calculated as follow [13]:

(15) $$P_{bt}=Z\frac{N_{H_2}RT}{M_{H_2}V_b}$$

(16) $$E_{\mathrm{tank}}=P_{bt}\times M_{H_2}\times LHV$$

where: $P_{bt}, E_{\mathrm{tank}}$ – pressure (in Pascal) and the energy size of tank respectively, N_{H_2} – quantity of H_2 delivered to the storage tank (in *kMol/s*), M_{H_2} – molar mass of H_2, T – operating temperature (K), R – universal gas constant, Z – compressibility factor as a function of pressure and LHV is the low heat value of the hydrogen [13].

3.5 Modeling of DC/DC converter

Since the DC voltage generated by the PV and FC systems is unregulated, DC-DC power converters are required to provide a regulated DC power to the load. A boost converter is used to step-up the low voltage output of the PV and FC systems to a higher voltage as required.

Fig.6 shows the equivalent circuit of a boost converter. In these converters, the output voltage is a function of the duty cycle of the switch (S) which can be defined by a proper modulation technique.

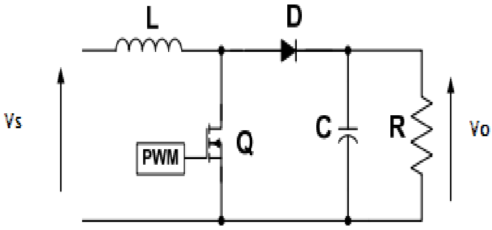


Fig.6. DC-DC boost converter circuit.

The conversion ratio is expressed as follows:

(17) $$\frac{V_0}{V_s}=\frac{I_s}{I_0}=\frac{1}{1-d}$$

With: $$\begin{cases} d=T_{on}/T \\ T=T_{on}+T_{off} \end{cases} \quad 0\le T\le 1$$

were : d – duty cycle of switching device.

the given Vs and Is are succesevely a voltage and current source . For more explanation consult [18, 25].

(18) $$\frac{V_{out}}{V_{in}}=\frac{t_{on}}{T_s}=D$$

3.6 Modeling of DC/AC inverter

The three-phase voltage source inverter (VSI) used in this paper is shown in Fig.7. A detailed mathematical model can be found in [19].

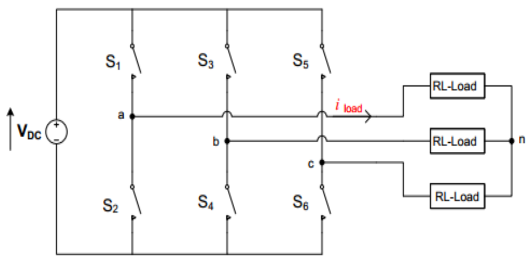


Fig.7. Three-phase VSI circuit diagram [11].

Table 1. State of VSI switches.

State	Phase "a"	Phase "b"	Phase "c"
1	S_1 *on* and S_2 *off*	S_3 *on* and S_4 *off*	S_5 *on* and S_6 *off*
2	S_1 *off* and S_2 on	S_3 *off* and S_4 on	S_5 *off* and S_6 on

4. Power management of PV/FC HRES

Key challenges for a successful HRES application are to ensure autonomous and cost-effective operation with high efficiency and reliability. To achieve these, the proposed HRES requires a power management strategy to determine how energy is allocated between the sources according to the operating conditions of the changing load demand. The flowchart of Fig. 8 illustrates the proposed power management for the HRES.

There are three main states of the HRES:

- State1 $\left(P_{PVG}=P_{Load}\right)$ – When the power generated from the PVG is sufficient to satisfy the load demand. In other words, this power is used directly and therefore storage of energy in the form H_2 and PEMFC is disconnected.
- State 2 $\left(P_{PVG}\succ P_{Load}\right)$ – The power excess from PVG, is used to supply the *ELEZ* to produce H_2 and store it in the tank.
- State 3 $\left(P_{PVG}\prec P_{Load}\right)$ – In this case the deficit power for the load will be provided from the *PEMFC*.

5. MPPT control of PV/FC HRES

This section illustrates the design of MPPT controller to maximize the power output from both PV and FC sources. Several MPPT methods have been proposed in the literature, in this study Perturb & Observe (P&O) and fuzzy logic control-based (FLC) MPPT algorithms are adopted and compared. The DC output voltage of the PV/FC system will also be regulated for the VSI.

5. 1.MPPT based on P&O

The P&O MPPT method is largely employed because of its simplicity and ease of implementation. P&O algorithm practically consists of perturbing the voltage and observing the power variation to determine the direction of increase or decrease of the voltage reference V_{ref} to apply [20]. The flowchart of P&O algorithm is illustrated in Fig.8. The main drawbacks of the P&O method are the resulting power oscillations around the MPP and the difficult choice of step size applied to V_{ref} .

5.2 MPPT based on fuzzy logic control

The P&O method for MPPT cannot respond quickly to fast weather changes (temperature or irradiance) and results in oscillations when searching for the MPP. Fuzzy logic control (FLC) has several advantages including better tracking performance and robustness, works well with imprecise input and does not requires a complex mathematical model of the system[22, 21].

FLC generally consist of three stages as shown in the figure (10)

Fuzzfication: converts a crisp input variables into linguistic variable based on a membership function.

Inference engine: converts fuzzy controller input to fuzzy controller output basing on the linguistic rule (rules are given in the fig.11 b).

Defuzzification: convert the fuzzy output back to suitable crisp output.

The FLC has usually two inputs: the error $E(k)$ and the change of error $CE(k)$.

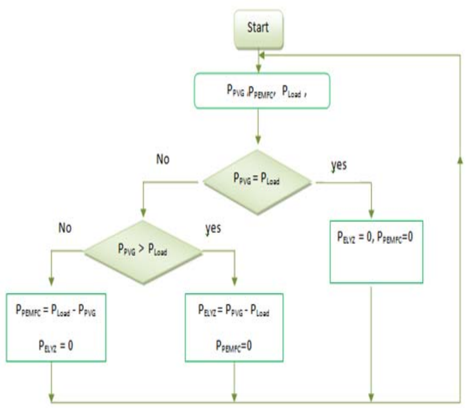


Fig.8. Power management strategy flowchart.

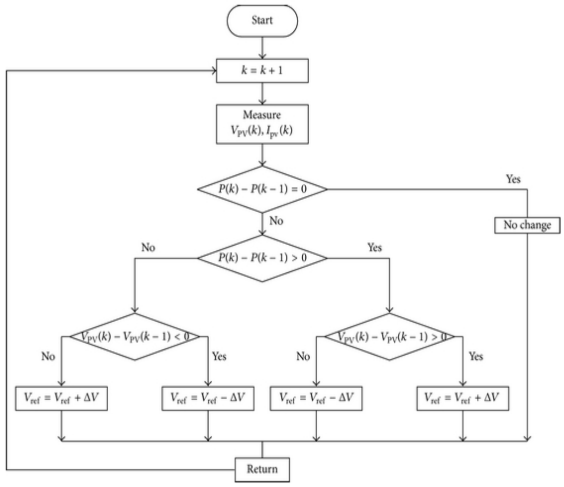


Fig.9. P&O algorithm flowchart.

(19)
$$\begin{cases} E(k)=\dfrac{P(k)-P(k-1)}{V(k)-V(k-1)} \\ CE(k)=E(k)-E(k-1) \end{cases}$$

The surface of the fuzzy rules is shown in Fig. 11. Mamdani's inference method is used in this work.

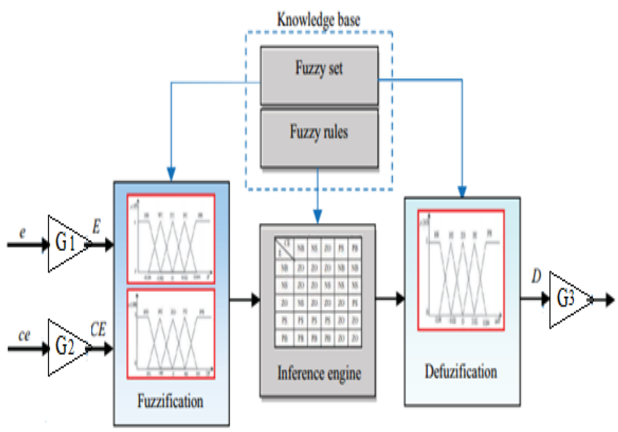


Fig.10. FLC structure. [23]

E \ CE	NB	NS	ZE	PS	PB
NB	ZE	ZE	PS	NS	NB
NS	ZE	ZE	ZE	NS	NB
ZE	PB	PS	ZE	NS	NB
PS	PB	PS	ZE	ZE	ZE
PB	PB	PS	NS	ZE	ZE

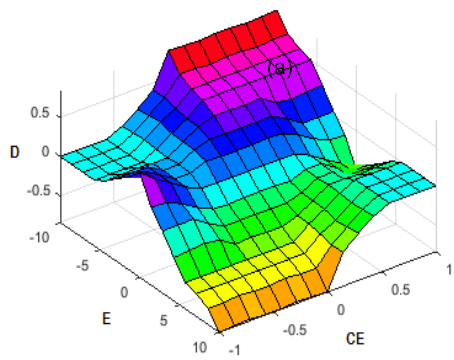


Fig.11. (a) rules surface , (b) Fuzzy rules.

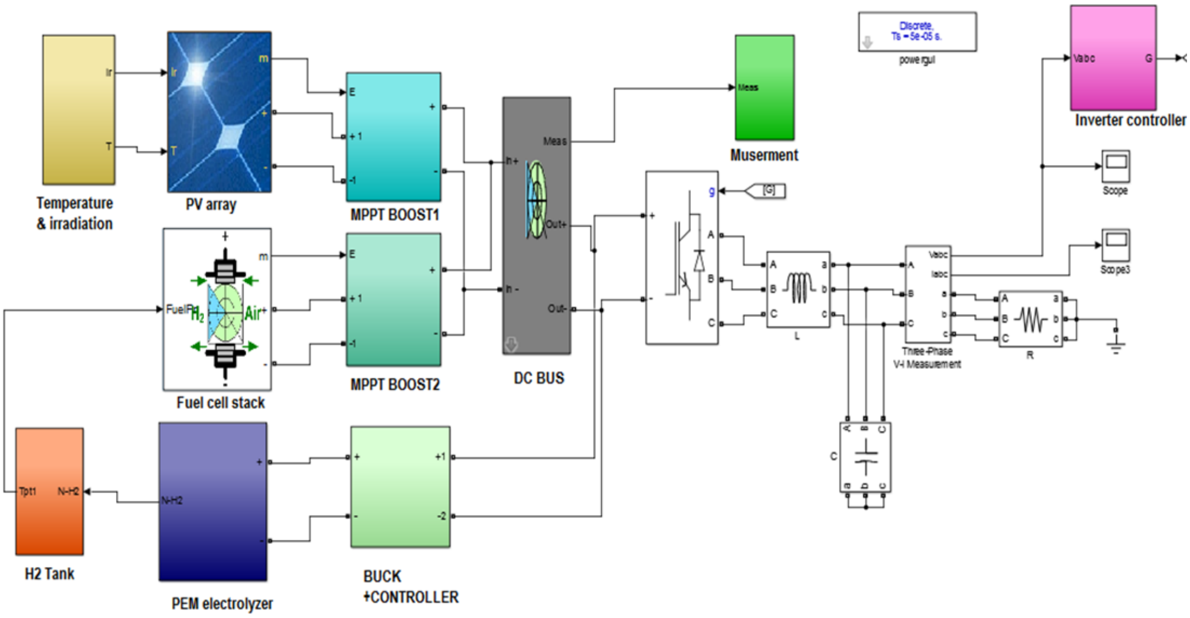


Fig.12. A model of PV/FC hybrid system o

6. Simulation results and discussion

The overall model of the HRES is implemented in Matlab/Simulink. The PV model considered is based on Kyocera Solar KD220GX-LFBS with 7.9 kW. A PEMFC of 6.5 kW is used. The electrolyzer operates under 80V and produces approximately 675 mole of hydrogen per day.

Tables 3 and 4 in the appendices show respectively the parameters of the Kyocera Solar KD220GX-LFBS PV array and the PEMFC respectively.

A figure 12 present a model of PV/FC hybrid system simulated on Matlab/Simulink, where a PV array source and FC source are connected to DC bus via the MPPT boost controller that which use an unified P&O MPPT and fuzzy MPPT in order to lets each source works at his maximum also to increase the voltage to the unified voltage that this last one supply a DC/AC inverter.

The figure13 shows a boost controlled by P&O algorithm with a step of 0.0001 after that by the switch the converter will regulated by FLC MPPT using Mamdani's method

Fig. 14 shows the voltage, current and power waveforms of the PV array for a solar irradiance of 1000 W/m² and a temperature of 25°C.The PEMFC stack works at temperature of 65°C and an air pressure of 1bar. The voltage, current and power wave forms of the PEMFC are shown in Fig.15. These results are compared with both P&O and FLC based MPPT controller.

Fig.16 shows the voltage and current waveforms of DC bus. Fig. 17 shows the power delivered by HRES.

The output power of the PV array depends on the solar irradiance variation during the day. Fig. 18 shows the solar irradiance of a typical day and variation of the power generated by the PV system. Fig.19 show the corresponding current and voltage of the PV array system. It can be seen that the tracking of MPP based on FLC gives better results than MPPT based on P&O.

The PV array operates at the maximum power point, and the power produced is about 7930 W. The extracted voltage and current are 106.2 V and 74.67A respectively. The PEMFC, on the other hand, operates at maximum power under standard test conditions (STC) conditions where the average power generated is about 10000 W. The voltage is 46V and the current is 223A. The PEMFC start to function after 2s when FLC MPPT is applied but it starts at 2.5s when P&O MPPT is useful.

There is a disparity of 13% between results of MPPT based on FLC and that of MPPT based on P&O. hence a FLC MPPT greatly improves the productivity of PV array and FC stack.

The DC/DC boost converters of each source are connected to the DC link with capacitance of 0.002F and provide a unified regulated voltage.

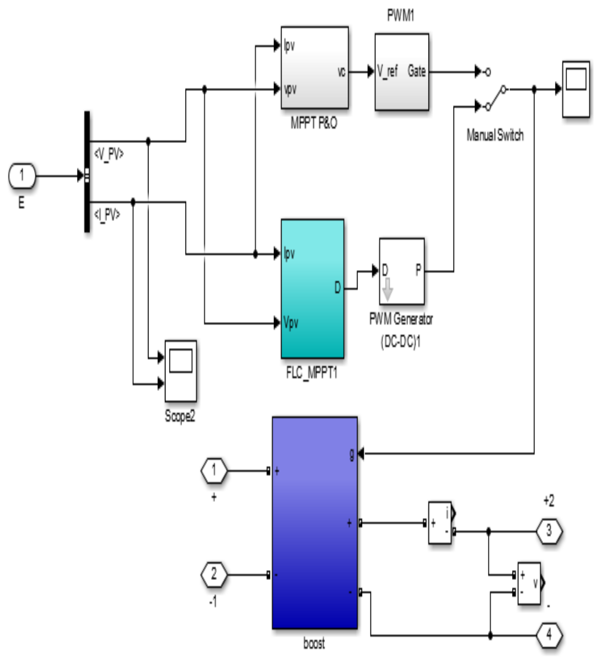


Fig.13. The MPPT control for the boost converter

According to the fig.20 it is seen that during the control of the system using FLC MPPT, the PEMFC starts at 11 am. Apparently, the GPV begins to work at 7 am. So the time between 7am to 11am represent the time of the production and the storage of hydrogen that subsequently feeds the PEMFC. According to the results shown in fig.21, the PEMFC starts at 17h when the system is controlled by P & O MPPT. The GPV runs at 10am. So, at this control.

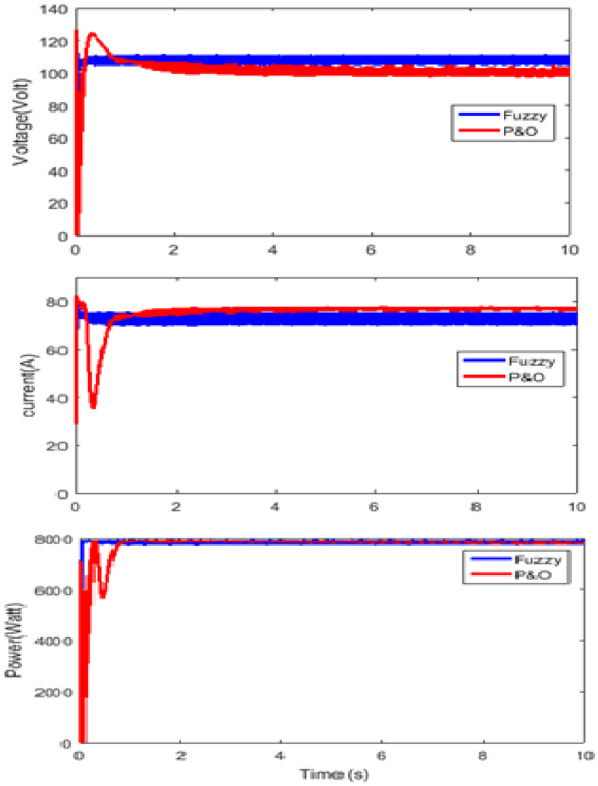


Fig.14. Voltage, current and power of the PV array system operating at 1000 W/m² and 25°C.

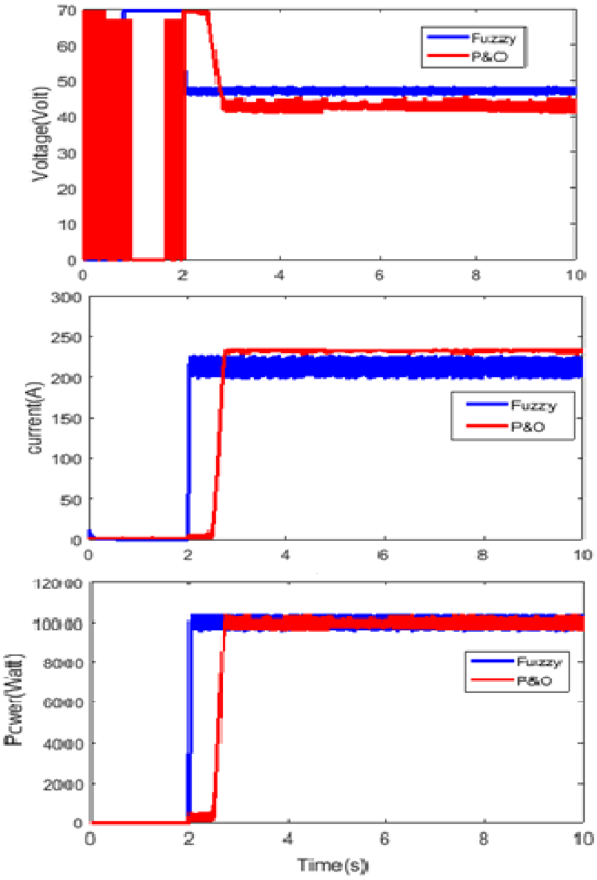


Fig.15. Voltage, current and power of the PEMFC stack system operating at 65°C and $P_{air} = 1\ bar.$

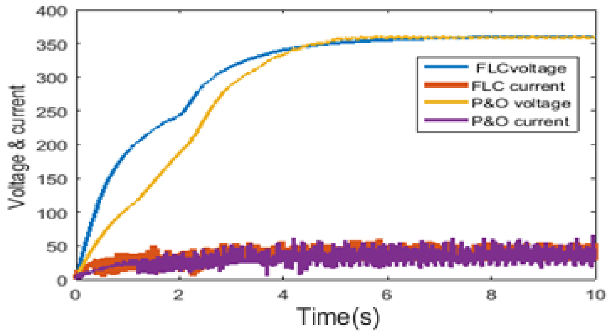


Fig.16. Voltage and current of DC link with FLC and P&O MPPT controllers

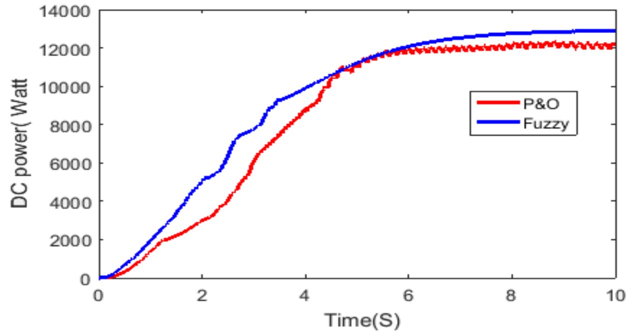
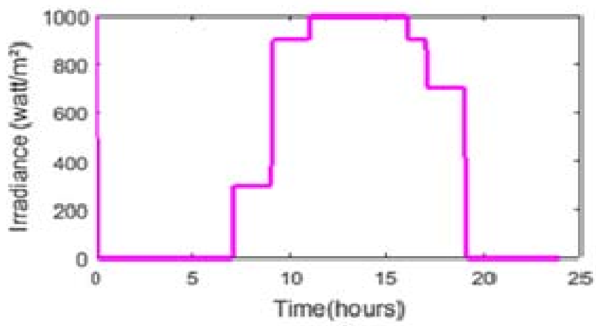
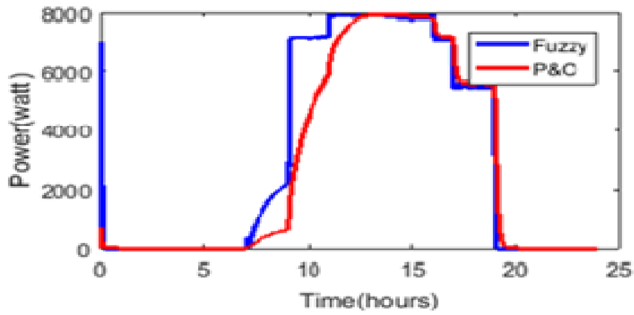


Fig.17. Curve power of DC link with FLC and P&O MPPT controllers

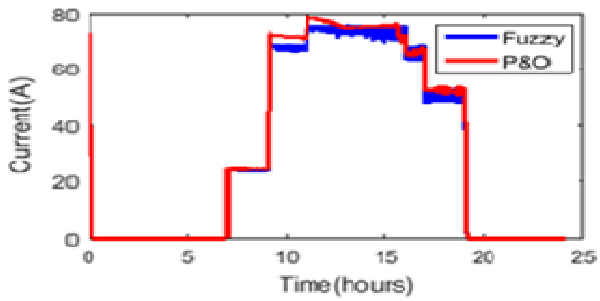


(a)

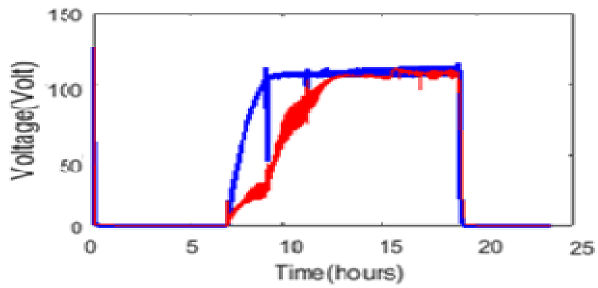


(b)

Fig.18. (a)solar irradiation, (b)power of PV system.

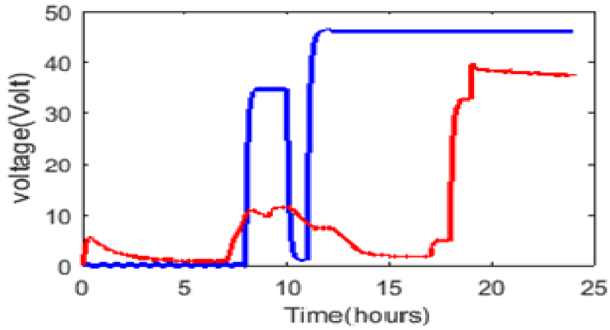


(a)

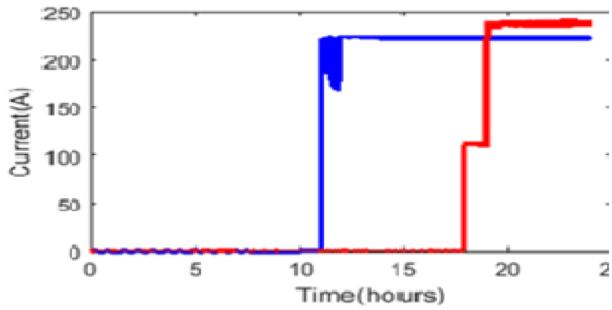


(b)

Fig.19. (a) voltage and (b) current of the PV system.



(a)



(b)

Fig.20. Voltage, current of the PEMFC system

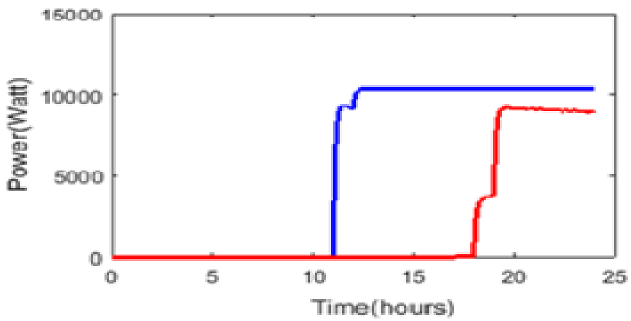
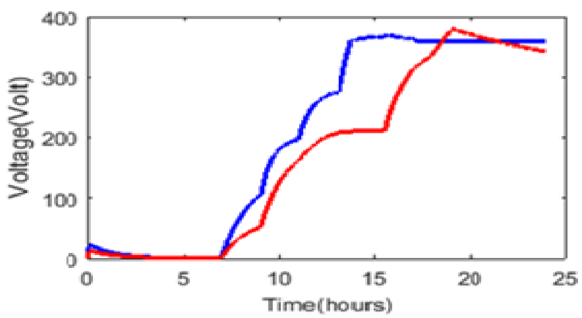
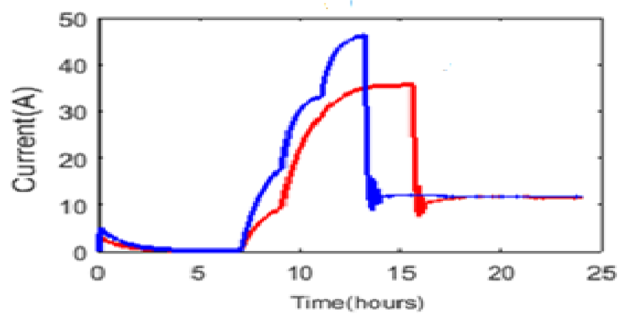


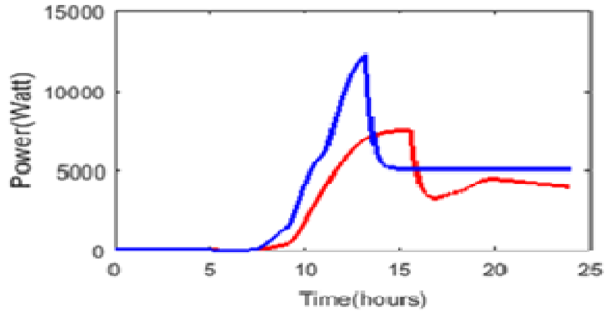
Fig.21. power variation of PEMFC



(a)



(b)



(c)

Fig.22. (a) DC Link voltage, (b) current, (c) power.

7. Conclusion

The hybrid system component of PV generator, PEMFC and PEM electrolyzer has modeled and sized to power the proposed isolated house. The control and simulation of this system are performed on the MATLAB / SIMULINK environment. In this work, the direct operation of GPV, PEMFC and electrolyzer are presented. The influence of the irradiance variation on the power of the DC link also is discussed. The performance of FLC control, applied to the system, is compared by the performance of P&O MPPT control. The simulation results during the FLC MPPT control mode show the correct tracking of the maximum power during irradiation variation. So, based on the obtained results, the FLC MPPT control present more efficiency than the control P&O MPPT in term of power tracking.

APPENDICES

Table 3. parameter values of PV array

parameter	values
$P_{\max}(W)$	220.2
V_{oc}(V)	33.2
V_{mp}(V)	26.6
I_{sc}(A)	8.98
I_{mp}(A)	8.28
I_{mp}(A)	1.12
E_g(V)	9.544×10^{-11}
I_{rs}(A)	0.948

Table 4. Parameter values of PEMFC

parameter	values
Nominal power (W)	5998.5
Maximum power (W)	8325
E_{nerst} (V)	1.128
N_0	65
Nominal operating point	*I*(A)= 133.3 *V*(Volt)=45
Maximum operating point	*I*(A)=225 *V*(Volt)=37

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