Implementation of a Multi-control Architecture in a Photovoltaic/ Grid/ Electrolysis System for Usual Use and Clean Storage by Hydrogen Production

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Abstract- In this article, the authors proceed to the implementation of an architecture built on a platform of diversified control algorithms. These algorithms are designed to supervise a system that supplies an alternative load by using two sources of energy: photovoltaic (PV) as the main source and the national electric grid as an emergency source).The design of this system is developed by the authors around DC/DC converters in cascade (buck and boost), a DC/AC inverter and an electrolysis for the production of hydrogen as clean storage. Each converter is equipped with its own control algorithm (Maximum Power Point Tracking (MPPT) for the buck and proportional–integral (PI) regulation for the boost). The electrolysis's too, accompanied by a specific control guaranteeing optimum hydrogen production. For the DC/AC inverter, it is controlled by a conventional control strategy pulse width modulation (PWM Bipolar) to supply an alternative RL load. The electrical grid only intervenes in the last place to fill the energy deficit caused by the photovoltaic source. This assembly of these devices requires an efficient distribution of energy which is achieved by the development of a distribution algorithm to ensure the supply of the load under all circumstances and the production of hydrogen when the photovoltaic energy is in excess.

Keywords Photovoltaic, MPPT, electrolysis, hydrogen, grid, control.

1. Introduction

Researches are addressed in the field of renewable energies respectful of the environment, such as photovoltaic, to improve safety, reliability and sustainability. One of the major challenges for systems using photovoltaic energy is the inadequacy between the supply of energy of intermittent nature and the dynamic demand of energy. Energy should then be stored during periods of abundance and reused during off-peak periods. The two clean solutions that are interesting are:

- The connection of the photovoltaic system to the electrical grid
- Clean storage by production of hydrogen

This article does not address the first solution in the radical and rational sense of coupling (PV-Grid). This is a pragmatic connection of the electrical grid with the photovoltaic source. A connection which does not deal with the question of injection of PV energy in the electricity grid but in the sense of the latter's contribution, with the PV source, to compensate the eventual deficit caused by the intermittence of the PV energy. This type of hybrid sources makes it possible to ensure the supply of the energy of the load in all circumstances.

On the contrary, the second clean storage solution deserves our attention and takes a good part in our research [1]. This work focuses on the storage of photovoltaic energy surplus in the form of hydrogen by using the electrolysis of water. The possibility of using PV energy to produce hydrogen for use in different fields has been studied by many researchers [2, 3, 4, 5, 6, 7, 8 and 9]. In each of these works, hydrogen is produced for a particular purpose (electric vehicles, electricity in homes, cooking application, heat, applications in medicine for therapeutic purposes, etc.)

Moreover, and since the designed system involves more than one component, it is natural to make it more efficient and effective. This requires multiple actions and at different levels of the system. First, the system must provide the maximum available PV power [10] [11] [12], this power is consumed by two probable receivers (electrolysis and AC load), which further complicates the adaptation of the receiver to the PV source. Indeed, for each type of receiver, it is necessary to envisage an adequate adjustment structure for each component of the system and an algorithm controlling this structure. In addition, the system must be equipped with a specific power distribution algorithm. Different control algorithms and power management strategies have been studied for various hybrid systems configurations [13, 14, 15, 16, and 17]. Nevertheless, the integration between photovoltaic and grid to supply the load and in the same times produce hydrogen by the excesses of energy has little reported in the literature. This solution allows making the hybrid system more reliable, flexible and safe. On the other hand, this same solution requires the development of several local control algorithms and acting at the right time.

In this article, we briefly describe the mathematical and electrical models used for each block constituting the designed system and implement for each functional block its own local control algorithm. All these implemented algorithms constitute a complete architecture around the designed system, and then allows it to be supervised. In this case, we focus on:

- Maximizing the PV power by implementing a new control algorithm, based on the use of a variable step size of the duty cycle, equipped with a mechanism of acceleration [1]
- Maximizing hydrogen production by improving the production process through two levels of electrolysis optimization.
- The regulation of the supply voltage of the inverter by maintaining this voltage constant by using the control loop (PI) of the boost converter,
- The usual use of the AC load by the power supplied by an inverter, controlled by a PWM strategy, located between the boost converter and the load.
- The distribution of energy in the system by using an algorithm that is responsible for dispatching energy between the different blocks.

We implement all these control algorithms using the Simscape and the C language power provided by CMEX S-function integrated in the Matlab/Simulink environment.

2. Configuration of the Hybrid System PV/Load/ Electrolysis/ Grid

1.2. System Proposal

In this work, we focus on the supply of an AC load and an electrolyser through a photovoltaic system. When the charge is properly powered and there is still excess energy, the surplus is sent to an electrolyser to produce hydrogen gas by electrolysis of water phenomenon. The hydrogen produced at one of the electrodes of the electrolyser is stored in its own form in bottles for it to be used later for various purposes. In the case where the energy from the PV is insufficient to supply the load, we use the electrical network to compensate for this energy deficit and to meet the needs of the load. Under these conditions the electrolyser is completely disconnected from the system. The electrolyser produces hydrogen only by the excess of the PV energy. This way of distributing optimal energy in the system increases its complexity by introducing more blocks and requiring the development of an intelligent power management strategy.

2.1. Synoptic Description Diagram of the Model

In “Fig.1”, we have presented the configuration of the PV/ load/ electrolysis/ grid system developed in this article to ensure the supply of the load with alternative current. As it appears in the synoptic diagram, the path of the energy produced by the PV modules can take two paths: A main track to the load and a second track to the electrolysis for clean storage. In both ways, the introduction of energy adaptation devices is necessary. These devices are energy converters, themselves controlled by specific and adequate algorithms. The system is thus built around the converter stages and has varied control architecture. The system comprises successively a main chain (from the panel to the load), a secondary chain (panel to electrolysis) and a power management block.

2.2.1 Main Chain

The system includes:

- Photovoltaic bloc consisting of two PV panels (PV UD180MF5 type of 180 Watt each) capable to produce a peak power of 360 W
- An adaptation bloc contains a DC/DC buck converter already dimensioned and designed to operate at a frequency of 100 KHz. This block is locally provided with a control algorithm which allows tracking the maximum power point (maximum power point tracking PPT). The control algorithm used here is the “'incremental conductance'”, with variable step iteration.
- A regulation stage based on a DC/DC boost converter to increase the voltage level to a constant value of 172 V. This voltage is stabilized to its value by a local control (PI) in the boost which delivers a pulse width modulated signal at 100 KHz which is responsible for maintaining the boost output voltage constant Regardless of the source of power supplying the load.
- An inverter structure for converting the DC power to the AC power supply meeting the requirement of the load in terms of rated voltage and current. The inverter is powered by the voltage of boost stabilized at 172 V.
- The national low voltage grid blocks to overcome the intermittency problems related to PV and cover the energy requirements of the load.

2.2.2 Secondary Chain

In addition to the PV source equipped with the block maximizing its power, this chain comprises a clean storage block materialized by electrolysis. This electrolysis is supplied by the buck converter when there is excess PV energy. Excess PV energy is converted into hydrogen production at one of the electrolysis electrodes. This block is equipped with a water pump and a water flow controller.

2.2.3. Power Management Block

This block is considered the conductor of the system. It collects information on the status of the load (in terms of power) and decides on the energy path. The operating principle of this calculation unit is described later in this article. In a first approximation this unit makes it possible to determine the best compromise of distribution and transfer of energy between the elements of the system.

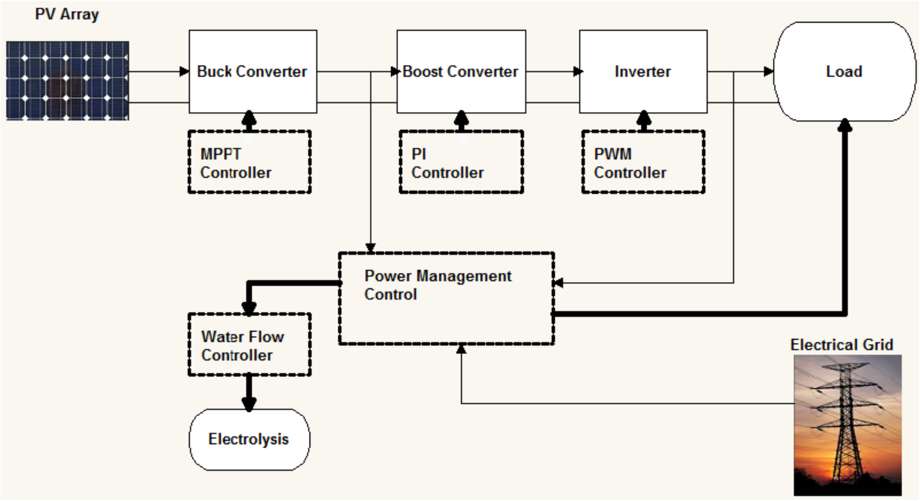

Fig.1. Schematic layout of the proposed PV/grid /electrolysis hybrid system with load

3. Electrical Modeling of System Blocks

3.1. PV panel electrical model

The fundamental physical device that includes the construction of the PV panel is the solar cell. In the literature, the electrical model of an illuminated PV cell is presented in "Fig. 2".

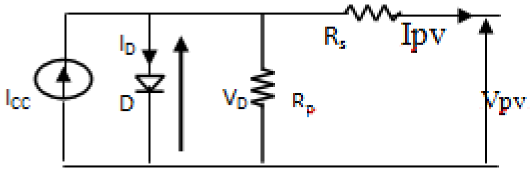

Fig. 2. Electrical design of the illuminated photovoltaic cell

In an illuminated PV cell, the electrical current Ipv produced by the cell is written in the form [18]:

$$Ipv \approx I_{cc} - Is \bullet \left[\left(exp \frac{q(Vpv + R_S Ipv)}{KT} \right) - 1 \right] - \frac{Vpv + R_{S_r} Ipv}{R_P} \quad (1)$$

Where: $I_s$is light-generated current (photo-current), $I_s$is saturated diode current, q is unsigned electron charge, A is an ideal factor, (varies between 1.2 and 5), k is Boltzmann's constant and T_c is the absolute cell temperature. The resistors R_S and R_P represent respectively the resistances of the metal contacts and leaks of the PN junction.

We worked on two UD180MF5 panels of 180 Watt for each (from Mitsubishi Electric), with an optimal voltage 24.2V and optimal current 7.45A.

3.2. DC-DC Converters (Buck and Boost) and Control Laws

Step-down and step-up DC-DC converters are presented as the most efficient topologies "Fig.3" for better matching energy conversion chains. In the designed system, these converters are controlled by a pulse width modulated (PWM) signal to transfer the maximum power of PV generator to the load and to the electrolysis (MPPT control) or to regulate a voltage to a constant value (PI control). They are designed, in previous work, to operate at a switching frequency whose duty ratio D of the control signal is:

$$D = \frac{t_{on}}{t_{on} + t_{off}} = \frac{t_{on}}{T} \quad (2)$$

Where: $T = t_{on} + t_{off}$ signal period (t_{on} and t_{off} are respectively switching time in the low state and in the high state).

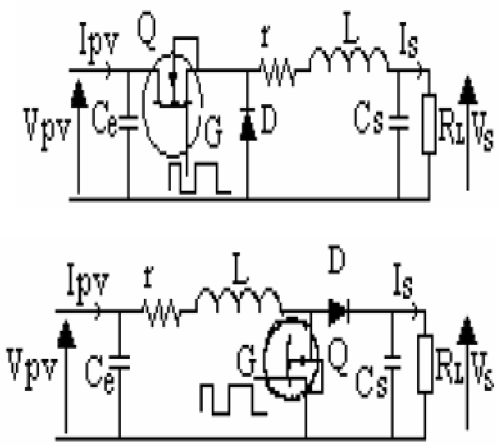

Fig. 3. DC/DC Buck and boost converter respectively used in photovoltaic system

By neglecting the losses, it is easy to express the various quantities as a function of the parameters characterizing the DC-DC converters. The various electrical quantities are summarized in “Table 1.” [19].

3.3. Polymer Electrolyte Membrane (PEM) Electrolysis

Electrolysis of water is dissociation of water molecules into hydrogen and oxygen by the application of difference potential across the electro chemical cell. This process can be expressed by:

At the anode: $H_2O_{(l)} \rightarrow \frac{1}{2} O_{2(g)} + 2H^+ + 2e^-$ (7)

At the cathode: $2H^+ + 2e \rightarrow H_{2(g)}$ (8)

Therefore, the overall reaction of this decomposition can be written as:

$$H_2O_{(l)} \rightarrow \frac{1}{2} O_{2(g)} + H_{2(g)} \quad (9)$$

When the current flows through the solution of the PEM cell, the voltage of the electrolytic cell can be represented as the sum of: the Nernst voltage E_{rev}, activation overvoltage at the cathode η_c and anode η_a, overvoltage due to the membrane η_m and interfacial overvoltage η_I “Fig.4”.

$$E = Erev + \eta a + \eta c + \eta_m + \eta_I \quad (10)$$

According to the second Faradays law, the mass of hydrogen produced at the cathode is proportional to the amount of electrical current through the electrolyte:

$$m_{H_2} = \frac{M.I_S.t.n_c}{n.F}.\eta_F \quad (11)$$

With:
m_{H2}: mass of hydrogen formed to the electrode (in kg)
n_c: number of cells
M: molar mass of hydrogen (in kg.mole-1)
I_{el}: current through the electrolysis (in A)
t: time of electrolysis (sec)
n: number of electrons per mole of product formed
F: Faraday’s number (F = 96485 C/mol)
η_F: Faraday efficiency.

Table .1. Expression of the Electrical Quantities in the Step-Up and Step-Down Converter

	Boost converter	Buck converter
Output voltage V_s	$V_s = \frac{V_{PV}}{(1 - D)}$ (3)	$V_S = DV_{PV}$ (4)
Converter Efficiency	η_{bs}	η_{bc}
Output current I_s	$I_s = \eta(1 - D) I_{pv}$ (5)	$I_S = \eta_{bc} \frac{I_{PV}}{D}$ (6)

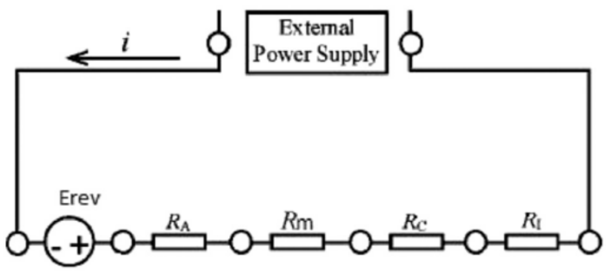

Fig. 4. The electrical circuit for the water electrolysis process

3.4. Modeling of the inverter

We also carried out the modeling of the single-phase inverter in the Matlab/Simulink environment according to the diagram in “Fig.5”. The load is taken alternative.

To supply the AC load, we have inserted the inverter between the boost which delivers a constant voltage and the load. The single-phase inverter is composed of four switches controlled by a conventional PWM control strategy.

4. Control Algorithms Managing the System

4.1. MPPT control for maximizing power

The conventional analog or digital MPPT algorithms described in the literature using a fixed step size present a common disadvantage concerning the compromise between the stability and the oscillation around the maximum power point (MPP) under stable conditions [20] [21] [22].

To optimize the overall efficiency of the system, we used the approach of the variation of the step iteration by using mathematical expressions which can be changed according to the distance that separates the position of the current operating point from the point of maximum power. This technique of the variable step iteration has been developed in our previous work [10] and uses the equation (12):

$$D(k) = D(k-1) \pm N \cdot \left| \frac{\partial P_{PV}}{\partial V_{PV}} \right| \quad (12)$$

Where:
D: the duty cycle of the signal controlling the power converter,
P_{PV}: Power generated by the photovoltaic
V_{PV}: Voltage at the terminals of the PV panel
N: scale factor assigned to the design time to adjust the step size $N < \Delta D_{\max} \cdot \left| \frac{\partial P_{PV}}{\partial V_{PV}} \right|^{-1}_{\Delta D_{\max}}$

The technique used in this work to maximize the maximum power produced by the panels and transfer it almost to the load called incremental conductance (InCon) based on the variable step size approach. This digital control algorithm is equipped with an acceleration mechanism, as described in reference [23], which makes it possible to quickly reach the maximum power point with great precision while maintaining a very satisfactory stability.

4.2. Voltage control at the terminals of the boost converter

The power delivered by the PV panels is now optimal. This power is maximized by the buck converter controlled by the designed MPPT algorithm. However, the voltage at the terminals of the buck can fluctuate when the solar irradiance change. The power in the load must be consumed under a constant effective voltage (110V). This requires inserting a boost converter between the buck and the inverter which raises and maintains a constant DC voltage (172V) to power the inverter. This boost converter is controlled by a PI control loop.
This converter is equipped with its control loop designed to be used as a modular unit. Thus, by choosing the appropriate DC/AC inverter, the voltage supplying the inverter can be modulated.

4.3. Electrolysis optimization

In a photovoltaic system, the output power of the PV panel depends to the weather conditions (rapidly changing). The quantity of hydrogen produced depends, therefore, on these variations. It would then be more convenient to take account of this dependence when we optimize the electrolysis by focusing instead to the mass flow of hydrogen produced than the quantity. We have shown that the mass flow of hydrogen produced can be presented in the form:

$$\dot{m}_{H_2} = \frac{m_{H_2}}{t} = \frac{M.I_S.n_c.\eta_F}{n.F} \qquad (13)$$

We consider that all the hydrogen produced over time by the electrolysis is sent to the storage tank. The mass of hydrogen stored in the tank at any given time t is given by:

$$m_{H_2STORED} = \int_0^t \dot{m}_{H2}\, dt \qquad (14)$$

However, in our previous research [23] we have shown that there is proportionality between the water flow injected in the electrolysis and the electrical power available from PV. Hence the need to control the water flow introduced into the electrolysis. For this purpose, we have proposed a flow control system according to the optimum power supplied by the PV panels to produce the maximum of hydrogen.

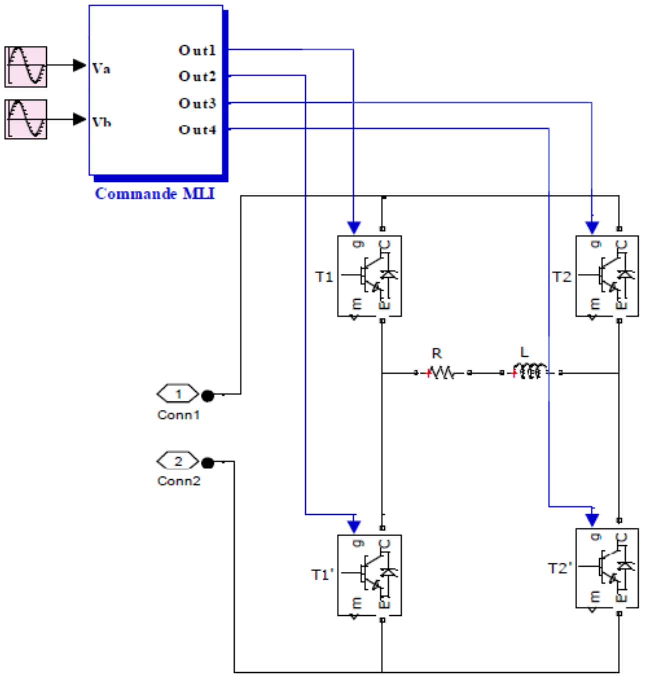

Fig. 5. Simulation diagram of the inverter and the RL load with the MLI command

The system consists of a level controller, a water pump and a control valve. The electrolysis system operates according to the diagram of “Fig. 6”. The level controller measures the water flow corresponding to the optimum power of the PV panels.

The measured flow rate is converted into an electrical signal which controls the valve connected by a pump to the water storage tank. This assembly aims to control the optimal water flow that will be injected in the electrolysis.

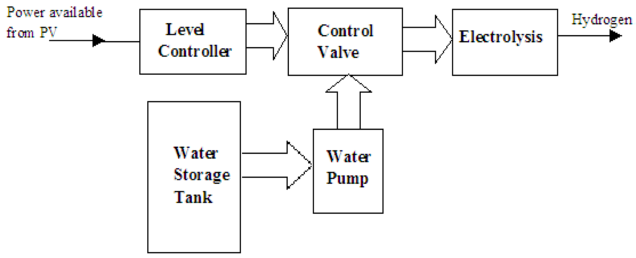

Fig .6. Block diagram of water flow controller

4.4. Control strategy of the inverter

4.4.1 Principle of strategy

The control strategy of the inverter adopted in this work is called control by pulse width modulation PWM, which is based on the comparison of a sinusoidal reference voltage with the triangular signal in order to generate the control signals “Fig.7”.The main aim of the modulation techniques is to reach the maximum voltage at the output of the inverter with the lowest harmonic distortion.

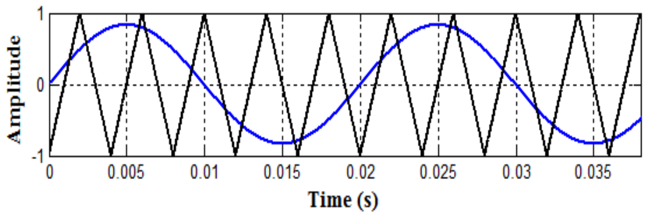

Fig.7. Sinusoidal MLI, generating control signals by a sinusoidal triangular carrier

4.4.2 Fourier analysis

The Fourier transform of a periodic signal with symmetry on the quarter period and anti-symmetry on the half-period is given by:

$$U(t) = \sum_{n=1}^{k} b_n \sin(nwt) \quad (15)$$

With: $$b_n = \frac{4E}{n\pi}\left[1 + 2\sum_{n=1}^{k}(-1)^k \cos(n\alpha_k)\right] \quad (16)$$

The effective value of the first (fundamental) harmonic is given by:

$$V_1 = \frac{b_1}{\sqrt{2}} \quad (17)$$

$$V_1 = \frac{4\sqrt{2}E}{\pi}\left[1 - 2\cos(\alpha_1) + 2\cos(\alpha_2) - 2\cos(\alpha_3) + 2\cos(\alpha_4) - 2\cos(\alpha_5)\right] \quad (With\ k = 5) \quad (18)$$

From the simulations, we have observed the values of the angle α in degrees "Table .2":

Table .2. The values of the angle α in degrees

α_1	α_2	α_3	α_4	α_5
17	19	30	54	76.33

Where $V_1 = 0.64 * E$ (19)

4.5. Power Management Strategy (PMS) of the Hybrid System

4.5.1. Management strategy principle

The main purpose of the power management strategy developed in the hybrid system (PV grid integration) is to satisfy the requirements of the load according to the principle described in the following.

In general, the power of the load is variable (the maximum power is 250W in our system). The PV source can provide a maximum power of 360 W. This power can degrade, depending on the incident solar radiation and the temperature (weather conditions), to a power lower than the power demanded by the load. We are therefore in the presence of several scenarios that depend on both variable load requirements and the random weather conditions. It happens then that the system, left to itself, returns to an indeterminate situation from the point of view of energy flow. To manage this situation and to determine the common sense in which energy is to be conveyed, it is necessary to develop a power management strategy (PMS) including the electrical grid.

The logic of operation would have been fairly simple if the PV power was constant or varied slowly over time. However, the large variability of electricity production, mainly due to the stochastic behavior of the PV source, increases the complexity of the management of the system [24]. As a result, the electrical network becomes an important component of the system. The management strategy sought is aimed at managing the variability of the photovoltaic energy production and that which can be provided by the electricity network with regard to a random behavior of the load and the meteorological conditions.

The main purpose of any energy management strategy is its ability to provide operational management policies in conditions that are constantly changing. The development of such a strategy should ensure the satisfaction of electricity needs and maintain operating costs at a reasonable level. As a result, the operation of the hybrid system involves a number of decisions regarding the management and use of power. The main indicators which govern the operation of the system are the instantaneous state of the load in terms of power and the possible surplus of power supplied by the PV source. The strategy developed in this work is committed to take charge of two functions:

- The permanent supply of the load (for the PV source or the electrical grid).

- The potential surplus of power delivered by the PV system is potentially stored in the form of hydrogen by electrolysis of water. The hydrogen produced can be further processed to produce electricity. This last process of transformation is not discussed in this article.

4.5.2. Energy management algorithm of the system

The block diagram for PMS is presented in "Fig. 8". The system power balance is checked at each perturbation (weather change or load variation). The input data such as solar radiation, PV power, load power and harmony losses P_{loss} at inverter ($P_L = P_l + P_{loss}$) is used, so that the algorithm can make the decision on the interconnection of the load to the appropriate source. Indeed:

- If $P_{PV} >= P_L$ and the $P_{PV} - P_L > 0$, the load operate at its maximum power $P_L = P_{L\_max}$ and the excess of power is transferred to the electrolysis to produce hydrogen $P_{el} = P_{PV} - P_L$.

- If $P_{PV} - P_L = 0$, all the power produced by the PV will be transferred to the load. In this case, there is no surplus of energy which implies no production of hydrogen $P_{el} = 0$.

- When the output power of PV is lower than the P_L, the necessary power to satisfy the load is provided by the grid $P_L=P_{PV}+P_g$.

When the solar radiation or the load changes (perturbation), the algorithm rechecks the value of the power loads, using the electrical grid, so that a new decision on the distribution of energy can be made between the probable energy sources on one hand and between the storage unit and the load on the other hand. This energy management strategy is developed using the power of the C language.

5. Simulations Results & Discussions

To test the performances of the various control algorithms designed for the system (PV/ load/ Electrolysis/ Grid) presented in this work, we used the dynamic model of this hybrid system under meteorological conditions corresponding to a summer day at the city of Oujda "Fig. 9”.

5.1. Irradiance Rapidly Changing and Fixed Load

The load is fixed to consume a power of 250 W. "Figure.10" represents the results of simulations of the maximum power extracted from the photovoltaic source by means of the MPPT control. The PV source passes through all the possible scenarios with respect to the power required by the RL load (250 W) “Fig.11”. Indeed:

- For the duration of 10 to 16 hours, the PV generator is able to ensure the power needed by the load with a remarkable excess of energy. This excess power is transferred to the electrolysis to produce hydrogen. This hydrogen production, when it has taken place, is optimized by controlling the water flow injected in the electrolysis via a water pump "Fig.12" and "Fig. 13". The mass of hydrogen produced is stored in the tank "Fig.14". During this phase, the maximum power transferred to the load is insured by the MPPT control of the PV power.

- Outside the interval [10h to 16h], there is a partial or total deficit of the photovoltaic power ($P_{pv}<P_L$), the electrical grid compensates this deficit and then produces the complementary energy to satisfy the power of the load "Fig.15".Thus, in this case, the power balance is $P_L=P_{pv}+P_g$. Note that, although the PV power is insufficient, it is transferred by the MPPT control to the load with additional power guaranteed by the electrical grid whose distribution is done through the management strategy.

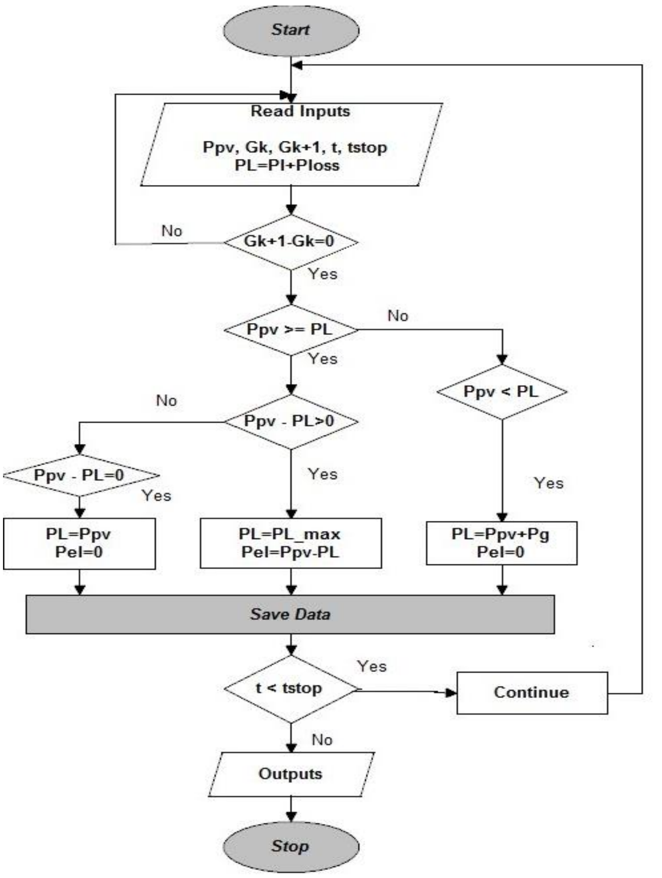

Fig. 8. Flow chart of the power management strategy of the hybrid system

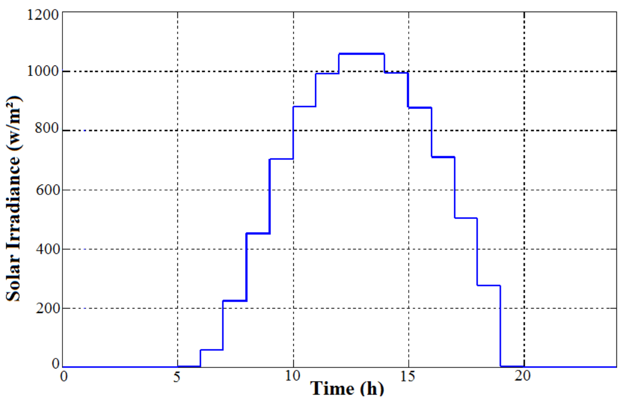

Fig.9. Solar Irradiance

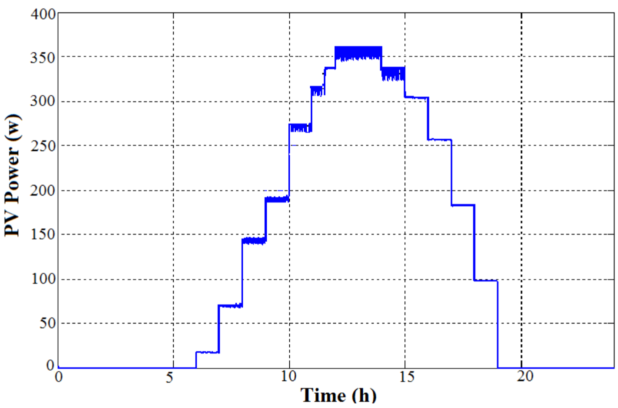

Fig. 10 . Output power of the PV panel

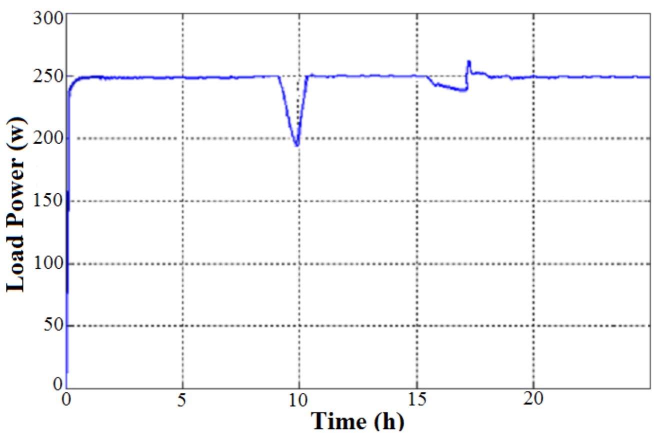

Fig. 11. Power required by the load

5.2. Irradiance and Load Rapidly Changing

In a second simulation series, we have exposed the system to a variable irradiance of the same as “Fig. 9” (The PV source can provide a maximum power of 360 W) and a fluctuating load with variable power (50W to 250W) “Fig.16”. The analysis of the simulation results shows that:

- The power extracted from the PV source is variable according to the incident irradiance power as in the previous case.

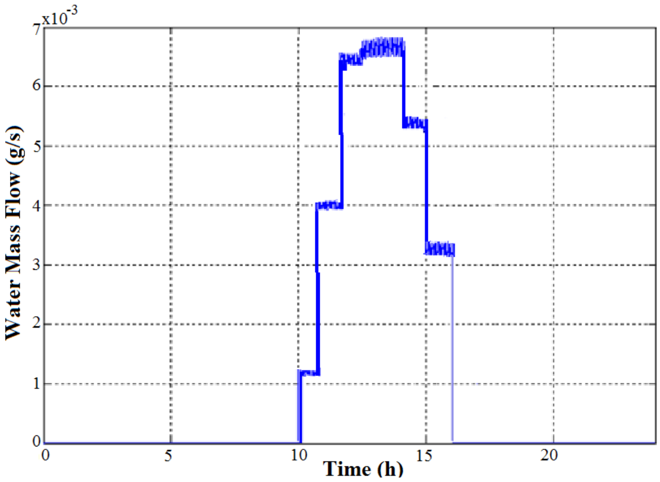

Fig.12. Mass flow of water injected into the PEM electrolysis

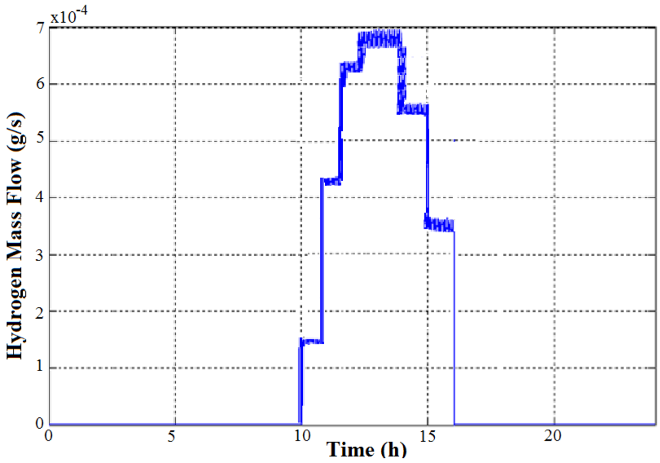

Fig.13. Mass flow of hydrogen produced

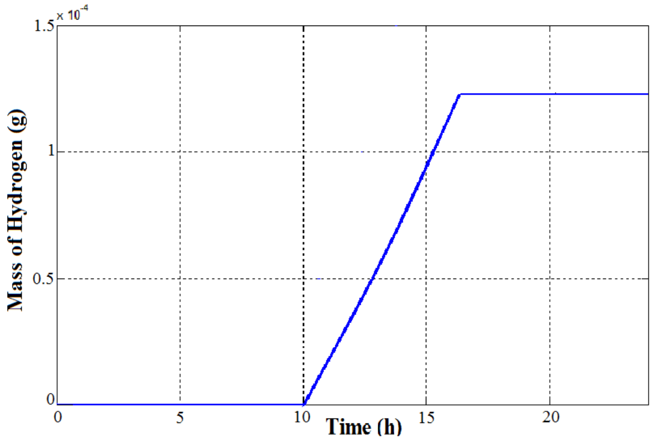

Fig.14. Mass of hydrogen stored in the tank

- The scenarios of the PV source are now dictated both by the variation of the irradiance and the variations of the load.
- The distribution of the power in the system is done according to the management strategy developed in this work.

The power of the load is covered. Between 9h to 19h, that is the PV sources that supports the supply of the RL load and causes excess energy that is transferred to the electrolysis. This results a clear hydrogen production and necessary water flow for the electrolysis "Fig.17" and "Fig.18".

In the case where the PV source is unable to satisfy the power demanded by the load (outside the range [9, 19 h]) "Fig.10" and "Fig.16". The electrical grid takes over to compensate for this energy deficit "Fig.19".

From the various analyzes and interpretations above, it is important to emphasize that:

- In all cases of simulations, power was transferred to the load using the PI control technique which controlled the output voltage of the Boost to the desired value (172V) to supply the inverter "Fig.20" and "Fig.21". This power is consumed by the load at a constant voltage of 110V "Fig.22". In addition, hydrogen production is optimized by the water flow control technique.

- The management strategy applied to the hybrid system takes into account the excess of PV power if it occurs, the load power requirement, the variations of weather and those of the load to decide how to connect the system to the source (PV or electrical grid). The power grid only intervenes to compensate the deficit of power. However, the electrical grid is a key element in the system. Indeed, for each perturbation that may affect the system, the management strategy must connect the system to the electrical grid to determine the state of the powers and to steer the system to the appropriate source.

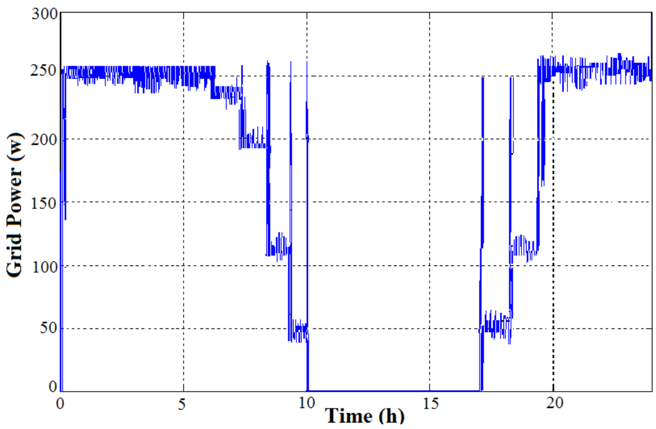

Fig.15. Grid Power transferred to the load

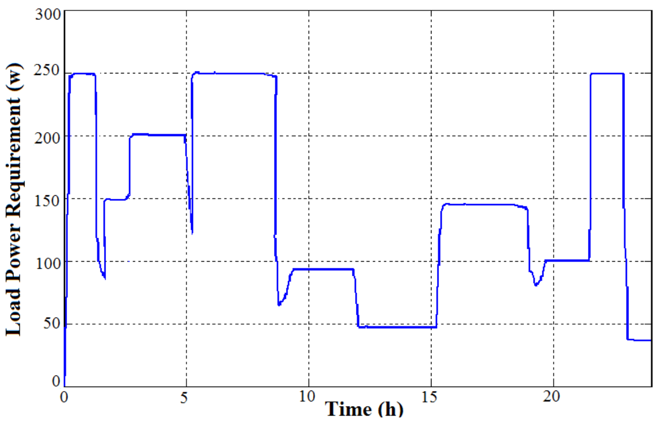

Fig.16. Power required by the load

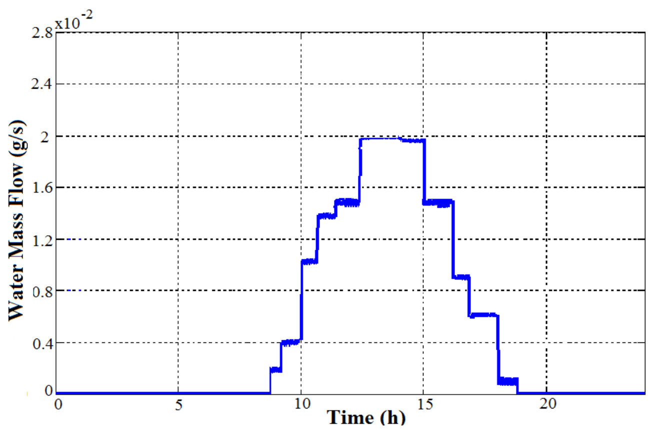

Fig.17. Mass flow of water injected into the PEM electrolysis

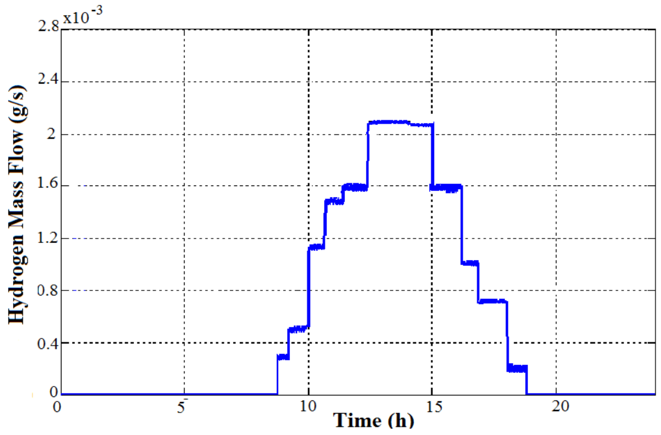

Fig.18. Mass flow of hydrogen produced

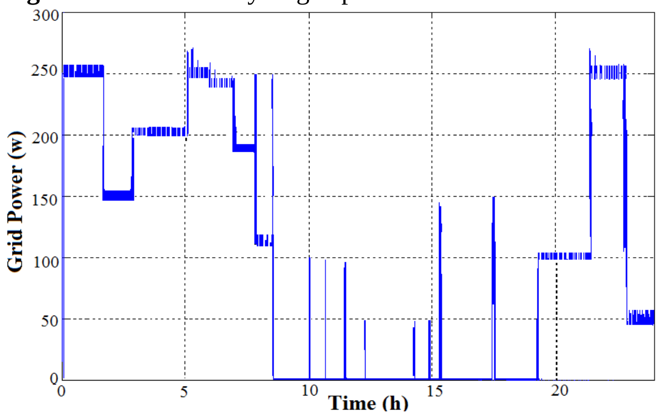

Fig.19. Grid power transferred to the load

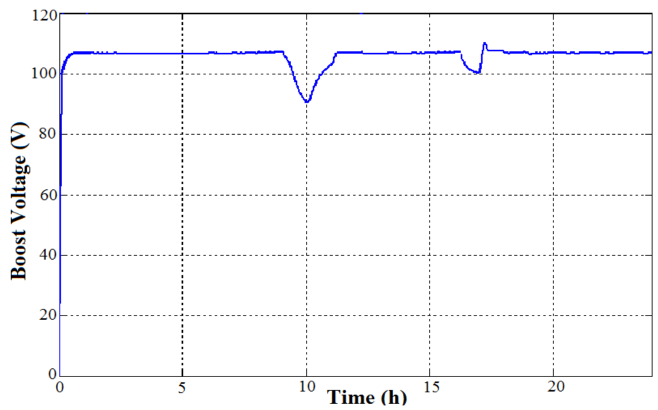

Fig. 20. Inverter output voltage

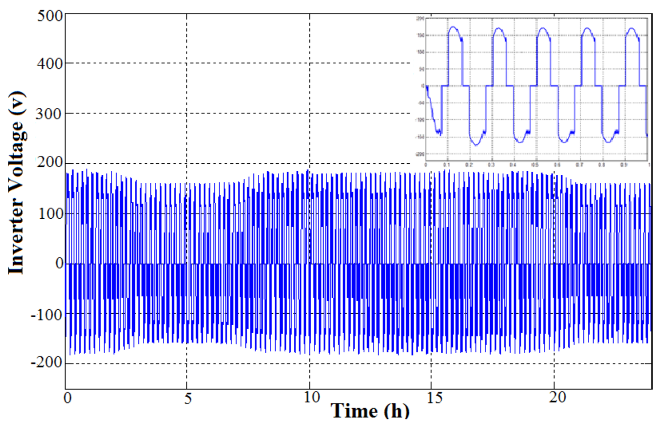

Fig.21. Voltage served at the terminal of the boost

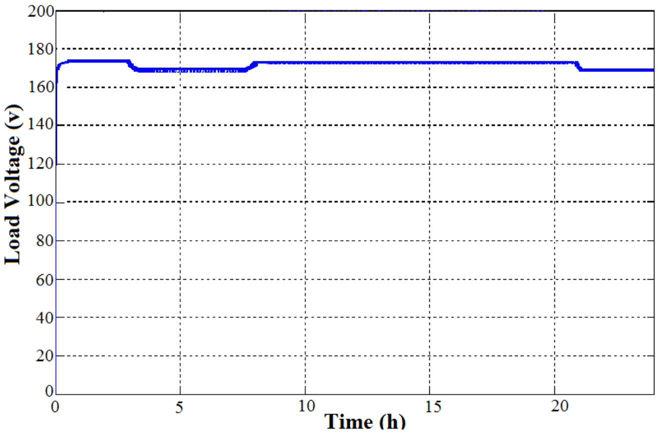

Fig.22. Output Load Voltage

6. Conclusion

In this work, we presented the modeling of the different components of the PV/ Grid/ electrolysis/ load (PEM electrolysis, PV, DC/DC converter, DC/AC inverter, electrical grid). We have provided each block of the system with a specific and local control algorithm. The implementation of these algorithms in architecture around the designed system allowed us to increase the overall efficiency and reliability of the system in terms of optimization, management and maximum exploitation of the available PV power. In addition, controlling the voltage at a constant value, in order to supply an inverter with the same characteristics of an electrical grid, seemed to us an unavoidable question that deserved our full attention. The modeling and simulation of the complete system in the Matlab/Simulink environment enabled us to identify the following important results:

- The maximum extraction of the power delivered by a photovoltaic generator by the integration of a DC/DC converter, equipped with a numerical algorithm control (InC MPPT) with variable step iteration and acceleration mechanism. We gained on this subject on the rapidity of trapping the maximum operating point and on the stability of the system.
- Optimization of the electrolytic process by controlling the flow of water injected in the electrolysis taking into account the power transferred by the PV system for optimal hydrogen production.

- The regulation of the supply voltage of the inverter to its constant value by using a control loop based on proportional integral PI.
- The development of an efficiency power management system based on the operating modes of a hybrid system that includes the production of energy from PV as a primary source, the power grid as an emergency source and the production of clean hydrogen as an alternative to the storage of energy by batteries whose risk of pollution is not excluded. This distribution technique supports the decision to connect the system to the appropriate source.

In future work, we are particularly interested in:

- The study of the economic aspect of the proposed hybrid system (PV/ load/ electrolysis/ grid).
- The life-cycle analysis of this system with regard to its impact on the environment
- The implementation of all these algorithms developed in this article in an embedded system (in DSpace card).

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