Performances system management: fuel cell / photovoltaic

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Abstract - *The fuel cell is intended to supply with the electrical energy from the primary resources. It has many advantages, notably when it is associated with a PV system. Indeed, the autonomous hybrid system presents the advantage of the important power supplied with reduced number of converters. The objective of this work presents a general study of the fuel cell system. The most components of this system are: the converter DC-DC booster –Converter DC-AC PWM– transformer and the isolated load. The different elements of the Fuel cell system are dimensioned to conceive a general model simulated with Matlab / Simulink. The obtained results show the validity and the efficiency of the model presented.*

Résumé – *La pile à combustible est destinée à la fourniture de l'énergie électrique, à partir des ressources primaires. Il y a de nombreux avantages, notamment lorsqu'elle est associée à un système photovoltaïque. En effet, le système hybride autonome présente l'avantage de fournir une importante puissance avec une réduction du nombre de convertisseurs. L'objectif de ce travail est de présenter une étude générale du système de piles à combustible. Les principales composantes de ce système sont les suivantes: le convertisseur DC-DC booster -Convertisseur DC-AC PWM- transformateur et la charge isolée. Les différents éléments du système de piles à combustible sont dimensionnées et simulées avec Matlab / Simulink, pour l'élaboration d'un modèle général. Les résultats obtenus montrent la validité et l'efficacité du modèle présenté.*

Keywords: Fuel cell – Ressources primaires – Système hybride – Modélisation.

1. INTRODUCTION

The fuel cells are largely recognized like as of the most promising technologies for electricity production future needs. The fuel cells convert, directly, the fuel and the oxidant to electric power by the electrochemical process, they can reach the exploitation efficiency. It is approaching a 60%, close to the double of conventional internal output combustion engines.

It produces very weak levels of pollutants broadcasts (NO, SO and CO). There are several types of fuel cells, which distinguish by the electrolytes material used, as shows in the **table 1**.

Protons exchanges Membrane (PEM) is the most important fuel cell used for the vehicular applications because of their low functioning temperature , the higher power density, specific power, the longevity, the efficiency, the durability relatively raised, and the capability of auto adaptation with the power exchanges.

Table 1: Fuel cell types and operating temperatures

Fuel Cell Type	Operating temperature
Proton Exchange Membrane (PEM)	80 °C
Alkaline Fuel Cell	100 °C
Phosphoric Acid Fuel Cell	200 °C
Molten Carbonate Fuel Cell	650 °C
Solid Oxide Fuel Cell (SOFC)	800 °C – 1000 °C

Fuel cells PEM can be easily started in the common temperature and can work in relatively low temperatures, below 100 °C [7].

## 2. FUEL CELLS TECHNOLOGY EXAMINATION AND THE OBTAINING OF ELECTRIC PARAMETERS

2.1 Fuel cell basic concepts

Fuel cells are electrochemical devices able to convert the chemical energy (during the use of the hydrogen as a fuel), of the fuel, to the electrical energy without any intermediate process, this operation is accompanied with generation of heat and water (second products). The mechanism of the basic energy conversion can be explained as follows:

Hydrogen pass has the electrolyte have foible the quoted electrode anode which is porous The first half chemical reaction can be found in the electrode-electrolyte side anode. It can be explained by the equation (1). The molecules of hydrogen are separated in protons and electrons. Because of the electrolyte is a insulating electric material, the proton's pass, only, by her. Then, electrons circulate through an external circuit for electricity product.

The second half of the chemical reaction takes place in the electrode-electrolyte side cathode. It causes the reaction of the oxygen with H+ and e- with generation of heat and water (equation (2)). Usually, a catalyst of platinum is used in fuel cells with low temperature to facilitate the chemical reactions.

There are other technologies of fuel cells with the various chemical reactions. Generally, they are classified according to their electrolyte and the temperature of reaction [8, 9].

$$2H_2 \quad \rightarrow \quad 4H^+ + 4e^- \tag{1}$$

$$O_2 + 4e^- + 4H^+ \quad \rightarrow \quad 2H_2O \tag{2}$$
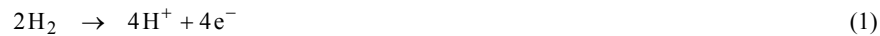
2.2 Electric characteristics of fuel cell

Comportment static Cell Fuel

Every electric generator has its own intrinsic characteristics which are not very different to the fuel cell. Essentially, there are three different regions which govern the voltage of the static fuel cells behaviour. That means when it is subjected to a periodic variation current, according to the speed of this variation, and hysteresis effect can be occur [10].

The fuel cell is considered as a voltage generator. This generator is not parfait. Hens, its characteristic current/voltage is not linear**.**

From a purely electric point of view, this fuel cell is considered as a source of tension. This source is however imperfect. Indeed, its characteristic current / voltage are not linear.

Fuel cell and the load, to obtain from the three-phase alternative electrical energy by assuring the transfer of the electrochemical energy load.

By the fact that already respectable power levels are obtained in tensions rather low, and these last ones fluctuate current according to the load, a voltage adaptation becomes necessary to inject of the load power.

Always for reasons of maximal efficiency, and to reach this tension uses a transformer, which will ask to put on the pile with potential of anode and cathode not imposed with regard to the ground. To choose the inverter, it is necessary to define criteria of selections such as harmonious and losses.

In this study determining, us the looks of current, voltage at the exit of the converter DC / DC, DC / AC and at the end to the load borders.

An electric source of energy based on a fuel cell, the converter DC / DC, the converter DC / AC and finally of one. In this article, determining us the looks of current, voltage, at the exit of the converter DC / DC, DC / AC and at the end to the borders of the load.

An electric source of energy based on a fuel cell consists of the fuel cell, the converter DC / DC, the converter DC / AC and finally of one smoothing filter.
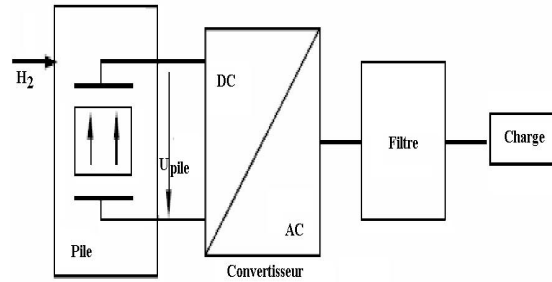

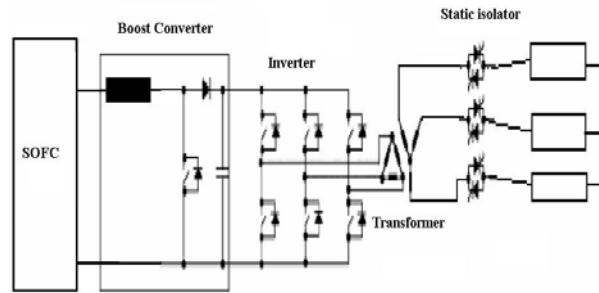
Fig. 1: Plan of the used model

Fig. 2: Electrical system diagram of the fuel cell

3. SIMULATION METHOD

3.1 Converter to booster

To use the system fuel cell in a conversion system of electrical energy, it is necessary to be able to connect the fuel cell to a continuous bar of fixed tension. In that case, it is necessary to raise the voltage of the fuel cell because it is very often lower than the continuous bar voltage (in full load) or here $V_{bar} = 48$ V [4].
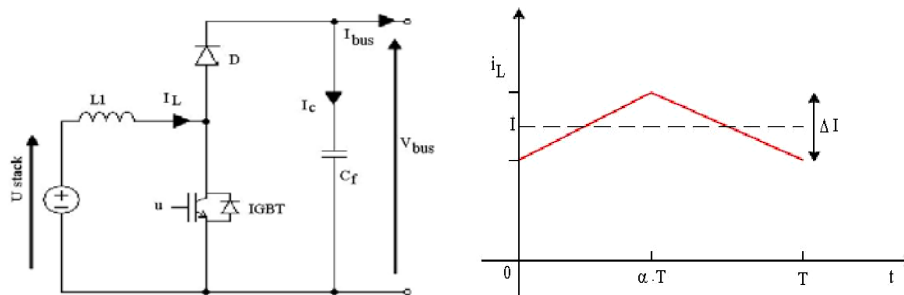
Fig. 4: Shape of the current

If we consider the conduction continuous mode which is preferable, a priori, with a fuel cell, we have two functioning sequences. The first one corresponds chargeable to the inductance L, the other one corresponds to its discharge. We got, from the current shape the voltages characteristic relation of the, and the expression of the current undulation:

$$\Delta I = \frac{2 \Pi \alpha}{L \omega} . V_1$$

The classic equations which govern the functioning of the converter:

$$V_1 = V_0 - R_0 i_L = r_L i_L + L\frac{di_L}{dt} + (1-\alpha)V_2 + \left[\varepsilon r_k + (1-\varepsilon)r_D\right]i_L$$

$$+ \varepsilon V_k + (1-\varepsilon)V_D C . \frac{dv_c}{dt} + \frac{V_2}{R} = (1-\varepsilon)i_L C . \frac{dv_c}{dt} + \frac{V_2}{R} = (1-\varepsilon)i_L$$

$$V_2 = V_C + r_C . i_c$$

Where r_K and r_D are the resistances in the state crossing switches, and V_D are V_K the sudden drops in blood pressure in the state crossing switches, and are respectively the internal resistance of the inductance and that of the condenser, e represent the state of conduction of the switch k (1 in the crossing(spending) state, 0 in the blocked state).

In permanent regime, we obtain in a approached way:

$$V_1 = \frac{V_1 - \alpha.v_K - (1-\alpha).v_D}{(1-\alpha) + \dfrac{r_L + \alpha.r_L + (1-\alpha).r_D}{(1-\alpha).R}} = (1-\alpha).R.I$$

Where α represent the cyclic report associated with the conduction of the switch k .
The current means expressed by:

$$I = \frac{V_0 - \alpha.v_K - (1-\alpha).v_D}{R_0 + r_L + \alpha.r_K + (1-\alpha).r_D + (1-\alpha)^2.R}$$

The average tension of exit of the pile is given by:

$$V_1 = \frac{V_0.\left[r_L + \alpha.r_K + (1-\alpha).r_D + (1-\alpha)^2.R\right] + R_0.\left[\alpha.v_K - (1-\alpha).v_D\right]}{R_0 + r_L + \alpha.r_K + (1-\alpha).r_D + (1-\alpha)^2.R}$$

The average tension of exit east given by:

$$V_2 = \frac{(1-\alpha).R.\left[V_0 - \alpha.v_K - (1-\alpha).v_D\right]}{R_0 + r_0 + \alpha.r_K + (1-\alpha).v_D + (1-\alpha)^2.R}$$

The relationship between the output voltage and the tension delivered by the pile is expressed by:

$$\frac{V_2}{V_1} = \frac{(1-\alpha).R.\left[V_0 - \alpha.v_K + (1-\alpha).v_D\right]}{V_0.\left[r_L + \alpha.r_K + (1-\alpha).r_D + (1-\alpha)^2.R\right] + R_0.\left[\alpha.v_K - (1-\alpha).v_D\right]}$$

However, the voltages report remains close to its theoretical value as long as the tension of exit does not collapse. The previous equation defining the report of the tensions can be which considered as valid as long as the tension of exit did not reach its maximum:

$$\alpha = 1 - \sqrt{\frac{R_0 + r_L + r_K}{R}}$$

3.2 Model used

Structures of the converters dc/dc often met in the literature for the systems with fuel cells [1, 2]. The simplicity of most of these structures is justified by the search for the convenience of realization or the moderate cost. However, Certain more complex structures lead to more raised performances, Fig. 5 [5].
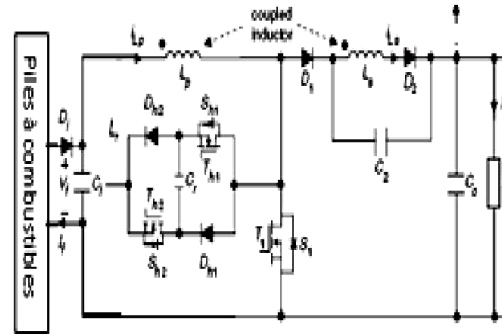
Fig. 5: Converter booster used

Systems SOFC are under development in the range of the applications of generation of power 5 kW. The same system could be used for the distributed electricity production. If more power is necessary, some of these systems could be placed in parallels, or the various systems can be distributed to answer the requirements of the power of the local loads [3].

A fuel cell of power 500 kW is used in this study for fed a local load. The fuel is reformed at first to obtain from some hydrogen which rich who is brought to the anode of the SOFC. The ambient air is drawn with a compressor and the pressure in approximately 300-400 kPa (3-4 atm).
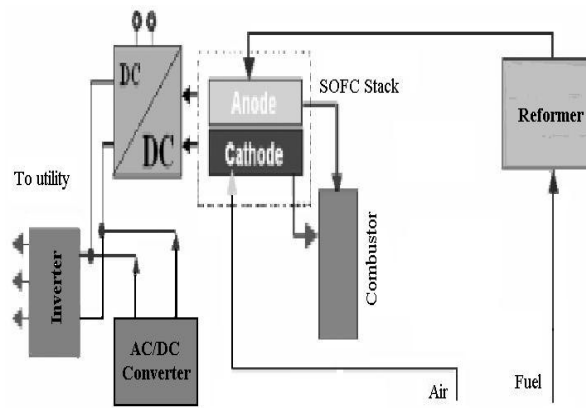
Fig. 6: System fuel cell SOFC

The compressed air is warmed by means of the escape. The cathode of escape of the SOFC and the unused party of the anode of fuel are burned in an incinerator to increase the temperature of exhaust gases in approximately 1000 °C.

The alternating current is converted at first to the help dc to be then organized with dc out of the fuel cell, thanks to the power of conditioning system.

3.3 Modelling simplified and command of the converter PWM

A feature common to the various types of source of production decentralized in electronic connection is the use of a three-phase converter with modulation of width of impulses to ensure of transfer of energy between the continuous bus and the load represent 8.

The study of this converter is interesting insofar as it is used in the majority of the new types of source of dispersed energy production connected to the network (wind mill, photovoltaic, fuel cell,…). But also like conditioner power (active filter, compensation of energy reactivates) [3].
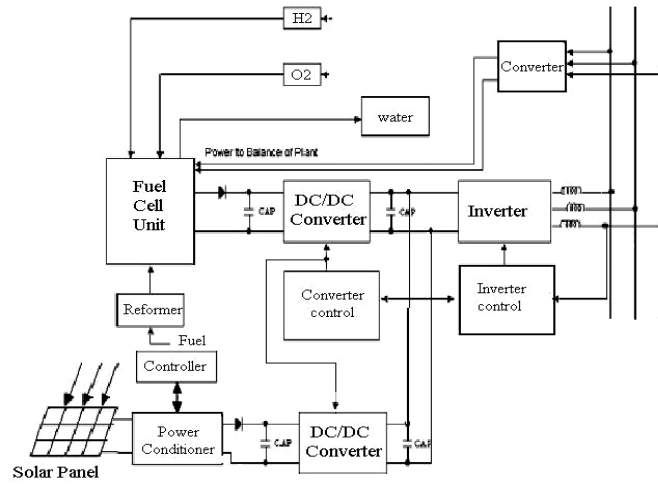
Fig. 7: Hybrid system Fuel Cell / Photovoltaic

The figure 8 represents an inverter step-up transformer; the circuit is formed by four branches.
The first one is the branch of the hoist, including a transistor and a mass diode. Other branches are formed by two couple transistor IGBT-diode in ant parallel which form the inverter.
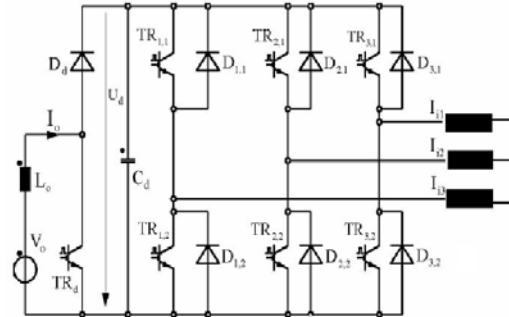

Fig. 8: Elevator plus inverter of voltage

The figure 9 represents the inverter of current with pulsation which has the property to be able to adapt the level of the continuous voltage compared to the level of the alternating voltage. It is made of three branches which include each one two switches, which must be able to block a negative voltage as well as positive. They consist of a diode in series with a transistor IGBT, Fig. 9.
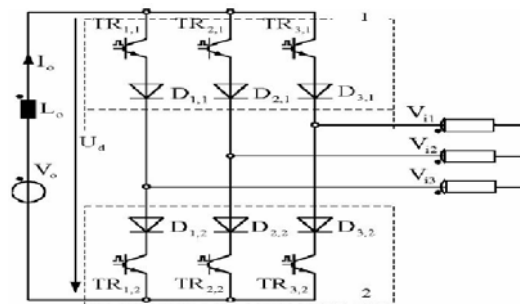

Fig. 9: Inverter of current

3.4 Simulation

We are interested in this work in the determination the parameters of the various constituted of our system of conversion of electrical energy (parameters of the converter DC, inverter, and transformer). We are interested in this work in the determination the parameters of the various constituted of our system of conversion of electrical energy (parameters of the converter DC, inverter, and transformer). The control and the regulation of the tension of the bus continue supplied with a fuel cell via a converter DC-DC, converter DC-AC, coupled with the networks. We simulated the operation of the complete system, for deferent loads RLC, RL, RC. We present in figure 9 the diagram of simulation carried out in Sim Power System in the Matlab software.
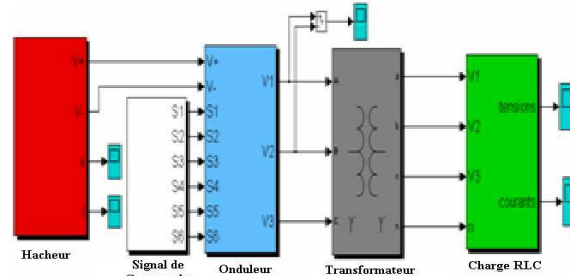

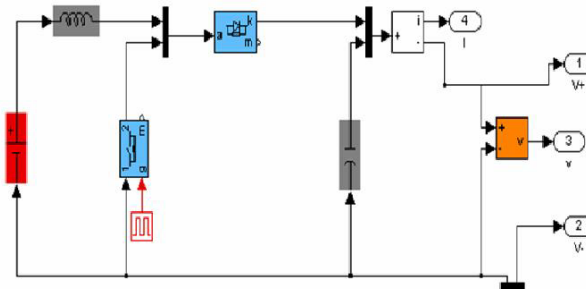Fig. 10: Diagram of simulation of a system of electric energy transformation

Fig. 11: Diagram of a parallel converter DC

4. SIMULATIONS RESULTS AND PARAMETERS

4.1 Parameters of simulation

a) <u>Parameters of the source</u>

For this system one has the following characteristics:

- Voltage of entry $V_1 = 12\,V$; - Current of entry $IT = 47\,A$

b) <u>Parameter of the chopper booster</u>

* Characteristic of the filter associated with the chopper

$L = 4e-5\,H$, $C = 400e-4\,F$; $V_2 = 48\,V$ (output voltage of the chopper)

* Characteristics of L'IGBT

$R_{on} = 0.01\,\Omega$, $R_s = 1000\,\Omega$, $C_s = \inf\ F$

* Characteristics for diode

$R_{on} = 0.01\,\Omega$; $L_{on} = 0\,H$; $V_f = 0.8\,V$; $I_c = 0\,A$; $R_s = 1000\,\Omega$; $C_s = \inf\ F$

* Characteristics of command

Amplitude: 10, Period $T = 0.001s$, $(1-\alpha) = 12/48$ avec $\alpha = 0.75$

c) <u>Parameter of the inverter</u>

$R_{on} = 0.01\,\Omega$, $R_s = 0.1\,\Omega$, $C_s = 0.01e-6\,F$

Command of inverter: $fr = 50$, $m = 50$ et $r = 0.85$

d) <u>Parameter of transformer</u>

$P_n = 10000\,VA$, $f = 50\,Hz$ _   For the first wind: V_1 (compose) $= 48\,V$, $R_1 = 0.2\,pu$,
$L_1 = 0.007\,pu$. For the second wind: $V_2 = 380\,V \times sqrt2$, $R_2 = 0.2\,pu$, $L_2 = 0.007\,pu$,
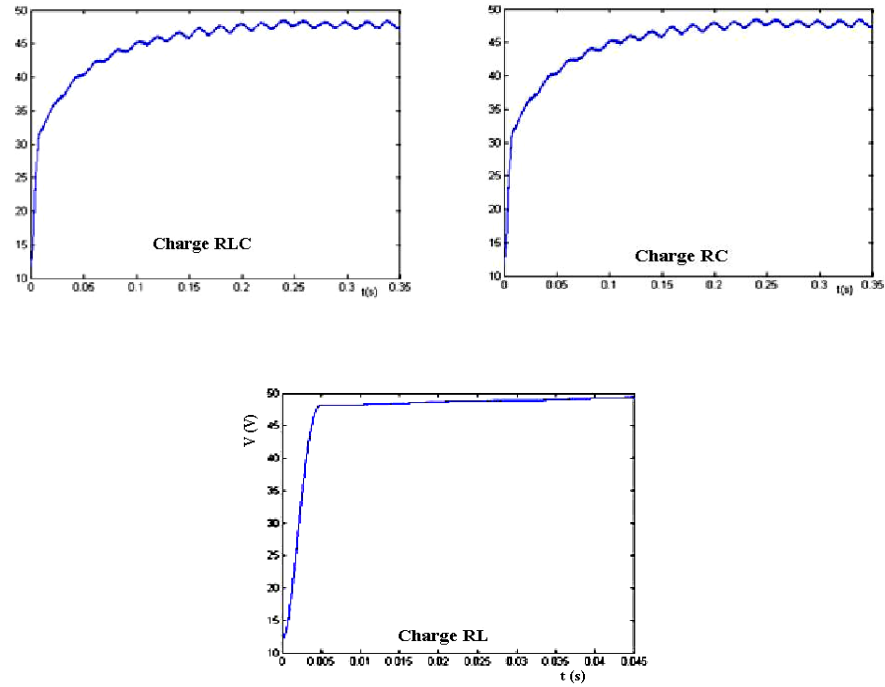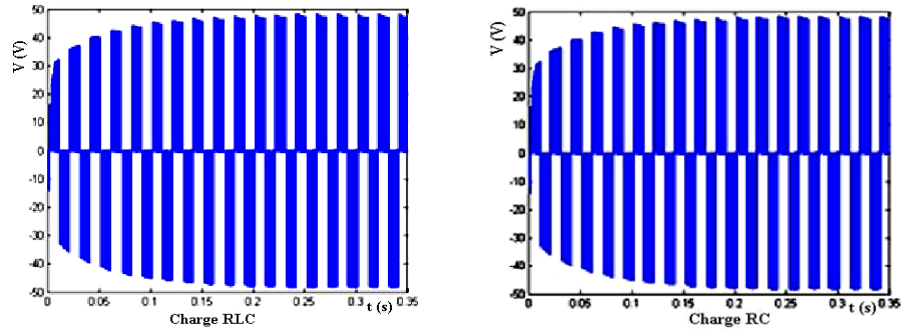$R_m = 100\,pu$, $L_m = 10\,pu$ _   Loads $V_n = 380\,V$, $f = 50\,Hz$.

4.2 Results of simulation

Fig. 12: Voltage at the exit of the converter DC

*** One notices that the shapes of the voltage curves at the exit of the chopper (Fig. 12) reach the value 48 V (Drunk continues), with undulations which are very visible for load RC attenuated for load RLC, almost non-existent for load RL.
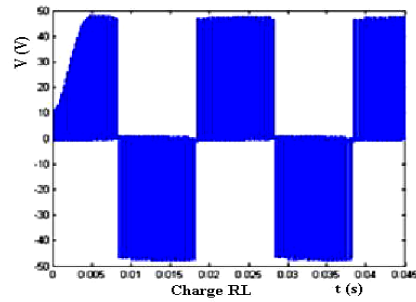
Fig. 13: voltage on the outlet side of the inverter

*** They point out that the paces of the curves of voltage at the exit of the inverter (Fig. 13) attain the value 48 V alternating, with an introduction of a filter for the load RL.
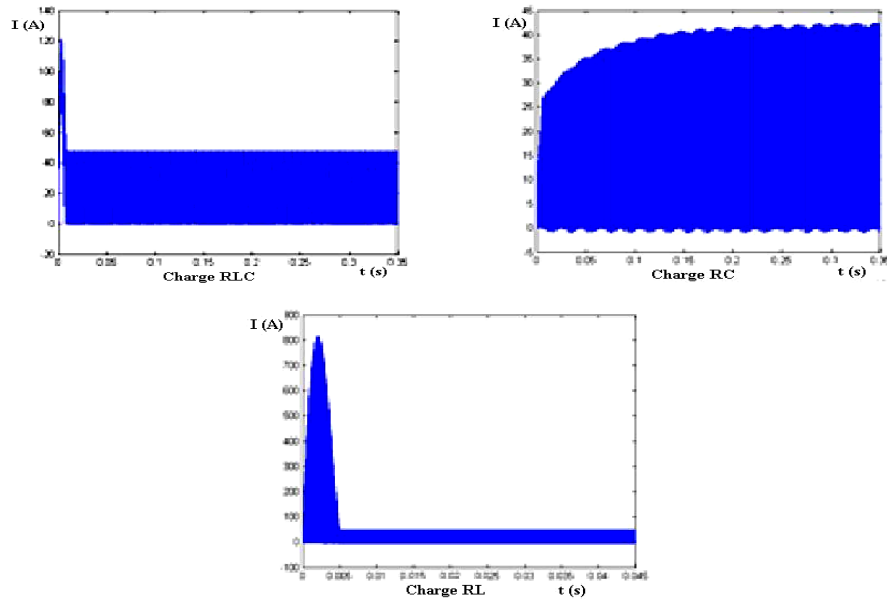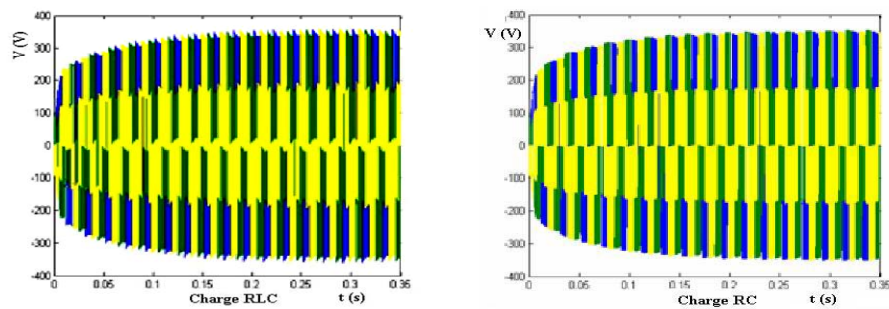

Fig. 14: Current output by the fuel cell

*** They point out that the current in transitional regime is very well brought up (Short circuit is not studied); the current debited by the pile in the three expenses is not the same (face 14).
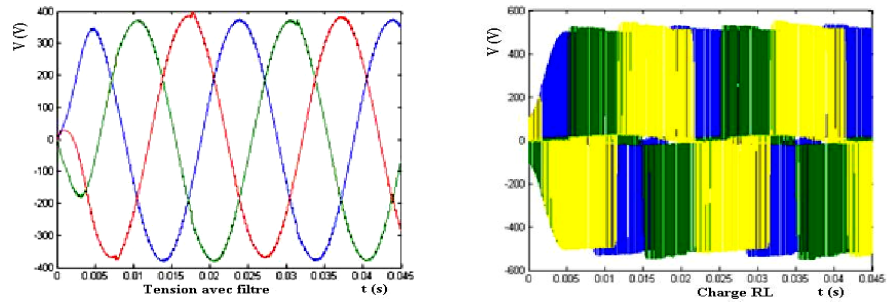
Fig. 15: Simple voltages at the load boundaries

   *** Simple voltage boundary RLC, RC has the same paces but the boundaries of the load RL have respectful paces. After introduction of a filter, they acquired the paces of figure 15.
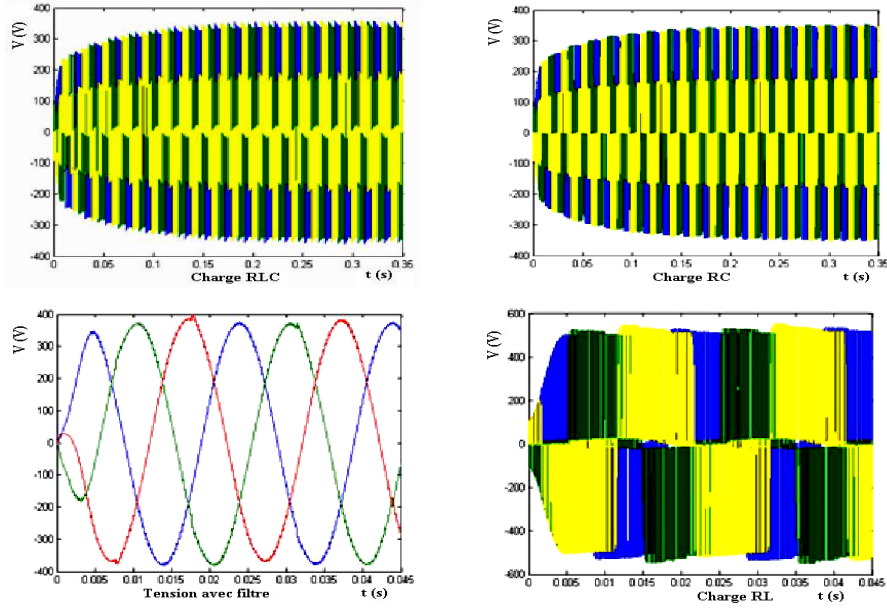

Fig. 16: Voltage made up at the load boundaries

   *** Voltages compounds for the three expenses have the same paces, and this very visible after introduction of a filter (Fig. 16).
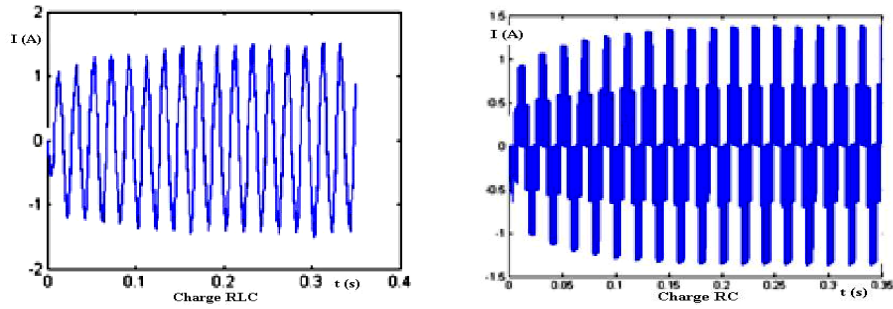

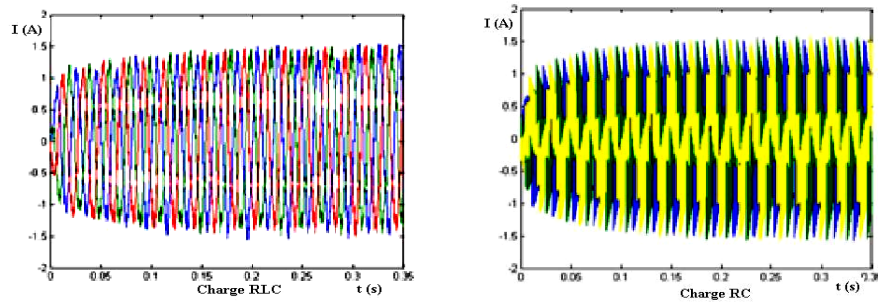Fig. 17: Simple currents circulating in the load

Fig. 18: Current composed in the load

4.3 Results and discussion

In general case, one can say that problem results in the time response of fuel cell systems with fuels applied as source of autonomous energy. The variation of the load has an influence directly on the functioning of the converter and the inverter, what requires in certain case of modifications in the parameters of these last load RL, RC.

If we examine of more taken looks of the curves of current produced by fuel cells, represent 14 one notice that in the case of the load RLC, RL he crosses by regime of coC circuit before of stabilized, whereas in the case of the load RC the variation is more monotonous it follows an ascending look until stabilized around a certain value 47 Has. The study was realized for deferential load constant who do not vary in the time, but if we want an application of fuel cells as autonomous source of energy, it needs to forces a variable load immediately and to see its influence on the source and also on the parameters of the converter, to inverter.

Indeed, one of the major problems of Fuel cells is the high time of answer in some instance auxiliaries (compressor, humidifier). This makes impossible the hacking of the current of Fuel cells beyond a certain frequency now its use in a domestic environment impose a minimal frequency of hacking of 10 kHz (non-audible frequency). It is thus indispensable to filter the frequencies towards Fuel cells.

5. GENERAL CONCLUSION

Our study allowed us to choose the characteristics of the source of supply which is the fuel cell, to size converters DC-DC and inductances associated with the static converters, the converters DC-AC and at the end to choose a transformer to obtain an alternative tension 380/220 V, for fed by loads RLC, RL and RC.

But all this work was realized for constant loads, it needs to make a study for a load which varies in the time and to see echo them on converters and source of supply. The sizing being realized, it is now necessary to control the system fuel cell so that it can supply the asked power. The command will thus have to allow a management of the system so that he supplies the energy safely. Furthermore, the command will have to regulate certain points of functioning of the system to optimize the functioning and not to be destructive simply.

REFERENCES

[1] J. Lachaise, '*Study of the Strategies and Systems Energetic to Fuel Cell (CAP) Intended for Traction*', Thesis of Doctorate of the Institute Polytechnic Toulouse, September, 2004.

[2] A. Lachichi, '*Modelling and Stability of a Regulator Hybrid of Current Application to the Converters for Fuel Cell*', Thesis of Doctorate of the University of French County, Electric , November, 2005.

[3] E.F. Mogos, '*Production Decentralized in the Distribution Networks Study Multi-Field of Modelling for the Control of the Sources*', Thesis of Doctorate of the School National Superior of Arts and Trades, Electric, July, 2005.

[4] A. Rufer and P. Barrade, '*Lesson of Electronics of Power*', EPF, Lausanne, 2000.

[5] C. Rivas, '*Evaluation of System of Modulation PWM for Matrix Converter 3x2*', EPF, Lausanne, 1999.

[6] K. Rajashekara, '*Propulsion System Strategies for Fuel Cell Vehicles*', Presented at the SAE 2000 World Cong., Detroit, MI, Mar. 6–9, 2000, Paper 2000-01-0369.

[7] Article, IEEE Transactions on Industry's Applications, Vol. 41, N°3, May/June 2005.

[8] K. Kordesch and R. F. Sproull, '*Fuel Cells and Their Applications*', Germany-Weinheim: VCH Verlagsgesellschaft, 1996.

[9] J.H. Hirschenhofer, D.B. Stauffer, R.R. Engleman *and al.*, Fuel Cell Handbook, USDOE, 2002.

[10] A.R. Balkin, '*Modelling a 500 W Polymer Electrolyte Membrane Fuel Cell*', Faculty of Engineering, UTS University of Technology, Sydney, Australia, 2002.

[11] Article, IEEE Transaction on Industrial Electronics, Vol. 53, N°5, October 2006.