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Study of a fuel cell generator

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Abstract-This paper presents the design and simulation of the electrical operation of a fuel cell connected to a boost converter adapted by a control ensuring the stabilization of the output voltage which can be injected into an urban electric network.

In this study we focus on setting the boost and the order.

Keywords—PEMFC, fuel cell (FC), boost converter, Forward, PWM

I- INTRODUCTION

Currently, energy demand has continued to expand, and economic growth has become synonymous with an ever increasing power consumption.
In the energy context, the use of hydrogen as an energy carrier currently appears as a promising solution for the future.
The use of hydrogen as an energy carrier necessarily involves the use and development of the FC. FC, based on the reverse reaction of the electrolysis, not only enable the generation of electricity at very high yields, but also the heat generation. In addition, the FC operating with hydrogen and oxygen, does not give rise to emissions. Due to outstanding performance, the FC is being considered as the future generator for many applications. Its high theoretical efficiency combined with the possibility of exploitation of the heat generated, open up many interesting prospects. It should also be noted that the FC require certain ancillary to ensure proper operation. In most cases, these auxiliary such electrical interface, are also the subject of research and improvements. However, the most compelling aspect of a FC remains a high economic cost. In what follows we will proceed to a comparative study between two installed electricity generation stack base fuel, has a base of a Forward chopper and the other based on a boost chopper.

II. FUEL CELL GENERATOR:

The equation summarizes the principle of operation of the FC is:

$\frac{1}{2}O_2 + H_2 \rightarrow H_2O$ + electricity + heat **(1)**

Where the chemical energy (by the flow rates of hydrogen and oxygen) is converted into electrical energy (electron flow between anode and cathode) while producing water and heat.

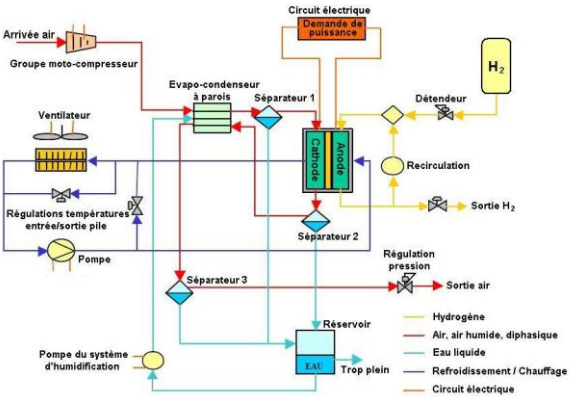


Figure II.1: Architecture of the fuel cell system [1]

A fuel cell is able to provide a low voltage between these terminals. To obtain a corresponding output voltage at the electrical load placed across the FC, it is necessary to stack multiple cells in series to form a stack.

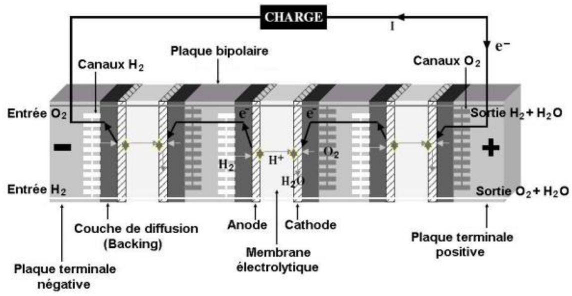


Figure II.2: A cell stack [2]

There are a large number of quasi-static models to describe the chemical reaction Present in a fuel cell stack. The equations to calculate the evolution of the voltage are taken from the work presented by Amphlett [3] .This model is described using the combination of basic laws and Empirical models. In the development of basic models, the field of transport are taken into account via the Maxwell equations. Potential of thermodynamic equilibrium are defined using the Nernst equation. The activation overvoltage are calculated by equations Tafel. The internal resistance is determined by the equations Nernst- Planck [3]. Using Ohm's law, we can express the cell voltage by:

Ecell= Erev+ηact – Rm.j **(2)**

Erev is the so-called reversible voltage expressed with :

$E_{rev}=\alpha_1+\alpha_2.(T_{pac}-298.15)+\alpha_3.T_{pac}.(0.5\ \mathrm{Ln}\ P_{O_2}+\mathrm{Ln}\ P_{H_2})$ **(3)**

η*act* is the activation overvoltage expressed by:

$\boldsymbol{\eta}_{act}=\beta_1+\beta_2.T_{pac}+\beta_3\ .T_{pac}\ \mathrm{Ln}\ (\mathrm{j}\ 5.10^{-3})+\beta_4.T_{pac}\ \mathrm{Ln}\ C_{O_2}$ **(4)**

With CO2 concentration (mol / m3) of oxygen in the physical area of the reaction determined by Henry's law, given by:

CO2= $\frac{P_{O2}}{5.08\ .10^6\ exp^{\frac{-498}{Tpac}}}$ **(5)**

Settings:
_ Tpac: Local temperature at the active layers of the electrodes (K).
_ PO2: Partial pressure of oxygen in the active layers (electrodes) (Pa).
_ PH2: hydrogen partial pressure in the active layers (electrodes) (Pa).
_ J: current density (A / m2).
_ Ai and bi: dimensionless constants snuff in the work of [Amphlett].
_ Rm: Membrane resistance (Ω.m2). The numerical values of the parameters are:
- 0.9514 (Cte) *Rm* 3.622.10-6 Ω.m2

Paramètres	Valeur	Paramètres	Valeur
α_1	1.229 (Cte)	β_2	$3.12.10^{-3}$ (Cte)
α_2	$-8.5.10^{-4}$ (Cte)	β_3	$-1.87.10^{-4}$ (Cte)
α_3	$4.3085.10^{-5}$ (Cte)	β_4	$7.4.10^{-5}$ (Cte)
β_1	-0.9514 (Cte)	R_m	$3.622.10^{-6}\ \Omega.m^2$

Table II-1: Parameters of the voltage law [3]

In our study we will use the fuel cell proton exchange membrane (PEMFC) since this is the type of fuel cell enjoying the most significant research and development, this is due to the fact that it has several advantages over other batteries as their own characteristics include operating temperatures and low pressures and a specific polymer electrolyte membrane ranges.

III- system electricity production based on a fuel cell (PEMFC).

1- The characteristics of the cell used:
- The nominal parameters of the fuel cell:
Stack power:
-Nominal =5998.5 W
-Maximal = 8325 W
- The resistance of the fuel cell =0.07833 ohms
Nerst the voltage of a single cell [En]=1.1288 V
- Nominal Use:
-Hydrogène[H_2] =99.56%
-Oxygène [O_2]=59.3%
- Nominal consumption:
-fuel =60.38 sIpm
-Air = 143.7 sIpm
Exchange current [i0] = 0.29197 A
Exchange coefficient: [alpha]=0.60645 A
- The variation of signal parameters of fuel cells:
-composition fuel [x_H_2] = 99.95%
-Composition Of oxygen: [y_o_2] = 21%-fuel flow rate to the nominal use of hydrogen:
-nominale = 50.06 lpm

-Highest = 84.5 Ipm
Flow rate of air to the nominal use of oxygen:
-nominale = 300 lpm
-Highest = 506.4 lpm
-temperature of the system: [T] = 338 kelvin
-pressure fuel supply [Pfuel] = 1.5 bar
air supply -pressure [Pair] = 1 bar

The following figure shows the characteristic (VI) and (PI) of the cell in question

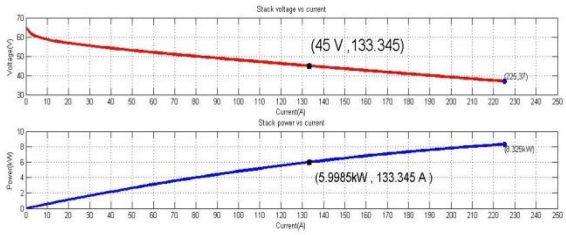


Figure II.3: The characteristics (V, I) and (P, I) of a PEMFC cell

The stack considered in this study is formed by 65 cells, so it provides 6 KW power with voltage 45 V and a current of 133 A in charge.
And in the following the assembly of the fuel cell facility used

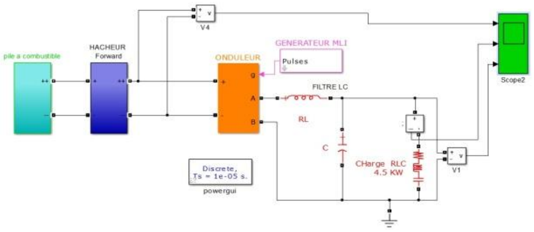


Figure II.4: a fuel cell system

1 : the DC/DC converter :

1.1: Types DC/DC converter used in grid-connected systems:

1.1.1: DC/DC converter **parallel :**

DC/DC converter **parallel** or the boost converter, is a switching power supply that converts a DC voltage into another DC voltage of higher value. The operation of a boost converter can be divided into two distinct phases according to the state of the switch S (see FIG II.5):

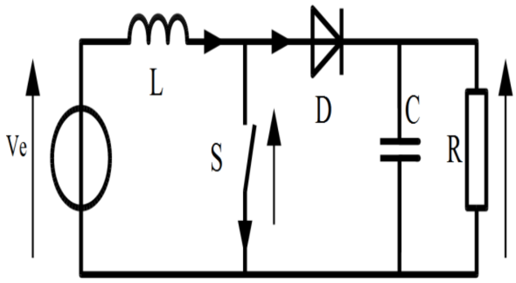


Figure II.5: Diagram basis of a boost converter. [4]

One phase energy storage: when the switch is closed if (state), this leads to the increase of current in the inductor so storing a quantity of energy in the form of magnetic energy. The diode D is blocked and the load is then disconnected from the power supply.

When the switch is opened, the inductance is then in series with the generator and its emf is added to that of the generator (booster effect). The current through the inductance is then passed through the diode D, capacitor C and the load R. This results in a transfer of the energy accumulated in the inductance to the capacity.

benefits:
Few components.
- Only one magnetic component.
- Economic Architecture for low power (<50W).

disadvantages:
- Assembly becomes cumbersome in great power, and the size of the inductance becomes large and the constraints on the switch multiply.

1.1.2 : Flyback converter :

The flyback type power supply is based on the principle of inductive storage converter (see figure II.6): The switch (T_p) αT is closed during the duration of the switching period T. When the primary source provides the energy to the L_1 inductance (current rise), the diode D is blocked (V_D <0), the load current is supplied by the discharge of the capacitor C. When the blocking (T_p), diode D provides continuity of the current in the inductor L2. Was then L2 discharge in RL and C.

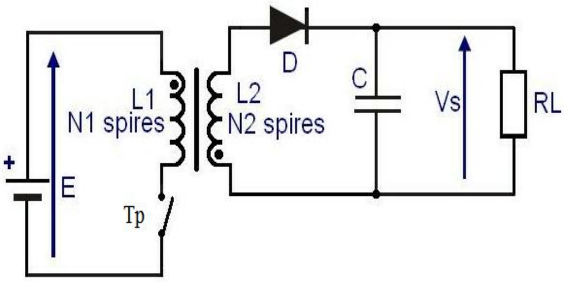


Figure II.6: basic diagram of the flyback converter. [4]

benefits:

- Few components.
- Only one wound component.
- Economic Architecture for low power (<150W).

disadvantages:

- Energy storing transformer.
- The energy is stored in the inductor coupled and the output capacitor, they become cumbersome for powers above 200 W, and flyback power becomes less interesting.
- Risk of over-voltage during load operation: the energy stored in the magnetization phase is then transmitted to the capacitor during the demagnetization phase. This energy is then stored by the capacitor sees tension rising, and there is then a risk of destruction.

1.1.3: ush-pull converter :

The push-pull structure is built around a dual primary transformer and two switches three segment types (t_AB) as shown in Figure II.7.

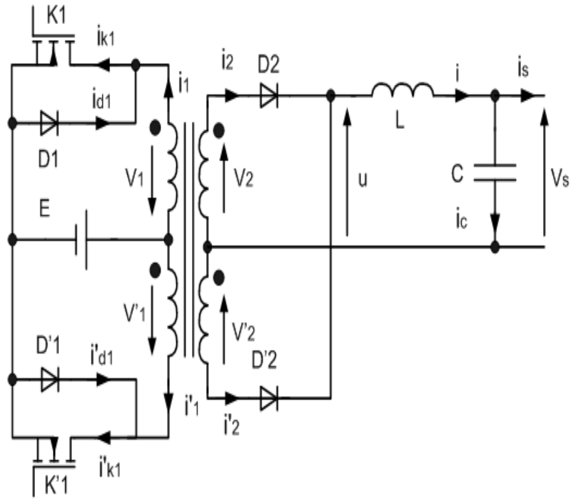


Figure II.7 basic diagram of the push-pull converter. [4]

The switches are always controlled fixed frequency and variable conduction time. There are several configurations in the structure of the push-pull. The implementation of the switches is more difficult in these structures.

benefits:
- Assembly used for high power.
- Load operation and load.

disadvantages:
- Complex Transformer.
- Implementation of the switches is very delicate.
- Mounting complex to achieve.
- Presence of two magnetic components.

1.1.4 : Forward converter :

- The Forwardtype power supply is a converter, this diet can fit a voltage source E (input) to an assembly comprising a power source. However, an output filter consisting of an inductor L and a capacitor C provides the terminals of the load a DC voltage Vs equal to the average output voltage.
-
- The Forward is a switching power supply with galvanic isolation for powers from hundreds of watts to several kilowatts. The need to generate a voltage purely

alternating voltage causes the presence of additional components shown in Figure II.8 which are:

- The two diodes D_3 and D_4 that allow the demagnetization of the transformer, as a result of the conduction of T_1 *and* T_2 .
- the diode D_{TR}, whose function is to isolate the output stage, consisting of the freewheeling diode and the filter, when the terminals of the transformer appears inevitable negative voltage corresponding to the demagnetization bay D_3 *and* D_4

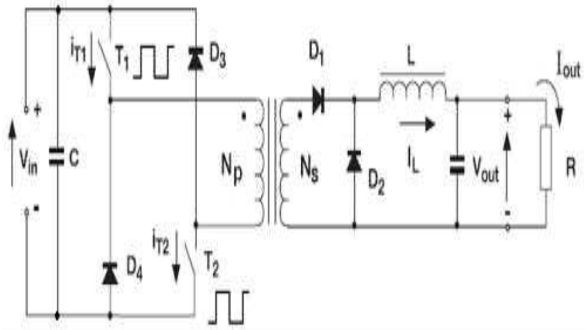


Figure II.8: Basic Diagram Forward converter asymmetrical half-bridge. [5]

First phase of operation:

To pair related phenomena, first the operation of the transformer, on the other hand the transfer of energy, it is interesting to think about the following system of equations:

➔ $n_p.i_p - n_s.i_s = R\emptyset$ **(6)**

Φ is the common flow in the core and the reluctance R of the same core, the linear magnetic behavior is assumed (no saturation).

L_p et L_s are the inductances of each winding:

$$\frac{1}{R} = \frac{L_p}{n_p^2} = \frac{L_s}{n_s^2} \qquad \mathbf{(7)}$$

During closing of T_1 and T_2 (figure II.6), $V_{in} = V_p$ (V_p : voltage terminal of the primary).

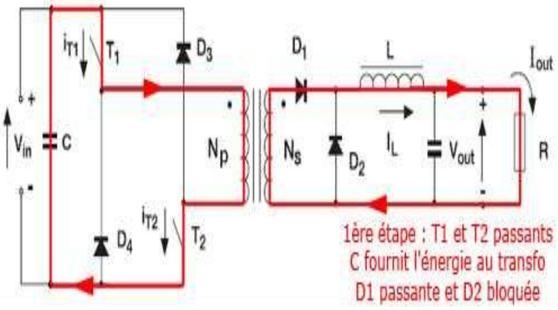


Figure II.9: First stage of the Forward converter's works. [5]

The capacitor C is connected to the primary during the time T_1 and T_2 are closed. Therefore generates a pulse at the primary, which is found in the secondary. Given the direction of travel in the transformer, diode D_1 is open and D_2 is blocked because of the reverse voltage across it. The energy of this pulse will then directly to the load through diode D_1 , L and the filter

$$V_s = \frac{n_2}{n_1}.V_{in} = m.V_{in}$$

$$V_{D2} = -m.V_{in} \qquad \mathbf{(8)}$$

$$V_{D3} = V_{D4} = -V_{in}$$

V_s="voltage terminal of the secondary"

D_2 ,D_3 et and D_4 are blocked. The energy transmitted directly to the capacitor through the D_1 diode. Meanwhile there magnetization of the transformer and thus storage of electromagnetic energy through the primary. During this phase, one obtains: $i_S=i_L$.

The previous system equation becomes:

$$n_p.i_p - n_s.i_L = R\emptyset$$

$$V_p = n_p * \frac{d\emptyset}{dt} = V_{in} \qquad \mathbf{(9)}$$

Which are deducted:

$\emptyset = \frac{V_{in}}{n_p}t$: in the event that the demagnetization is complete

$$i_p = \frac{n_s}{n_p}i_L + \frac{R.V_e}{n_p^2}t$$

$$= m.i_L + \frac{V_{in}}{L_p}t \qquad \mathbf{(10)}$$

$$= m.i_L + i_{pmag}$$

the current i_p contains a component due to the load (direct transfer) and a magnetizing component due to the presence of the transformer. At the end of the conduction phase, the count value of flow is: $\emptyset_M = V_e \alpha \frac{T}{n_p}$

Second operating phase

At the opening of T_1 et T_2, Continuity magnetizing ampere-turns is ensured through the diodes D_3 et D_4 figure (II.10) Here using 2 power transistors, but this time the 2 open and close at the same time, there is no alternation. The primary winding of the transformer is no longer supplied only in one direction also (top down here) and it is then necessary to provide a step of demagnetization between each pulse.

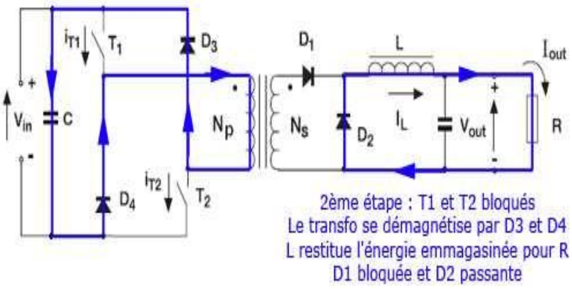


Figure II.10: Second Step for Forward converter's operation. [5]

To impose the direction of travel during the release of the residual energy when the transistors are off, the 2 diodes are used D3 and D4. It is obviously not waste energy since this has been referred in the capacitor C which is in parallel to the input voltage Vin. We will reuse it for subsequent cycles because it is the capacitor that uses energy reservoir to feed the transformer. During this phase, the current $i_{T_1} = i_{T_2} = 0$, while the freewheeling diode D_2 conducts current i_L.

2: Selecting the DC/DC converter :

In this case, it is necessary to raise the voltage of the source. We opted for a Forward converter (Figure II.8) saw its advantages: power up to a few KW, simplicity in installation, symmetrical control power switches with: V_e=48V

V_S=220 V

Therefore we chose a ferrite core transformer which losses at the operating frequency (20 kHz) are negligible. The number of turns in the secondary n1et primary n2, after calculation, it is found that:

n_1=100 spires.

n_2= 1200 spires.

The transformer must have a power equal to 1.2 kW, while the wire on the secondary side section must be equal to

6 mm² and primary equals 1.5 mm².

To test the system studied in Figure II.4 we implemented this law MATLAB-Simulink and we simulated the various stages of operation

FIG II.11 represents the chopper output voltage equal to the input voltage to 48 V at the output of a fuel cell

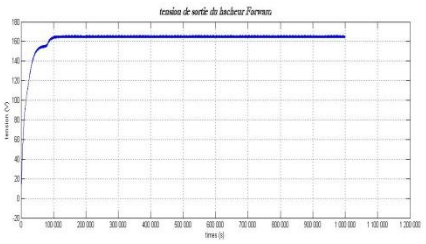


Figure II.11: Output voltage of the Forward converter

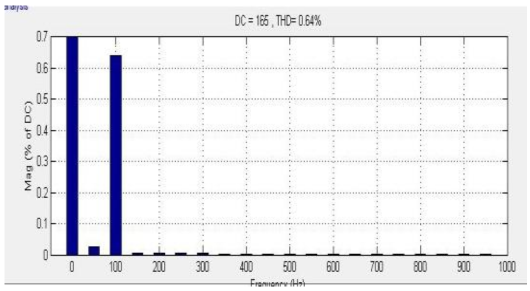
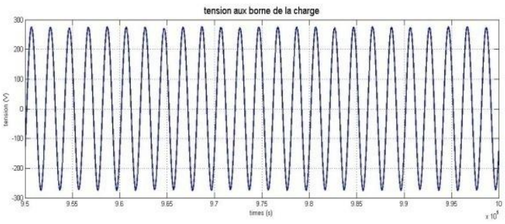


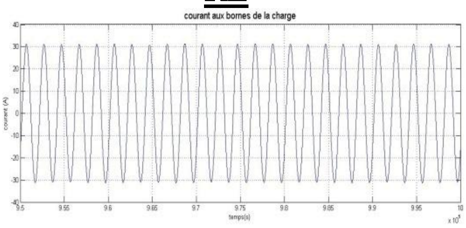
Figure II.12: Harmonic analysis of the Forward converter powered by a fuel cell

Note the presence of harmonics in the output signal from the chopper Forward applied to al fuel cell, the first harmonic is the most important. The DC component is DC = 165 and THD = 0.64%

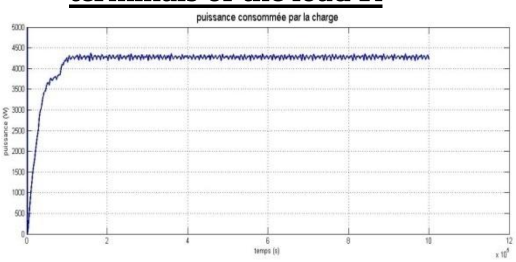
The voltage obtained across the load after going through an inverter controlled by a PWM generator is shown in Figure II.13.



<u>Figure II.13: The voltage across the load RL</u>



<u>Figure II.14: The stream obtained at the terminals of the load R</u>



<u>Figure II.15 Allure of the power consumed by the load</u>

Conclusion:

-
- We managed to achieve power generation base station has a fuel cell through a chopper booster has galvanic isolation (Forward).
- These results are important because the CAP is a source of harmonics and delivers a very high current and relatively low voltage.
- The effectiveness of the DC-DC converter with the FC means:

- Assembly used for a wide power margin to strong powers.
- Simple transformer to achieve.
- Filtering the output voltage.
- Symmetrical control switches.

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