International Symposium on Diagnostic Tools for Fuel Cell Technologies

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On-line diagnostic of a PEM fuel cell stack based on the electrical power converter

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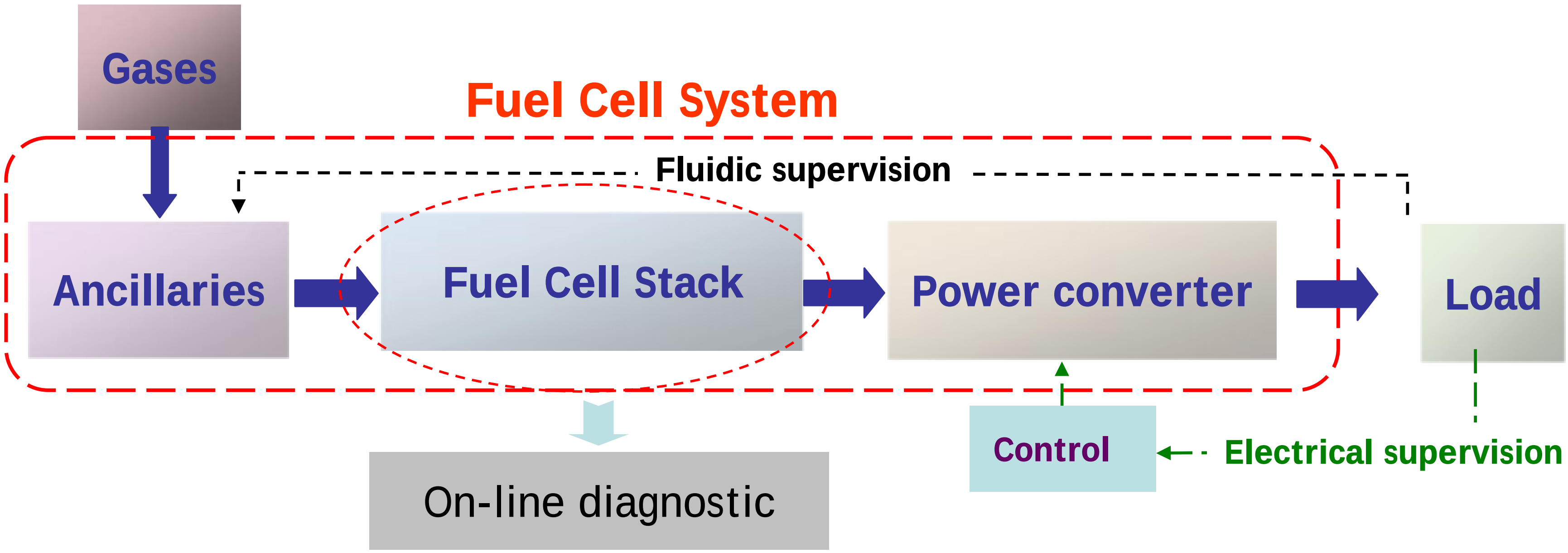
FC LAB Systèmes pile à combustible

General architecture of a PEM Fuel Cell system



How to optimize the FC behavior ?

Objective : design an on-line diagnostic tool dedicated to automotive applications

Outlines

1) Choice and sizing of the power converter
2) Real time control strategy
3) On-line impedance spectrometry
4) Conclusions

Choice and sizing of the power converter

PEM FC Stack :
115V (0A) - 55V (560A)

DC Bus :
540V

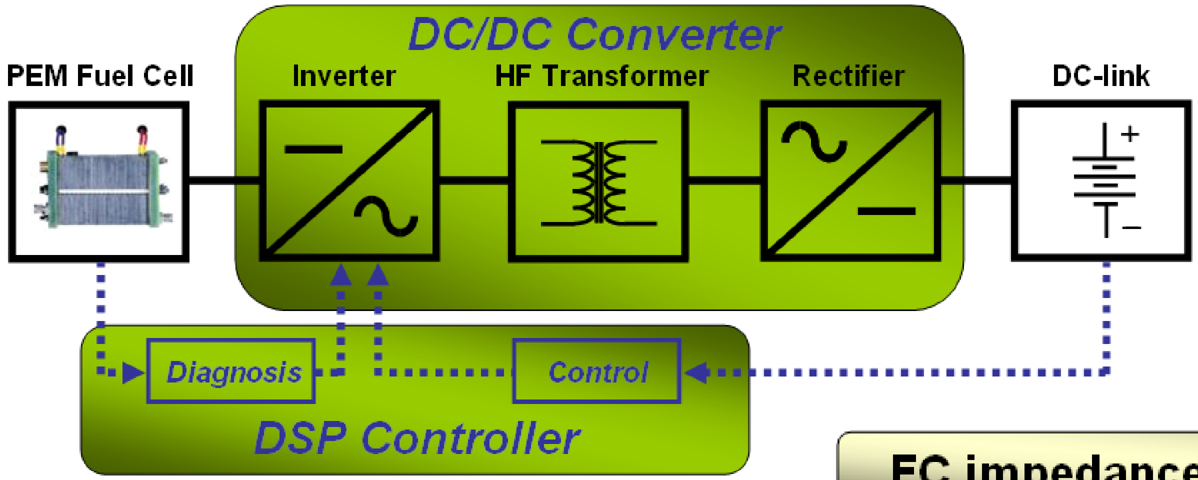
High voltage elevation ratio

Transportation applications ≈ 80kW

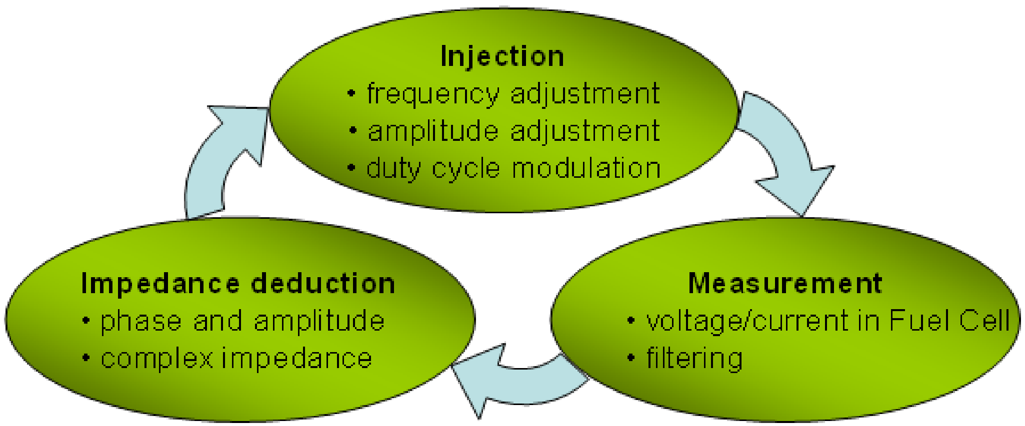
ECCE Hybrid Electrical Vehicle

- **Improvement of durability and reliability of PEMFC in embedded applications**
- **Control of DC-link with high transformation ratio, low switch constraints and high efficiency**
- **Optimization of size and cost**

General description of the energy conversion scheme



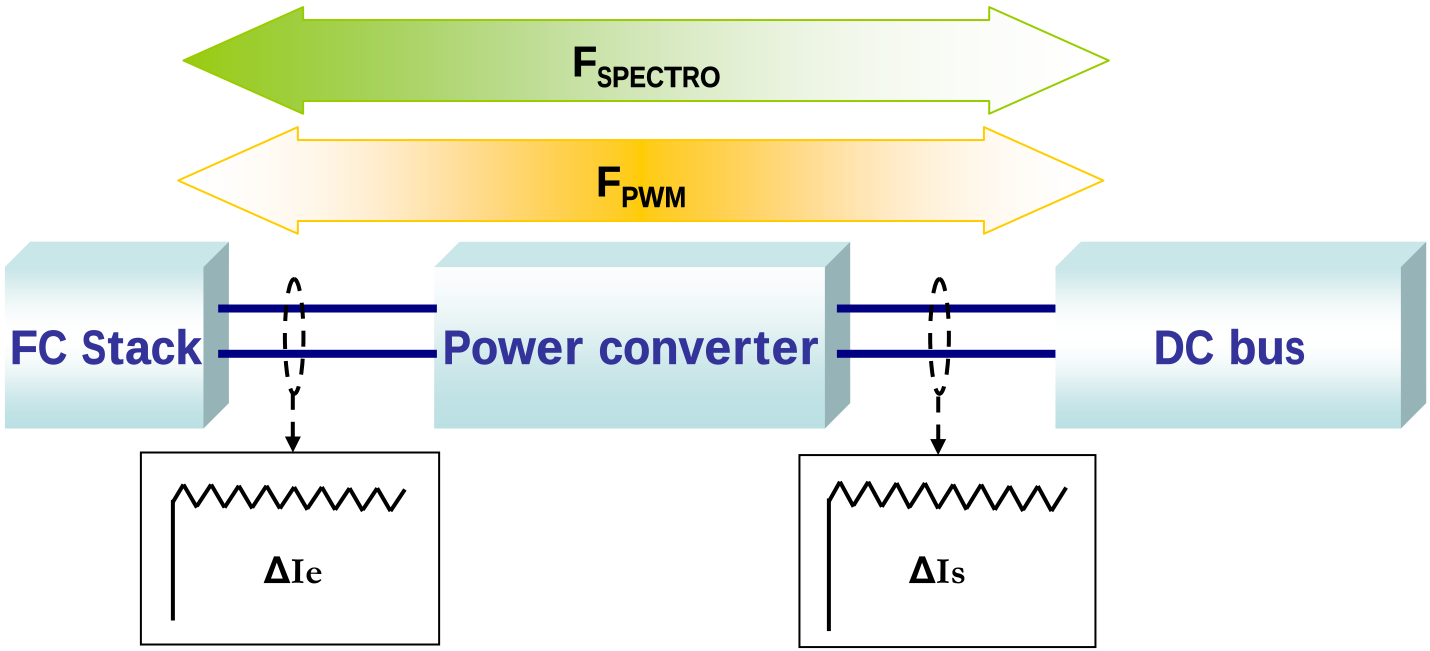
FC impedance spectroscopy principle



- **Semi-conductors : Mosfets + Diodes**
- **F_{PWM}=50kHz**
- **Planar technology transformer**

Choice and sizing of the power converter

Sizing of the power converter for impedance spectrometry



Sizing of the passive filters

$$C_f = \frac{Is}{\Delta Vs} \cdot \alpha \cdot \frac{1}{2.f}$$

$$L_f = \frac{V_S}{\Delta I_S} \cdot \alpha \cdot \frac{1}{2.f}$$

$$f_0(Hz) = \frac{1}{2.\pi.\sqrt{L_f.C_f}}$$

F_{PWM} = 50kHz

$F_{SPECTRO}$: 1Hz to 2,5kHz

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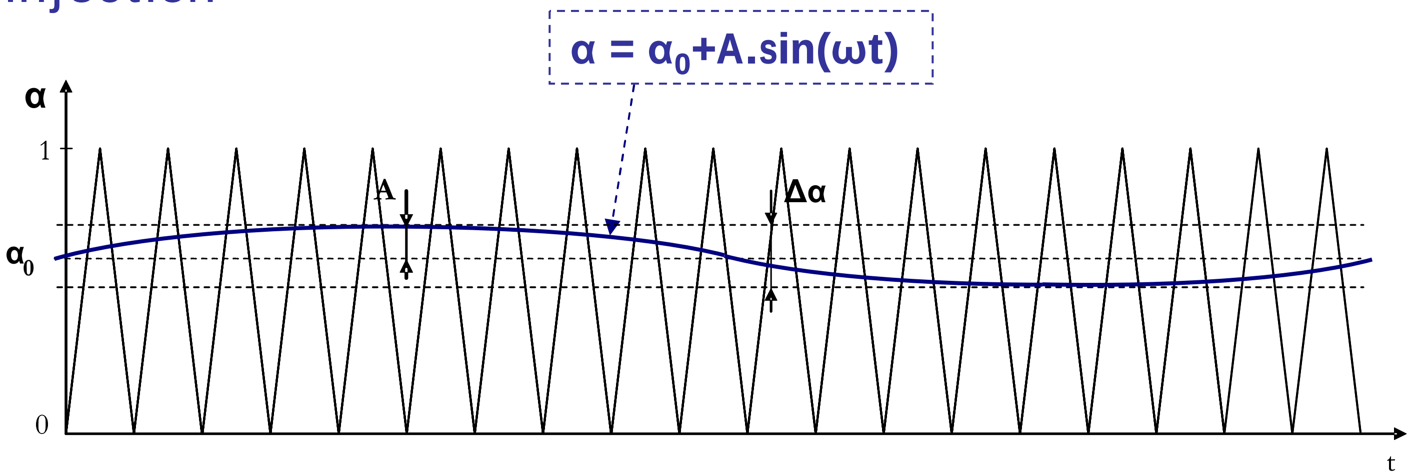
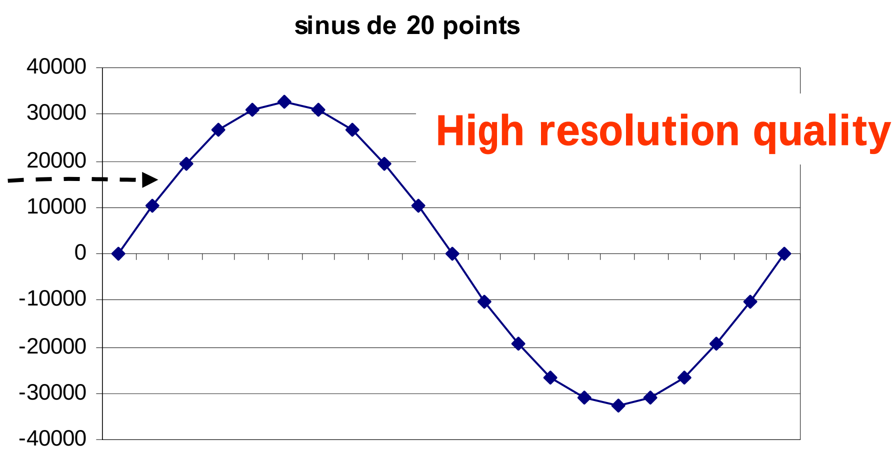
Impedance spectrometry done by the power converter

Current injection



α_0 : duty cycle => normal behavior
A : sinusoïdal modulation amplitude

$$F_{injection} = \frac{F_{PWM}}{20 \cdot k}$$



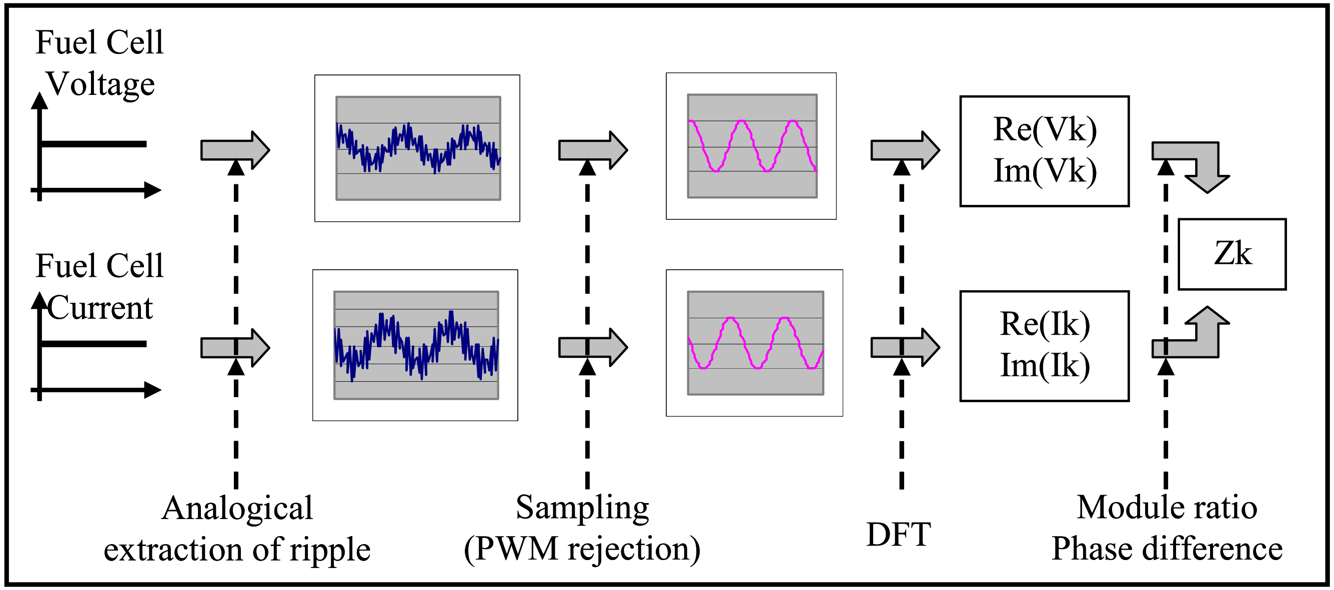
F_{PWM} = 50kHz

=> $F_{injection\_max}$ = 2,5kHz

Real time control

Impedance measurement

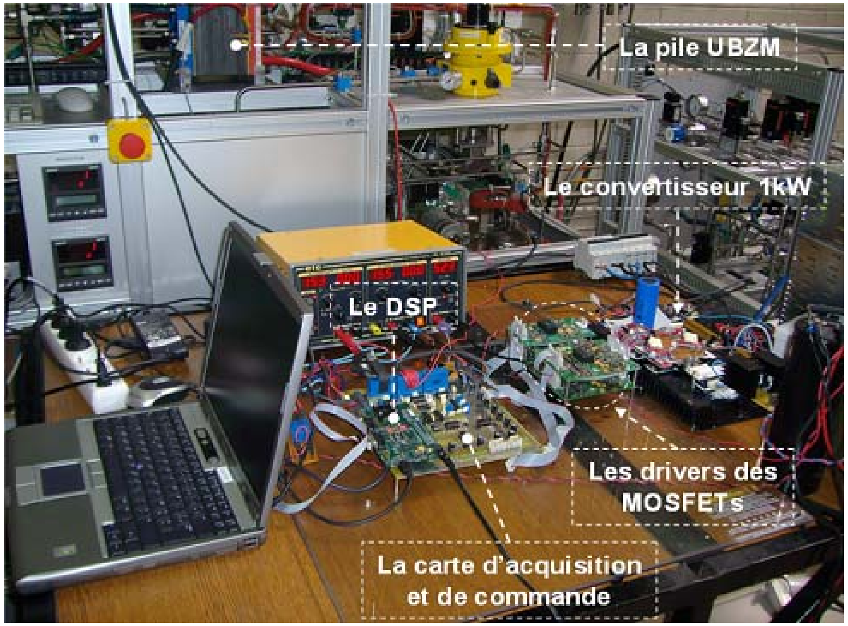
- ❑ extraction of ripple
- ❑ PWM rejection
- ❑ filtering and phase referencing of desired ripple with DFT (Discrete Fourier Transform)
- ❑ harmonic impedance

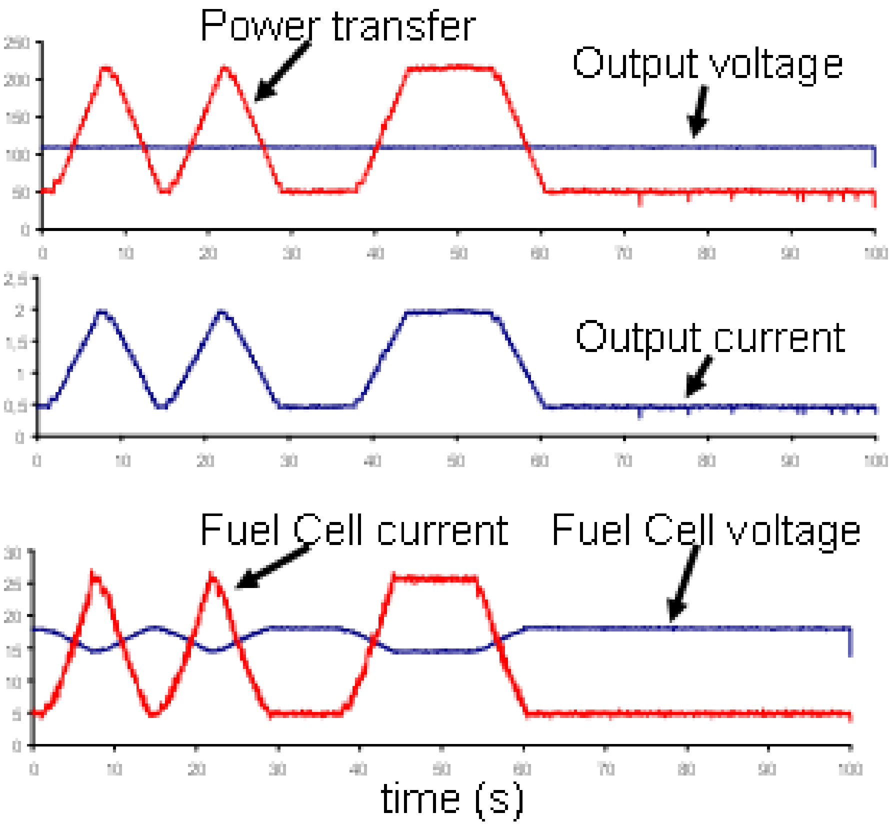


Real time control

Electrical behavior experimental results (1kW prototype)

Electrical behavior
- good DC bus voltage stability
- power flows control ability





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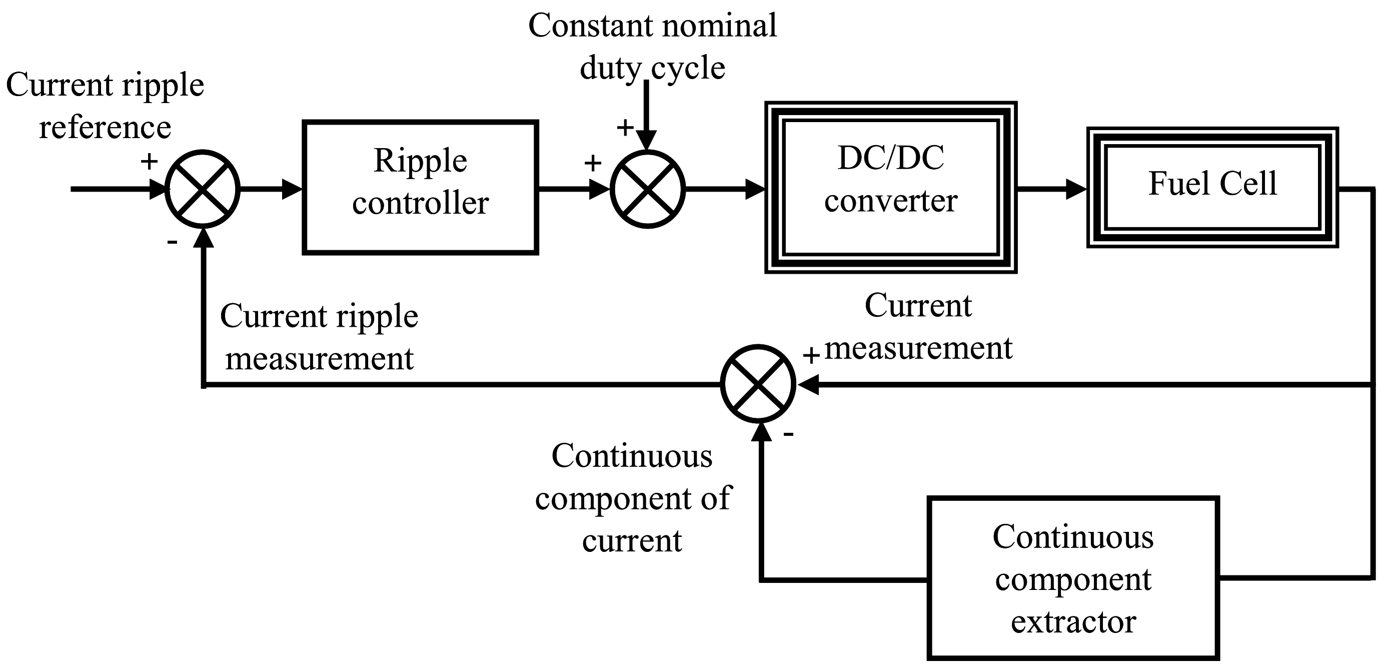
On-line impedance spectrometry

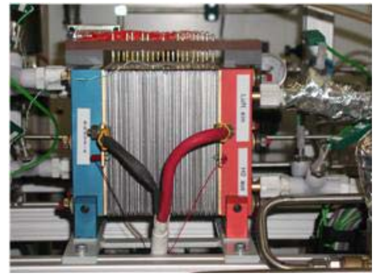
Injection strategy of fuel cell stimulus

- duty cycle sinusoidal modulation
- control of the current ripple amplitude



On-line impedance spectrometry

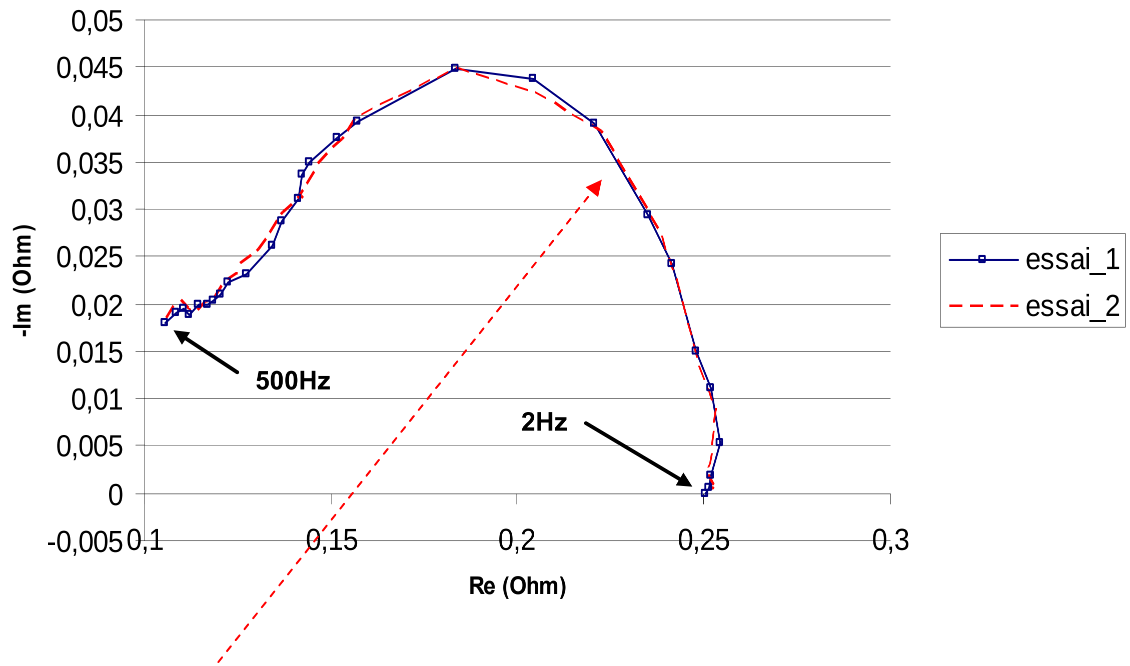
UBZM PEM 20-cell stack



Experimental values

Gas flows	**20A**
FC stack temperature	**48°C**
FC air dew point	**45°C**
FC stack voltage	**14,18V**
FC current	**12,15A**
Air hygrometry level	**85%**
Hydrogen hygrometry level	**20%**
Load current	**1,6A**

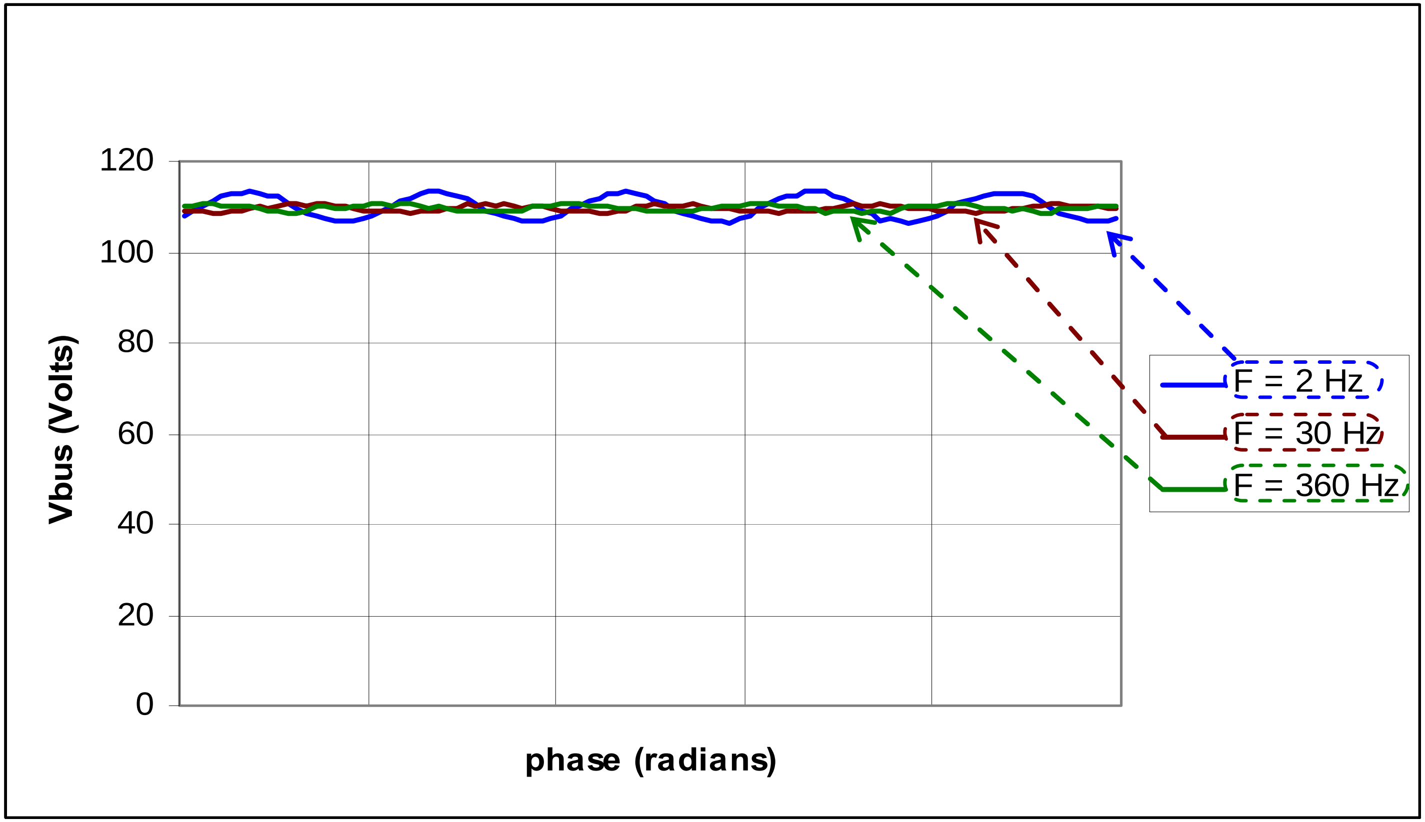
On-line impedance spectrometry result



Results reproducibility highest quality

On-line impedance spectrometry

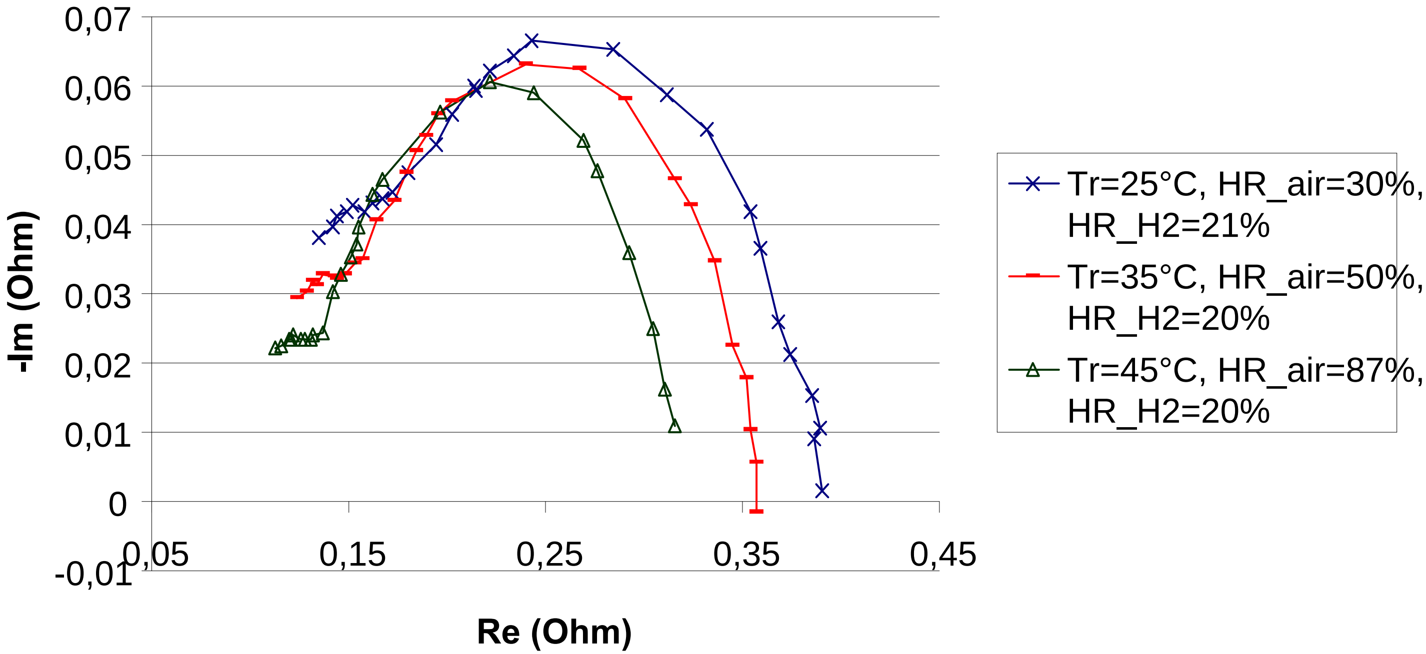
Influence of the spectrometry on the DC bus voltage



ΔVmax ⟹ Fmin and ΔVmax < 10% Vbus

Effect of the gas hydration level

Fuel cell operating point : 8A, T_{FC}=48°C, Igases=20A



Humidification level increases

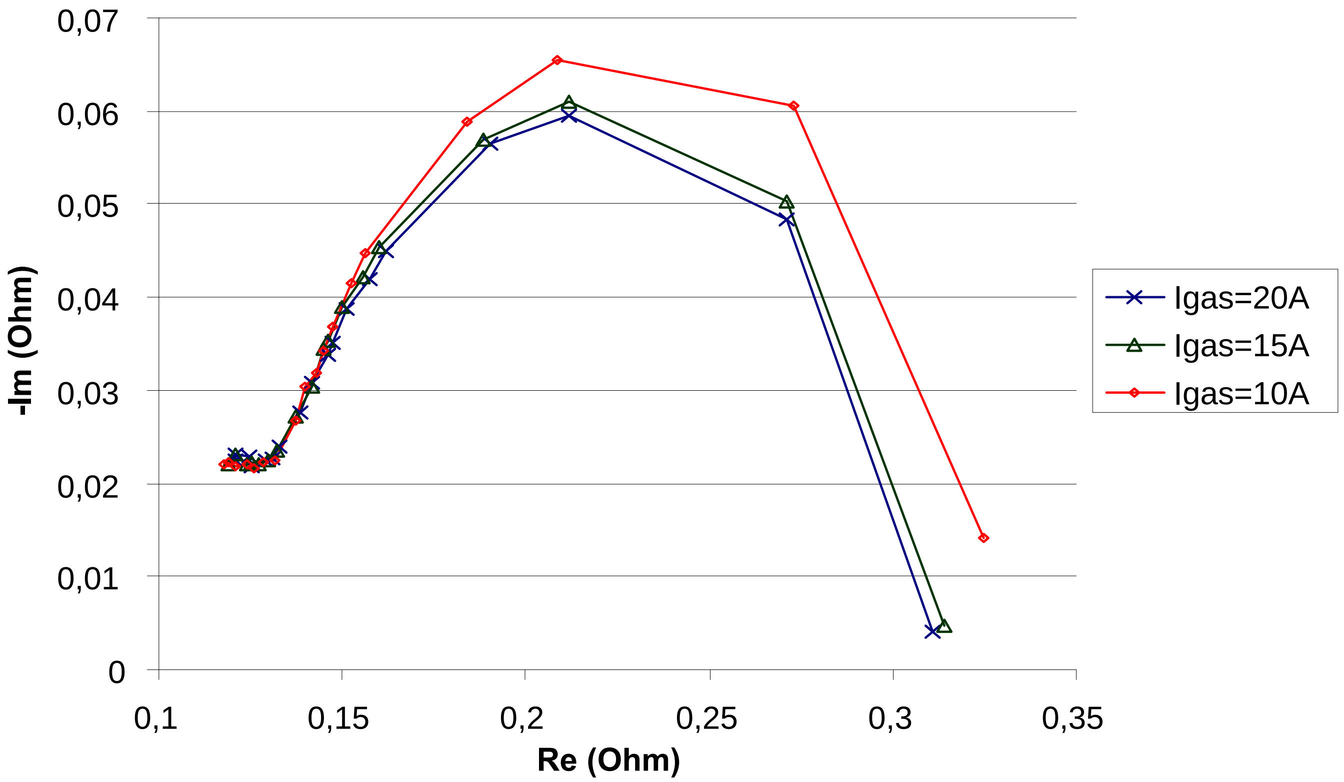
↓

Z_{stack} diminishes

On-line impedance spectrometry

Effect of the H_2 gas flow

Fuel cell operating point : 8A



H_2 flow increases

Z_{stack} diminishes in LF

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Conclusions

Many advantages :

- Important power flows transfer ability
- Ability to high transformation ratios
- High compactness
- On-line diagnosis ability
- Ability to modify in real time the FC control laws to improve durability / efficiency

Next to do :

- Higher power FC have to be considered
- Go from the impedance spectrometry to the FC stack on-line diagnosis
- Consider SOFC power plants

To go further…

[1] Hissel, D., Jemeï, S., Hubert, V., François, X., Péra, M.C., Kauffmann, J.M., *“A diagnosis-oriented model of a fuel cell power generator dedicated to automotive applications”,* ISNGVT'01 4th International Symposium on Next Generation Vehicle Technology, pp. 49-54, Gwangju, South Korea, 2001.

[2] Hissel, D., Péra, M.C., Kauffmann, J.M., *“Automotive fuel cell power generators diagnosis”*, Journal of Power Sources, vol. 128, n°2, pp. 239-246, 2004.

[3] Hissel, D., Candusso, D., Harel, F., *“Fuzzy clustering durability diagnosis of embedded polymer electrolyte fuel cells”,* IEEE Transactions on Vehicular Technology, vol. 56, n°5, pp. 2414-2420, 2007.

[4] Narjiss, A., Depernet, D., Gustin, F., Hissel, D., Berthon, A., *“Design of a high efficiency fuel cell DC/DC converter dedicated to transportation applications”,* ASME Fuel Cell Science and Technology, vol. 5, n°4, 11p., 2008.

[5] Steiner, N., Candusso, D., Hissel, D., Hernandez, A., Moçoteguy, Ph., Aslanides, A., *“A review of PEM voltage degradation associated with water management: impacts, influent factors and characterization”,* Journal of Power Sources, vol. 183, n°1, pp. 260-274, 2008.

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