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«New EMR approach for multi-physics energetic power flow»

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1. **Introduction**

2. **EMR formalism extended to other physical domains**
   - Extension to all physical domains
   - EMR example – Grid connected renewable energy power plant

3. **From power flow EMR to multiports EMR**
   - Thermo-pneumatic energetic flow: multiports EMR
   - Thermo-fluidic energetic flow: multiports EMR

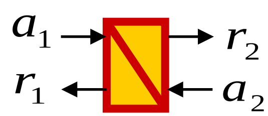
4. **New EMR approach for multidomain-multivariable energetic flow modeling**
   - New EMR approach describing multivariable energetic flow
   - New EMR approach describing multivariable energetic flow: thermo-pneumatic and thermo-fluidic domains

5. **Conclusion**

« 1. Introduction »

- 1. Introduction -

- EMR basic principles
  - Action reaction principle

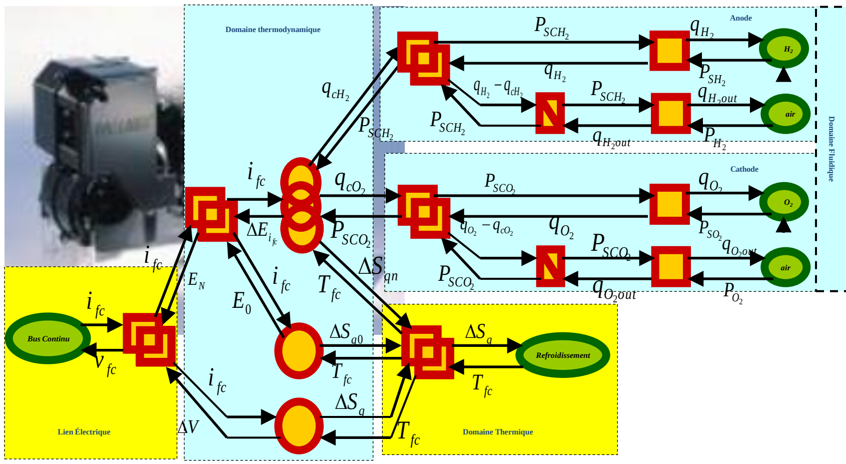


  - Physical causality $r_1 = r_2 = \int (a_1 - a_2) dt + a_0$
  - Power flow modeling $P[W] = r_1 \cdot a_1 \quad and \quad P[W] = r_2 \cdot a_2$
  - EMR is endowed with control feature

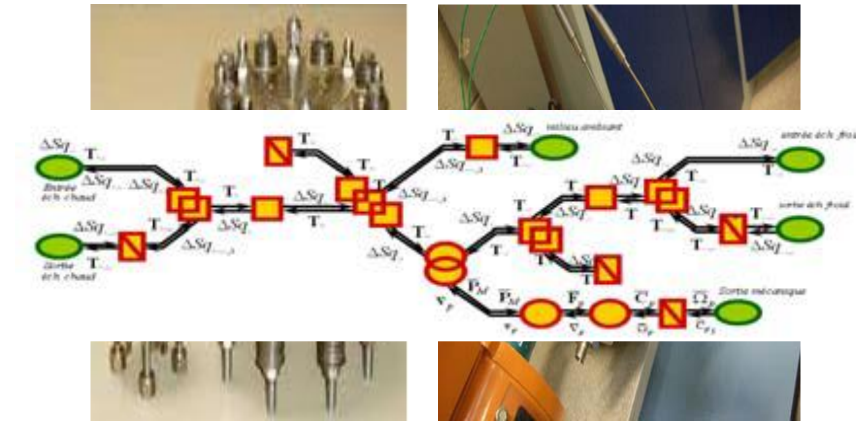
- EMR is applied to fuel cell systems since 2006 at FEMTO-ST Laboratory

- Multivariable energetic flow modeling led to the multiports EMR

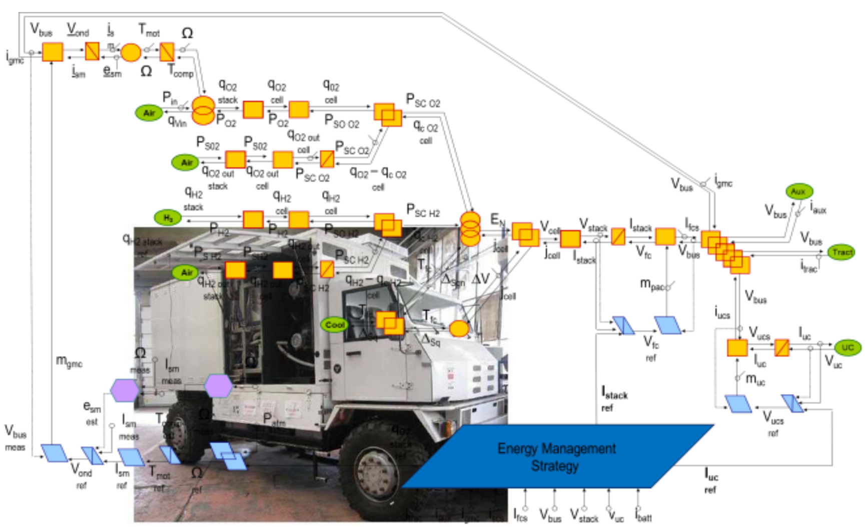
- Here, a new EMR approach based on power flow modeling and action - reaction principle is proposed for multiphysics systems



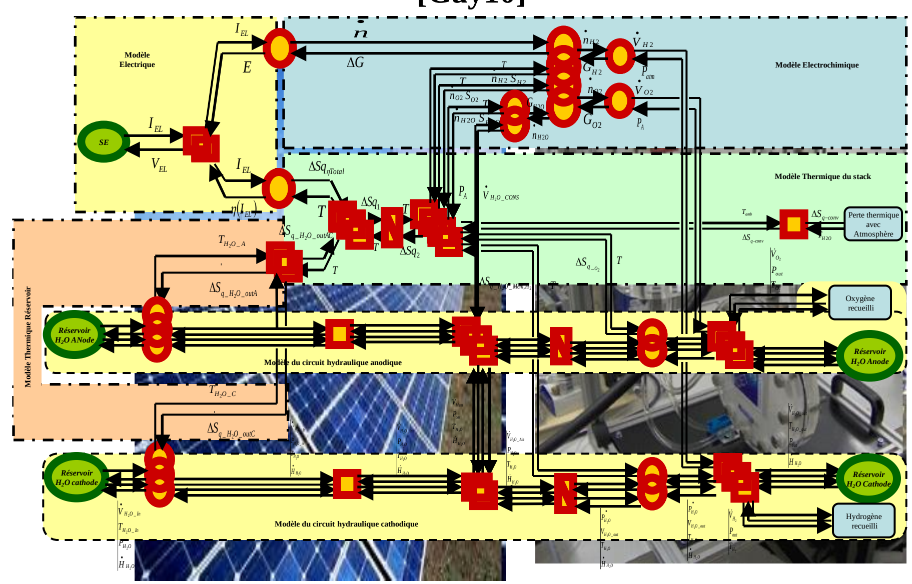
PEM Fuel Cell model and systems' models [His08][Boul08]



Cogeneration application based on SOFC and Stirling engine [Gay10]



Energy management strategy based on EMR model [Sola10] [Sola10]

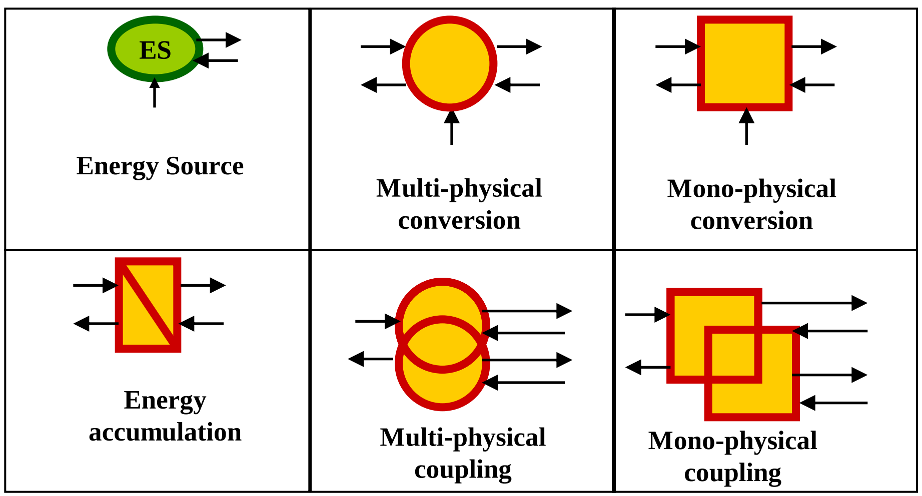


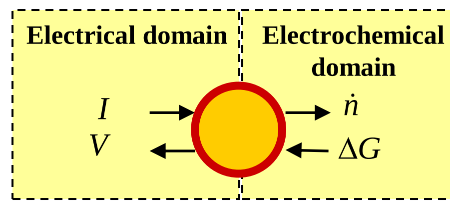
PEM Electrolyser powered by solar panels [Agbl11]

« 2. EMR formalism extended to other physical domains»

✓ From electromechanical to multiphysics systems modeling

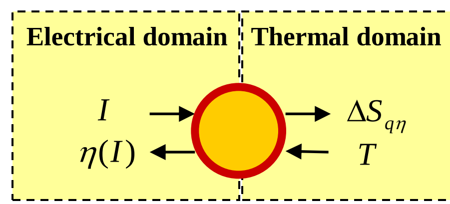
- Electrical, mechanical, thermal, chemical,
- Electrochemical, radiometric, photonic, ...





$$\dot{n} = \frac{I}{nF} N_{cell} \eta_F$$

$$E = \frac{\Delta G}{nF}$$



$$\dot{n} = \frac{I}{nF} N_{cell} \eta_F$$

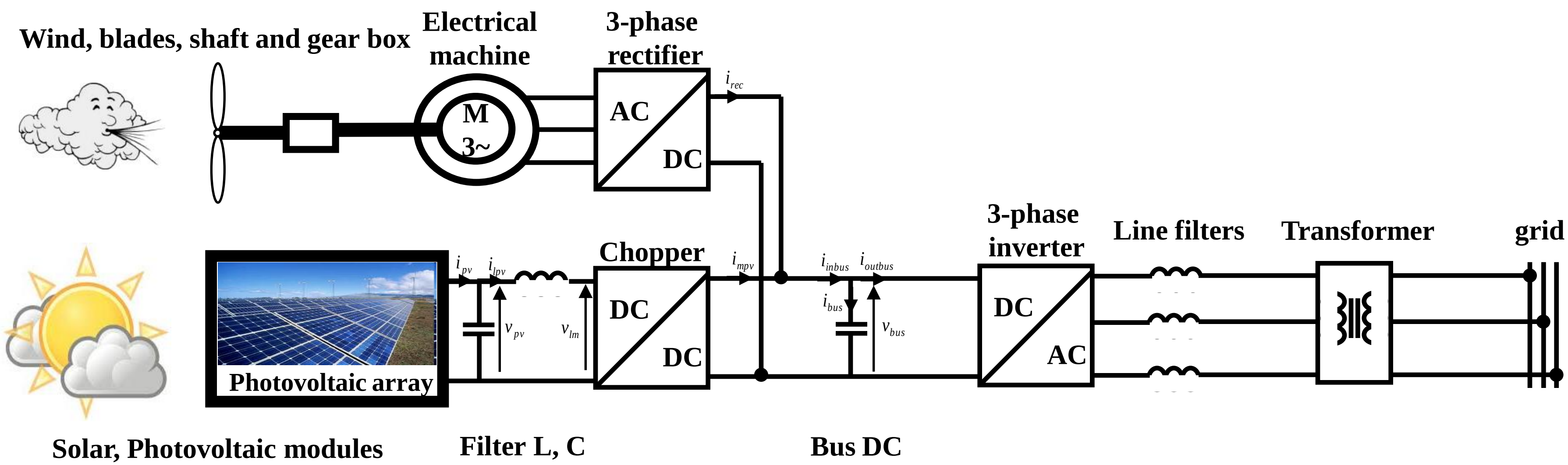
$$E = \frac{\Delta G}{nF}$$

✓ A few definitions:

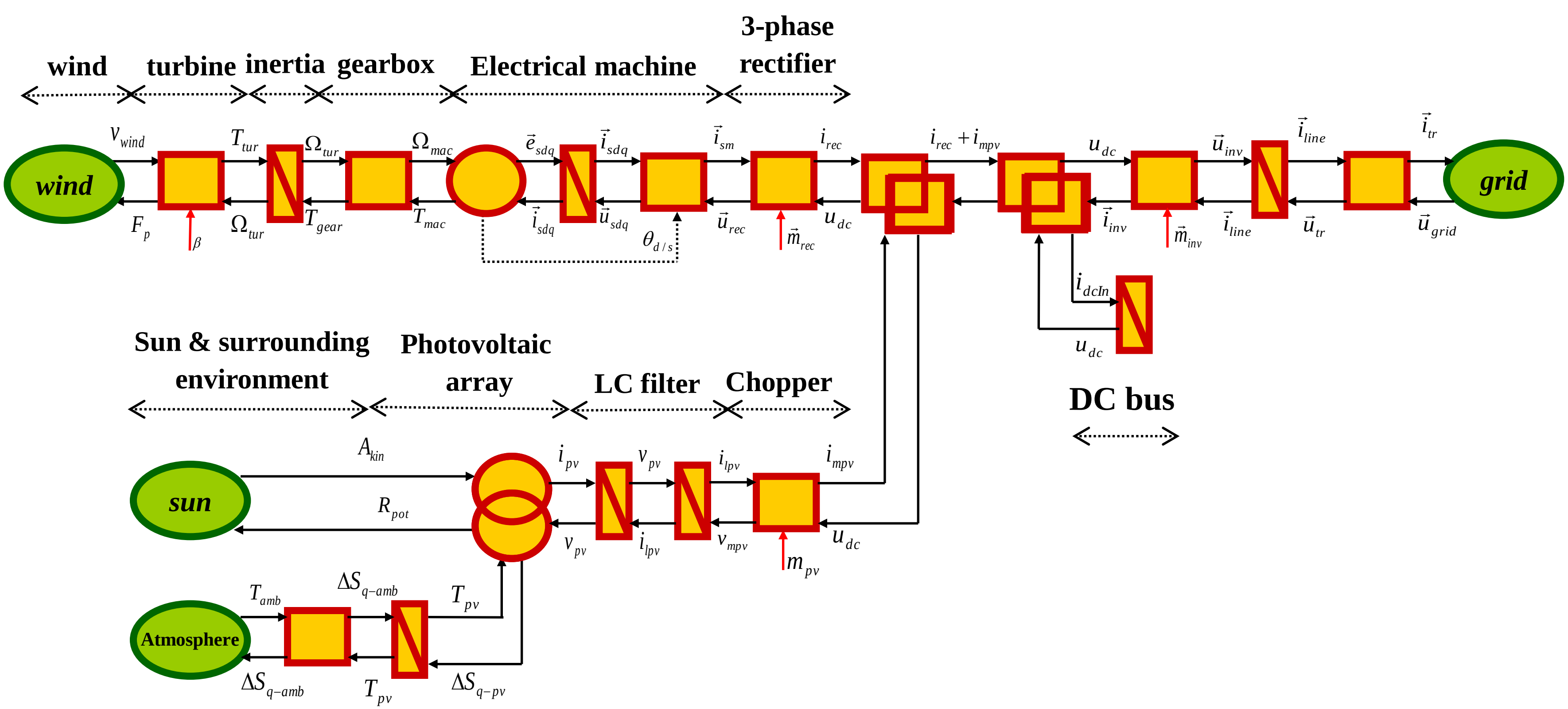
Multiphysics energetic flow
Multidomain energetic flow } **Energetic flow involving more than one physical domain**

Multivariable energetic flow: **Energetic flow described by more than two energetic variables**

- ✓ **Grid connected renewable energy sources power plant**



✓ The related EMR model



Upstream and downstream each pictogram, the product of the action variable and the reaction variable is a power value

«3. From power flow EMR to the multiports EMR»

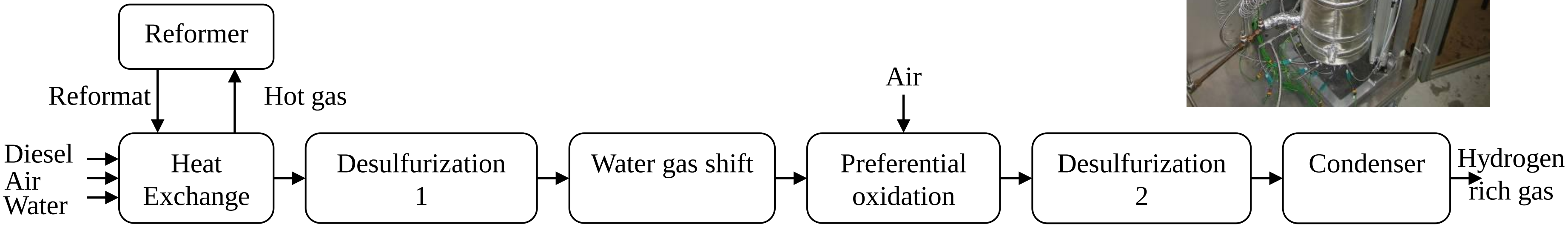
Efficiency enhancement purpose: from a system point of view

Issues:

- Improvement of system efficiency implies improvement of the reforming process
- That leads subsequently to the reduction of the fuel consumption

Overwiew of the diesel fuel processing unit [Chre09]

- **Conversion temperature in the reformer is around 1400°C**
- **Several chemical species are involved**
- **All chemical species are gaseous**



- **Gas vector of the process:**

$$Gas\ \ Vector = \begin{pmatrix} Diesel \\ Hydrogen \\ Carbone\ \ monoxide \\ Hydrogen\ \ sulfide \\ Carbon\ \ dioxide \\ Nitrogen \\ Water\ \ gaseous \\ Water\ \ liquid \\ Oxygen \end{pmatrix}$$

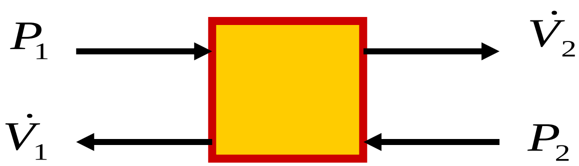
EMR power flow modeling issues in such a system:

1/ Take into account two modeling constraints:

- Mass balance
- Energy balance

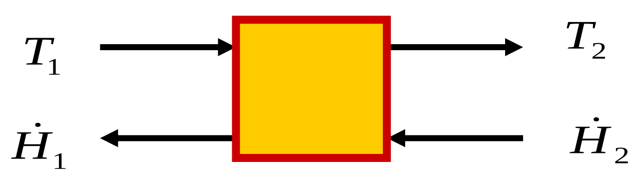
2/ Use of vectorial variables based on action/reaction principle

3/ Assess mass balance: Mass or volume flow within the reformer



Pneumatic domain without thermal feature

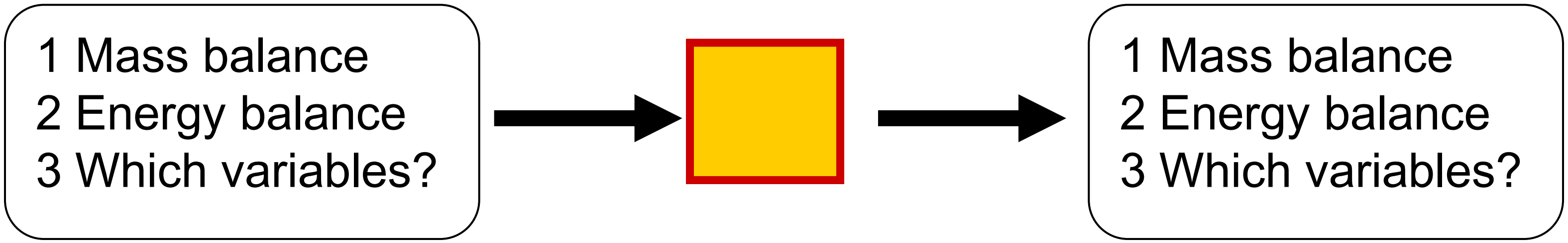
Assess energy balance: take into account thermal feature



To properly assess the energy flow, the mass flow is needful

How is it possible to model the power flow by highlighting both these strongly linked domains: thermal domain and pneumatic domain ????

EMR modeling constraints in the thermo-pneumatic domain



Physical analysis

- Mass balance: perfect gas law $$PV = nRT$$
- Energy balance: gas enthalpy law $$\dot{H} = \dot{m} c_p T$$

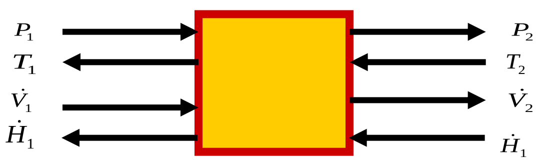
Needful energetic variables: $T \quad \dot{H} \quad P \quad \dot{m}$

Independent variables: $T \quad \dot{m} \quad P$

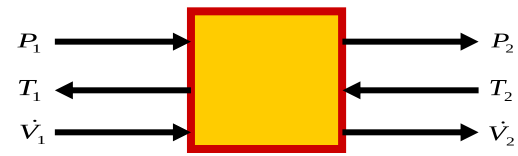
- 3.1 Thermo-pneumatic energetic flow: multiports EMR -

From physical analysis: multiports EMR is necessary

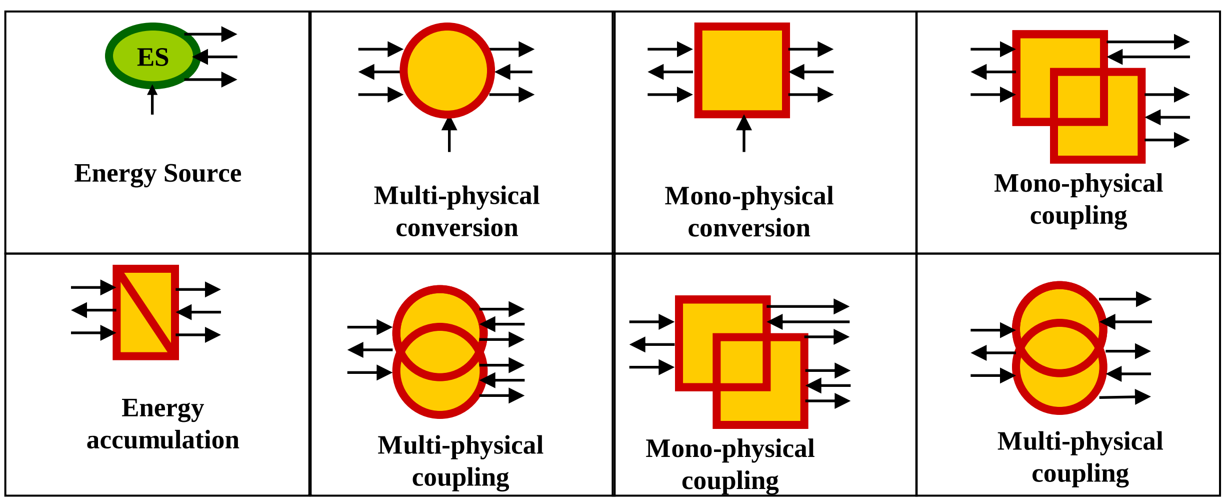
Using the needful energetic variables



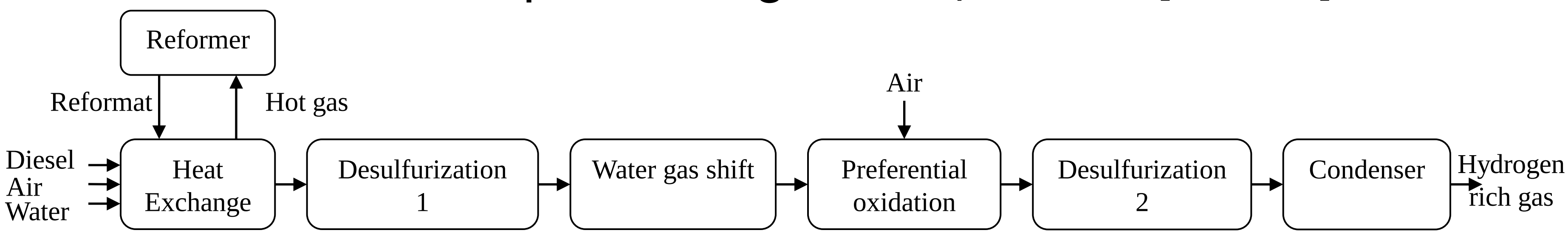
Using independent variables

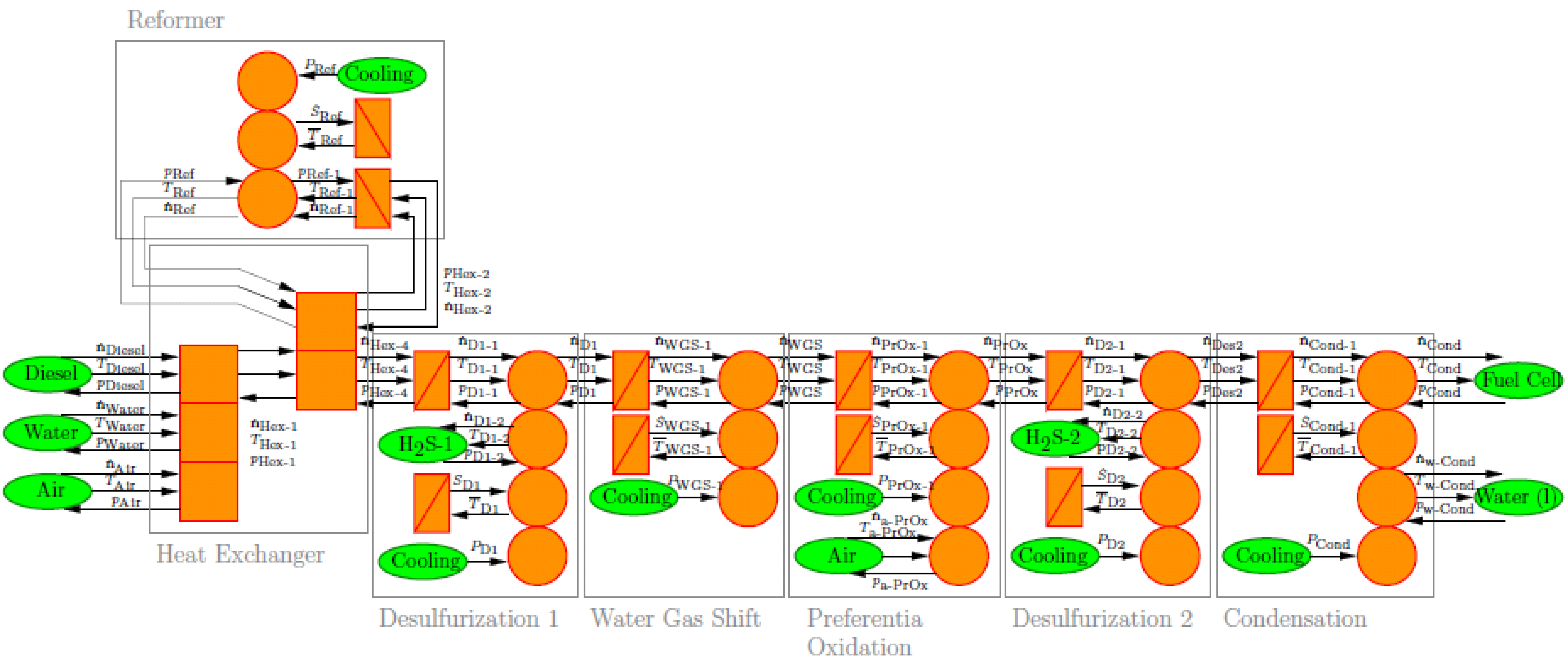


For gas flow modeling: 3-port EMR has been retained [Chre09]

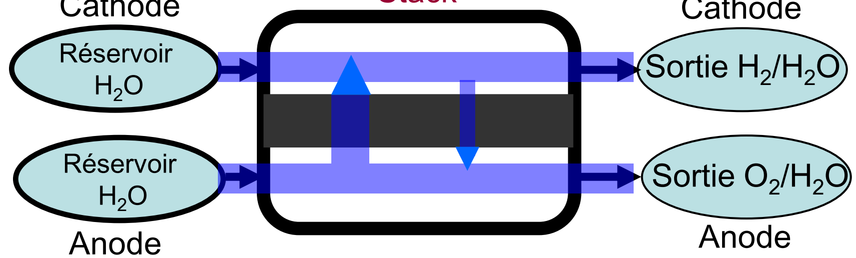


EMR of a diesel fuel processing unit: 3-port EMR [Chre09]





Liquid flow EMR modeling issue [Agbl12a]



water supply paths

Take into account two modeling process constraints:

- Mass balance
- Energy balance

Physical analysis

- Mass balance
- Energy balance

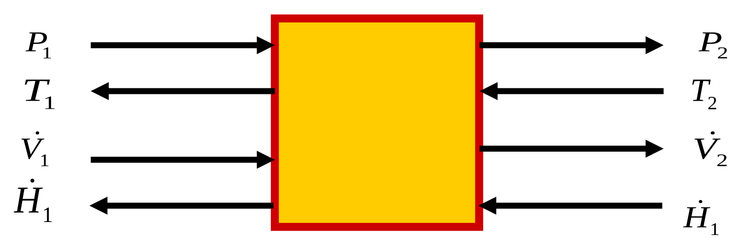
$$\left\{ \dot{H} = \dot{m}\left(c_p T + P/\rho + \rho \cdot v^2/2\right) \right.$$

Liquid flow EMR modeling issue [Agbl11]

Physical analysis conclusions :

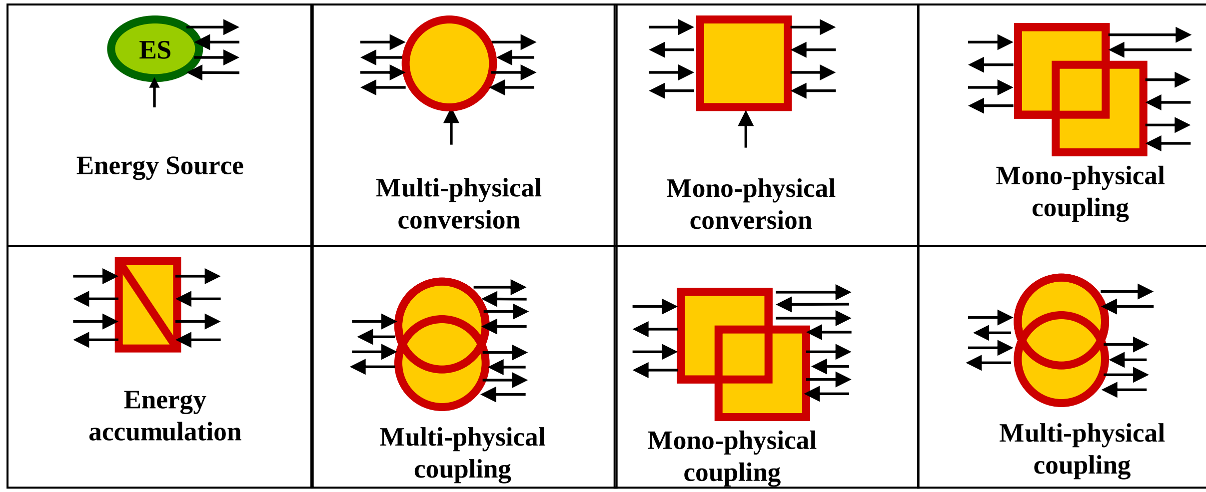
- Hydraulic domain:
  - Perfect gas law is unsuitable
  - Only enthalpy flow equation involving mass flow and thermal flow
- From physical analysis: multiports EMR

Needful energetic variables:



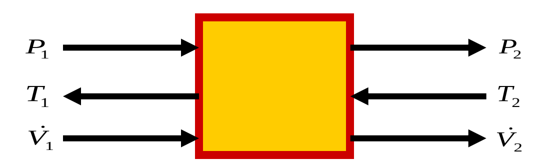
Independent variables: variables number can be decreased to three

4-port EMR [Agbl12b]

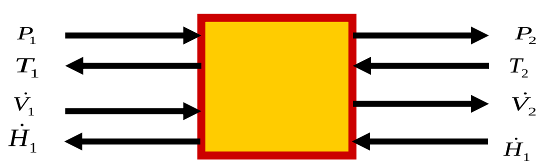


Multiports EMR weakness:

- it is far away from the power flow modeling
- control issues



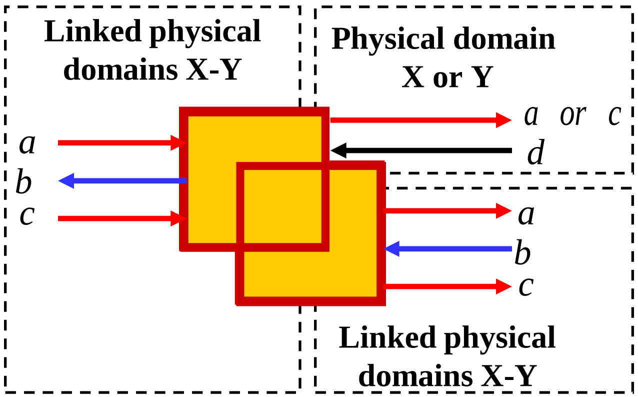
$$[\dot{m} \cdot T \cdot P] \neq [W]$$

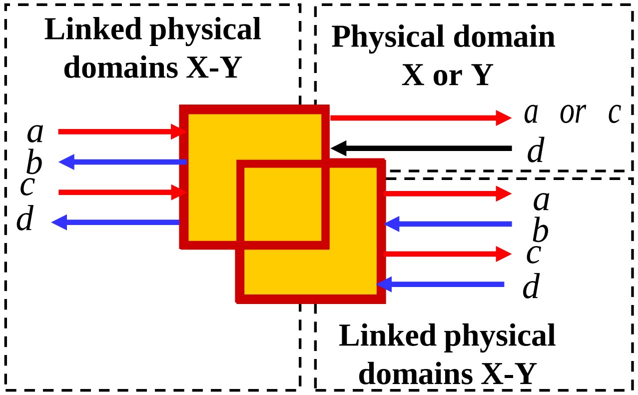


$$[\dot{H} \cdot \dot{m} \cdot T \cdot P] \neq [W]$$

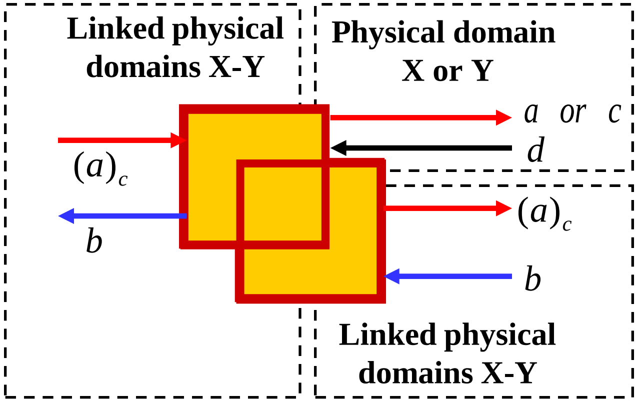
«4. New EMR approach for multidomain-multivariable energetic flow modeling»

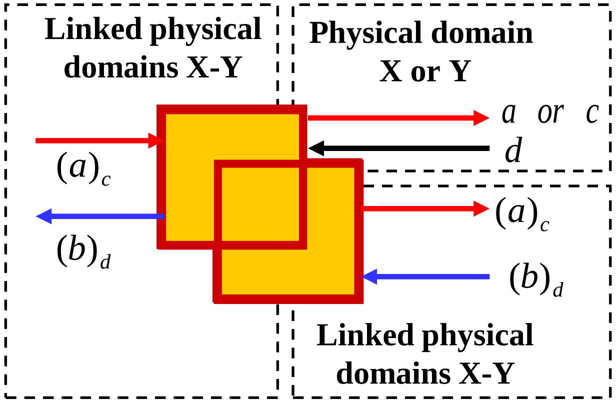
Identification of carrier and carried physical domains [Agbl12a]





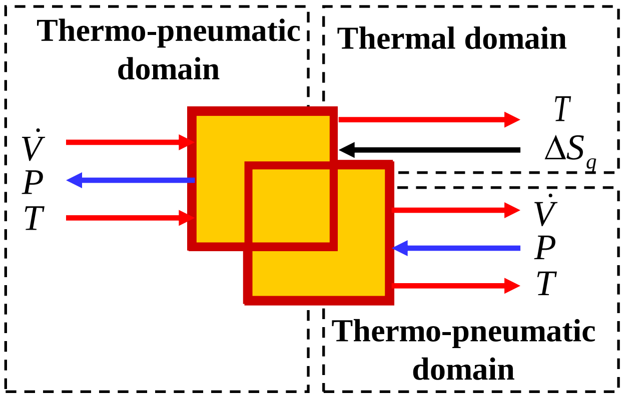
Main action-reaction variables complying to the power flow [Agbl12a]

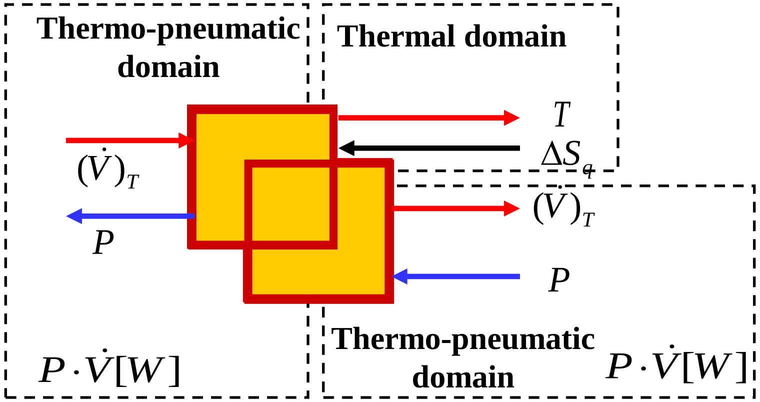


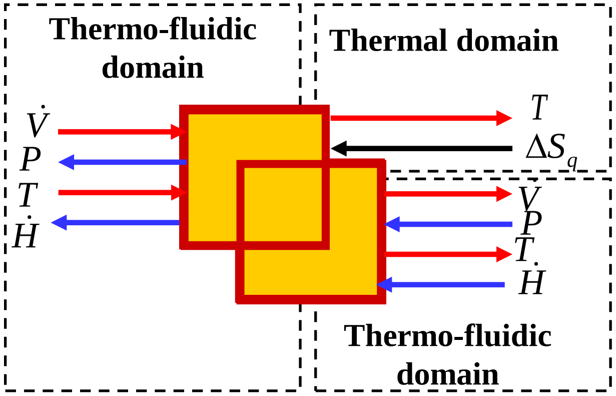


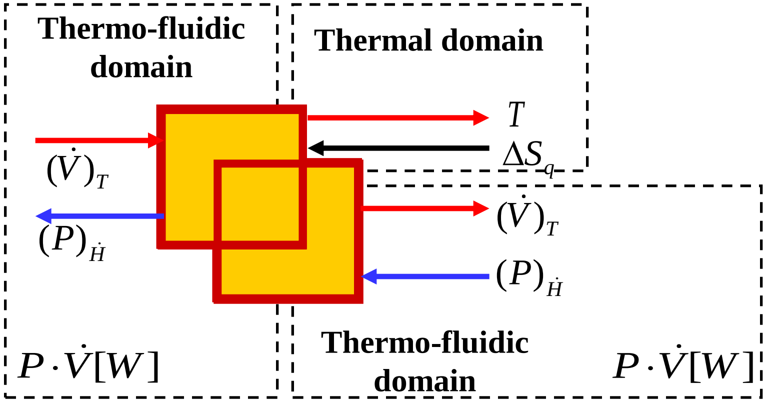
Identification of carrier and carried physical domains [Agbl12b]

Main action-reaction variables complying to the power flow [Agbl12b]

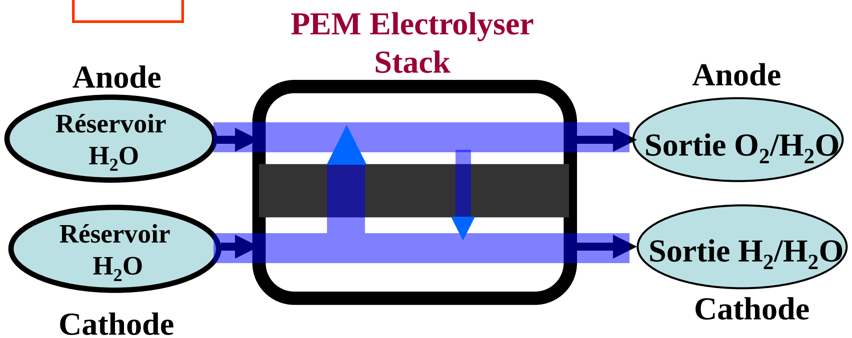




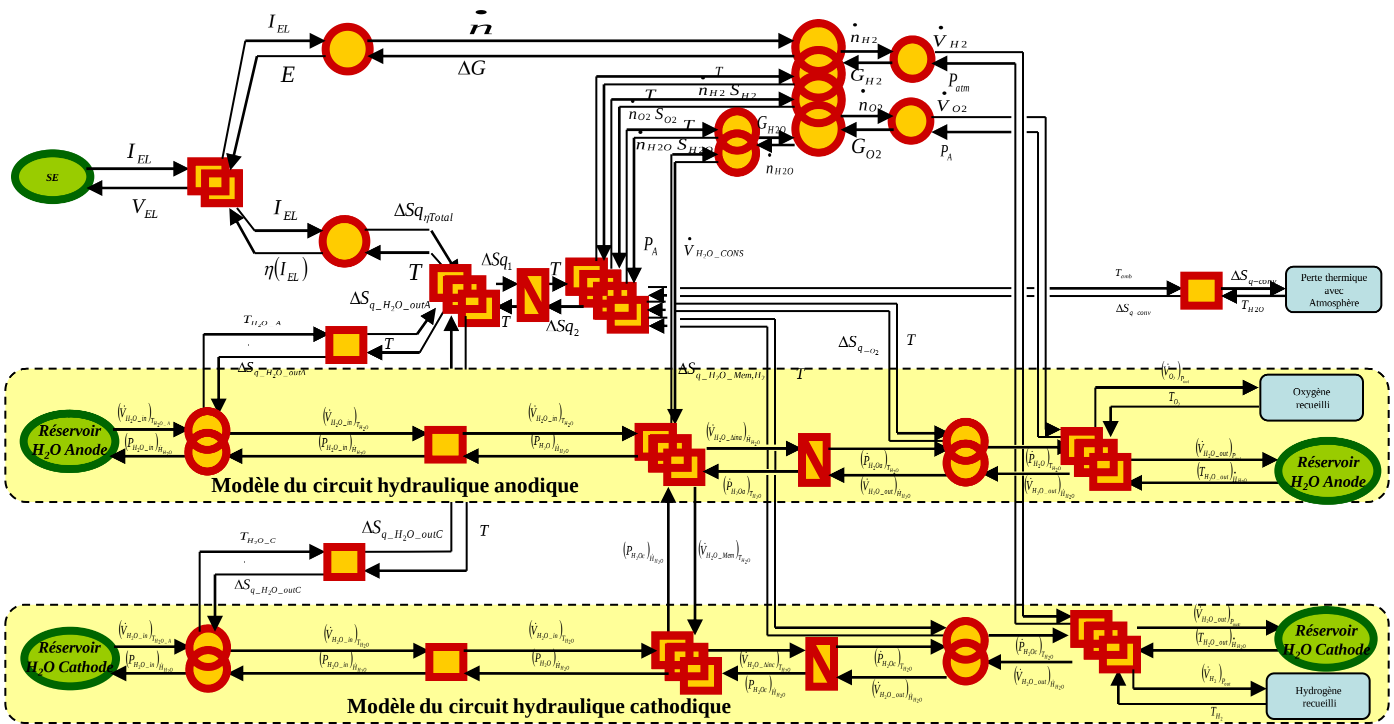




- 4.2 New EMR approach: PEM electrolyser -



water supply paths



[Agbl12a]

«5. Conclusion»

- Developed twelve years ago, the EMR is relevant for modeling and control

- EMR is suitable to model strongly linked multiphysics phenomena

- For multidomain-multivariable energetic flow, power flow EMR can by used thanks to a relevant phenomenological description

- Power flow EMR based on action reaction principle is very simple and readable

- The novelty of the proposed EMR modeling approach allows complying with the formal EMR whatever the complexity of the modeled system

- A further novelty is the possibility to be able to properly control the multidomain-multivariable models

« Biographies and References »

- Authors -

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- References -

[Agbl11] K.S. Agbli, M.C. Péra, D. Hissel, O. Rallières, C. Turpin, Doumbia I. Multiphysics simulation of a PEM electrolyser: Energetic Macroscopic Representation approach. Int. Journal of Hydrogen Energy. 2011 ; 36 :1382-1398.

[Agbl12a] Kréhi Serge AGBLI. Modélisation multiphysique des flux énergétiques d'un Couplage Photovoltaïque-Electrolyseur PEM-Pile à Combustible PEM en vue d'une application stationnaire. Doctorat de l'Université de Franche-Comté. 2012.

[Agbl12b] K.S Agbli, D. Hissel, M-C. Péra, Issa Doumbia. Energetic Macroscopic Representation (EMR): New approach for multiphysics energetic flows modelling. PPPSC2012, Toulouse (France). September 2012.

[Boul08] L. Boulon, D. Hissel, A. Bouscayrol, M.C. Pera, P. Delarue. Multi physics modelling and representation of power and energy sources for Hybrid Electric Vehicles. Vehicle Power and Propulsion Conference, 2008 VPPC'08. IEEE. Page(s): 1-6.

[Chre09] D. Chrenko, J. Coulié, S. Lecoq, M.C. Péra, D. Hissel. Static and dynamic modeling of a diesel fuel processing unit for polymer electrolyte fuel cell supply. International Journal of Hydrogen Energy. 2009;34:1324-35.

[Gay10] C. Gay, D. Hissel, F. Lanzetta, M-C. Pera, M. Feidt. Energetic Macroscopic Representation of a Solid Oxide Fuel Cell for Stirling Engine combined cycle in high-efficient powertrains. IEEE Vehicle Power and Propulsion Conference (VPPC),Lille, 2010. PP 1-8, 1-3 Sept. 2010.

[Hiss08] D. Hissel, M.C. Péra, Bouscayrol, D. Chrenko. Energetic Macroscopic Representation of a fuel cell. Revue internationale de génie électrique ISSN 1295-490X , vol. 11, no4-5, pp. 603-623 , 2008.

[Sola10] J. Solano-Martínez, D. Hissel, M.-C. Péra, M. Amiet. "Practical Control Structure of a heavy duty hybrid electric vehicle," IEEE Vehicle Power and Propulsion Conference (VPPC'10), Lille, France, 2010. pp.1-8, 1-3 Sept. 2010.

[Sola12] Javier SOLANO Martínez. Energy management of a hybrid electric vehicle: an approach based on type-2 fuzzy logic. PhD of Franche-Comté University. 2012.