«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
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   • New EMR approach describing multivariable energetic flow: thermo-pneumatic and thermo-fluidic domains

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« 1. Introduction »
EMR basic principles

- Action reaction principle

\[ a_1 \rightarrow \text{reaction} \rightarrow a_2 \]
\[ r_1 \leftarrow \text{action} \leftarrow r_2 \]

- Physical causality

\[ r_1 = r_2 = \int (a_1 - a_2) dt + a_0 \]

- Power flow modeling

\[ P[W] = r_1 \cdot a_1 \quad \text{and} \quad P[W] = r_2 \cdot a_2 \]

- 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.
«New EMR approach for a multi domain-multivariable energetic flow»

- 1. Introduction -

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]
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«2. EMR formalism extended to other physical domains»
From electromechanical to multiphysics systems modeling

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

A few definitions:

Multiphysics energetic flow: Energetic flow involving more than one physical domain

Multidomain energetic flow: Energetic flow involving more than one physical domain

Multivariable energetic flow: Energetic flow described by more than two energetic variables
- 2.2 EMR example on a power flow modeling -

✓ 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
Overview 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:

\[
\text{Gas Vector} = \left\{ \begin{array}{l}
\text{Diesel} \\
\text{Hydrogen} \\
\text{Carbone monoxide} \\
\text{Hydrogen sulfide} \\
\text{Carbon dioxide} \\
\text{Nitrogen} \\
\text{Water gaseous} \\
\text{Water liquid} \\
\text{Oxygen}
\end{array} \right. 
\]
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

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

1. Mass balance
2. Energy balance
3. Which variables?

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:
\[ T \quad \dot{m} \quad P \]
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]

Take into account two modeling process constraints:

- Mass balance
- Energy balance

Physical analysis

- Mass balance
- Energy balance

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

\[
[m \cdot T \cdot P] \neq [W]
\]

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

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EMR’12, Madrid, June 2012
«5. Conclusion»
- 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 be 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 »
«New EMR approach for a multi domain-multivariable energetic flow»

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*EMR’12, Madrid, June 2012*


