« BACKSTEPPING CONTROL OF A FUEL CELL VEHICLE USING EMR »

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Safe energy management: stable control

- Fuel cell vehicle structure -

• Important driving range
• No local emission
• Power transients

traction power
fuel cell power (f(dUf/dt))
supercapacitor power

power (pu)
time (s)
Backstepping control of a FC vehicle using EMR

- EMR and Inversion-Based Control (2000)

- Backstepping: step by step iterative procedure (1990)

**assumptions**

- Graphical tool.
- Energy management and real time applications.
- Global stability not demonstrated.

**energetic approach**

- Electromechanical
- Thermal
- Electrochemical
- Piezo-electric

**inversion**

- Peugeot 3008 HY4, ...
- DW10, ...
- Ballard FC, ...
- Stimtac Standalone

**system model**

- Linear IM
- Autonomous vehicle “Red Rover”
- Duffing oscillator

**Representation (integral causality)**

- Local / Global Control

**strategy**

- Mathematical tool.
- Tracking control. Non linear systems. No EV and HEV application.
- Ensure a stable control.
**Objective**

- Deduce a stable control of a Fuel Cell/ Supercapacitor vehicle. It is possible to use EMR and Backstepping?

**Outline**

1. Modelling and Representations
2. Backstepping control
3. Simulation
4. Conclusion and perspectives
« 1. MODELLING AND REPRESENTATION »

« Backstepping control of a FC vehicle using EMR »

- EMR of the FC vehicle -
« Backstepping control of a FC vehicle using EMR »
- State representation of the FC vehicle -

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3 state variables: $u_{bus}$, $i_{fc}$, $i_{sc}$
2 tuning variables: $m_{hfc}$, $m_{hsc}$
2 cascade loops: $i_{hfc}$, $i_{hsc}$

Tuning path from EMR

State representation

$$
\begin{align*}
\frac{d}{dt} u_{bus} &= \frac{1}{C_{bus}} (i_s - i_{sc}) \\
i_s &= i_{hfc} + i_{hsc} \\
i_{hfc} &= m_{hfc} i_{hsc} \\
\frac{d}{dt} i_{hsc} &= \frac{1}{L_{hsc}} \left( u_{hsc} - m_{hfc} u_{bus} - f_{hsc} i_{hsc} \right)
\end{align*}
$$

« 2. BACKSTEPPING CONTROL »
1. External loop control law: dc bus voltage loop

error $e_i$

$$e_i = u_{bus-ref} - u_{bus}$$

energetic approach first feedback gain to solve $dV_i/dt \leq 0$

Stability criterion as $dV_i/dt \leq 0$

$$\begin{align*}
V_i &= \frac{1}{2} C_{bus} e_i^2 \\
\frac{d}{dt} V_i &= C_{bus} e_i \frac{d}{dt} e_i = -c_i e_i^2
\end{align*}$$

1st local control law

$$i_{s-ref} = c_i e_i + C_{bus} \frac{d}{dt} u_{bus-ref} + i_i$$

$$i_{s-ref} = P_{i}^{-1} u_{bus-ref} + i_i + e_i C_{i}$$

2. Parallel connection and boost choppers

$i_{hfc}$ and $i_{hsc}$ are mutually considered themselves as perturbations

Solution: Inversion Based Control rules.

coupling $\rightarrow$ repartition

conversion $\rightarrow$ direct inversion
3. FC and SC current loops

**Energetic approach**

Error $e_{2,3} = i_{fc,ac-ref} - i_{fc,ac}$

Stability criterion as $\frac{dV_{2,3}}{dt} \leq 0$

\[
V_{2,3} = V_1 + \frac{1}{2} L_{fc} e_{2,3}^2
\]

$4^{th}$ local control law

\[
m_{hfc,sc} = \frac{1}{u_{bus}} \left( -L_{fc,ac} \frac{di_{fc,ac-ref}}{dt} - L_{fc,ac} (i_{fc,ac-ref} - e_{2,3}) + u_{fc,ac} - e_{2,3} e_{2,3} \right)
\]

\[
\Rightarrow m_{hfc,sc} = \frac{1}{u_{bus}} \left[ u_{fc,ac} \left( P_{1}^{-1} i_{fc,ac-ref} + e_{2,3} e_{2,3} \right) \right]
\]
« 3. Simulation »

« Backstepping control of a FC vehicle using EMR »

- Specifications -

2 strategy levels
1. Bus voltage : $u_{bus-ref} = 80$ V (supply voltage of the traction of the Tazzari Zero)
2. SC recharge : Thermostat strategy

Fuel Cell vehicle parameters
- Fuel Cell 78-55 V, 20 kW
- Supercapacitor 54 V, 130 F
- Smoothing inductors 5.5 mΩ, 0.25 mH
- dc bus capacitor 80 V, 53 mF
- Electric drive 15 kW
- Vehicle 811 kg
- Feedback gains $c_1 = 0.62$, $\xi_{2,3} = 0.13$
Fixed step at 1 ms using continuous derivatives.

- Matlab Simulink Simulation -

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Energy management

Voltage regulation

- Simulation results -

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4. CONCLUSION AND PERSPECTIVES

Backstepping control of a FC vehicle using EMR

- Conclusion -
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Perspective : application in real time -

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- Reduced scale Hardware in the loop simulation.
- Filtering strategy
- Taking into account the perturbation (adaptive Backstepping)

• Definition of stability rules : EMR control formalisation.

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- References -