FUEL CELL SYSTEMS
THE CHALLENGE OF MULTIPHYSICS SIMULATION
Fuel Cell Systems
The Challenge of Multiphysics Simulation

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Agenda

- Motivation
- Fuel Cell System
- Development and Simulation Approach
- Challenges
- Summary and Outlook
Motivation

- Our Goal = Proof of Concept
  - Specify “Balance of Plant” (BoP) components of a complete fuel cell system
  - Provide control strategies
  - Support software development with Co-Simulation → provide initial calibration for test bench
  - Acceptable simulation performance
  - Use MathWorks environment → MATLAB/ Simulink/ Simscape/ Stateflow

- Status at project start
  - Basic Simscape model from MathWorks used
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Motivation

- Why Fuel Cell?
  - Sustainable Mobility
  - CO2 fleet target
  - High average power demands
  - Short charging time requirements
  - Continuous operation demand
  - Payload critical applications
  - Weight critical applications

Requirements - Fuel Cell

→ Competitive TCO (Total Costs of Ownership)
→ Holistic approach – Modularity, scaling
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Fuel Cell System – Physical Domains/ Subsystems

- Thermo-Fluids
  - Hydrogen supply (Anode)
  - Air supply (Cathode)
  - Low and high temperature coolant circuit

- Electrical
  - Low & high voltage system

- Mechanical
  - Compressor, Pumps

- Controls
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Development/ Simulation Approach

System Definition

Subsystem

Module

System

Vehicle

System Testing

Subsystem Testing

Module Testing

System Testing

Approval

Target Confirmation

System Verification
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Development/ Simulation Approach

Vehicle

Targets
- Speed, Acceleration
- Drive cycles
- Range

Fuel Cell System

Fuel economy
- Pay load
- Driving performance (e.g. power-weight ratio)

Subsystem

Module

System Definition
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Development/ Simulation Approach

- Requirements to powertrain
  - Power output
  - Transient behavior
  - Operating strategy
- Vehicle integration
- Tank capacity

System Definition

Vehicle
Fuel Cell System
Subsystem
Module

Load Follower
Range Extender
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Development/ Simulation Approach

- Requirements to subsystem
  - How to achieve the required system power?
  - Which components are needed, e.g. compressor?
  - Layout of subsystem circuits
Development/ Simulation Approach

- **Vehicle**
- **Fuel Cell System**
- **Subsystem**
- **Module**

- **Stack requirements**
  - Electrical Load
  - Operating Temperature
  - Anode/Cathode Pressure

- **Requirements of BoP components**
  - Air delivery → compressor, charge air cooler
  - H2 delivery → tank capacity, jet pump, blower
  - thermal subsystems → radiators, pump size
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Development/ Simulation Approach

- Test harness for BoP components
- Use fixed in- and outputs
- Calibrate to stack requirements
- Component supplier sourcing
- Use referenced models
Challenges: Jet pump

- Supersonic conditions at primary nozzle
  - Additional math required to avoid supersonic conditions, (only supported through customizations)

- Overdetermined system
  - Information transfer between stack inlet, outlet and recirculation path
  - Reduce complexity
  - Modularize physical system model (moist air) and calculate them individually

- Purging interferes with “usual operation” (recirculation) – breaking the algebraic loop
  - Purge path into exhaust parallel to recirculation path
  - Additional math required
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Challenges: Passive Humidifier

- Water transport
  - create piping enabling transport from wet side to dry side
  - removal of transferred water vapor from wet side
- Thermal coupling
  - coupling of wet and dry side to improve accuracy of simulation
- Bypass design
  - modelling of local restrictions in terms of pressure drop
  - sizing of passive bypass throttle to maintain a specific mass flow
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Challenges: Controls/ Co-Simulation

- Fixed time step – model discretization
  - Performance-accuracy tradeoff (optimal time step)
- Continuous ↔ Discrete domains
- Tuning gains in cascaded controller
  - Cascaded control architecture
  - Sampling time selection
- Continuous development of plant environment
  - Integration through reference subsystems
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Summary and Outlook

Summary:
- Model accuracy improved
- Control strategies implemented
- Deeper understanding of Simscape modeling & troubleshooting thanks to MathWorks support

Outlook:
- Validate model with fuel cell test bench data
- Increase flexibility by using referenced/variant models for component selection
- Move from moist-air to a custom multi-species domain in Simscape to track more species, like N2, O2, H2...
THANKS