Pressurized SOFC for Efficient Hybrid Power Plants

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Overview

- Hybrid power plant
  - Motivation
  - Challenges and approach

- Pressurized SOFC
  - Experimental setup
  - Modeling
  - Experimental results and model validation

- System
  - Gas turbine
  - Efficiency
  - Current work
Overview

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Hybrid Power Plant – Motivation

Combination of SOFC and gas turbine
- Fuel flexibility (natural gas, biogas, reformates, hydrogen)
- High electrical efficiencies of 50-70 % (LHV)
- High part load capability
- Scalability
Challenges and Approach

Complex interaction between turbine and SOFC system
- SOFC operating pressure determined by gas turbine
- Small tolerance of differential pressure of SOFC
- Matching of SOFC and gas turbine
- Temperature management

Combined theoretical and experimental approach
- Experiments on pressurized SOFC stacks
- Multi-scale modeling of SOFC stacks
- System modeling
- Construction of demonstration power plant
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Presurized SOFC – Experimental setup

- Pressure: 1 to 8 bar
- Temperature: up to 950 °C
- Anode gas:
  - H₂, N₂, CH₄, CO, CO₂, H₂O
- Cathode gas:
  - Air, O₂, N₂
- Various stack designs
- Fuel cell and electrolysis mode

- Analysis
  - V(i)-characteristics
  - Gas analysis
  - Impedance spectroscopy
Pressurized SOFC – Multi-scale modeling

- Based on in-house software DENIS
- Elementary kinetics at anode
- Butler-Volmer kinetics at cathode
- Diffusion in porous electrodes
- 2D-simulations along gas channels and through MEA
- Navier-Stokes equations for gas transport in channels
- Gas distribution to single cells
- Isothermal calculations for each cell
- Thermal coupling of adjacent cells and surroundings

Pressurized SOFC – V(i) characteristics

Pressurization results in:
- Higher OCV
- Decrease of slope
- Improved performance
- Enhanced efficiency

Model validation:
- Wide range of operating conditions
  - Pressure
  - Temperature
  - Gas composition at anode and cathode, including reformate gases
Pressurized SOFC – Impedance spectra

Impedance spectroscopy allows for better understanding of processes and dependencies at cell

Higher pressure leads to:
- Constant ohmic resistance
- Polarization impedance decrease
- Gas concentration resistance fairly constant
- Ohmic resistance
  - Independent of pressure
  - Dependent on temperature → determination of temperature changes of cell
- Results used for model validation

Higher pressure leads to:
- 1.35 bar
- 4 bar
- 8 bar

Anode
- 70 Hz
- 4 kHz
- 10 mHz

Cathode
- Gas Concentration

Experiment
Fit

R_{HF} = 0.23 \, \Omega \cdot \text{cm}^2
R_{LF} = 1.35 \, \Omega \cdot \text{cm}^2
R_{HF} = 0.23 \, \Omega \cdot \text{cm}^2
R_{Pol} = 0.95 \, \Omega \cdot \text{cm}^2
R_{Pol} = 1.18 \, \Omega \cdot \text{cm}^2
R_{Pol} = 0.91 \, \Omega \cdot \text{cm}^2
R_{LF} = 1.14 \, \Omega \cdot \text{cm}^2
Pressurized SOFC – Reformate gases
Power density increase

- Logarithmic behavior for all fuels
- Highest absolute increase for reformate 2 at 800 °C (154 mW/cm²)
- At 700 °C smaller power density increase
- At 700 °C similar performance of H₂/N₂ and reformate 2

Fuels: H₂/N₂
Reformate 1: 18% H₂, 34% H₂O, 2% CO, 27% CO₂ and 19% CH₄
Reformate 2: 58% H₂, 20% H₂O, 12% CO, 6% CO₂ and 4% CH₄
Pressurized SOFC – Reformates Temperature

- Internal reforming leads to cooling of stack
- Lower temperature leads to lower performance
- Same stack temperature leads to similar performance

- Cooling is pressure dependent because equilibrium is pressure dependent
- Low current density: temperature increases with pressure
- High current density: Temperature decreases with pressure

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System
Gas turbine

- Micro gas turbine by MTT
- 3 kW electric
- Normally used for CHP
- Electrical efficiency 12%

Characterization and adaptation for Hybrid Power Plant at DLR-VT:
- Understanding the behavior at different operating points and load changes
- More flexibility in control parameters
- Adaptation of control to demands of Hybrid System
System – Efficiency

- Fixed system components
- Variable turbine speed
- Variable SOFC electrical power
- Large power range from 200 kW to 700 kW
- Very high efficiency of 60% from 300 kW to 700 kW
System – Current Work

- Dimensioning and construction of demonstration power plant (approx. 15-30 kW\textsubscript{el})
  - SOFC stack size
  - Reformer, recirculation (ejector)
  - Experimental analysis of acceptable differential pressures between anode and cathode
  - Characterization of micro gas turbine (3 kW\textsubscript{el})
Conclusions

- Positive influence of pressure on SOFC performance
- Similar increase for different fuels
- Internal reforming leads to pressure dependent cooling of stack and lower performance

- Large power range of system with high efficiency is possible
- Construction of demonstration plant at DLR has started
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Thank you for your kind attention!