System concepts for distributed and grid-scale electrical energy storage with reversible solid oxide cells

Christopher Wendel, Robert Braun
Department of Mechanical Engineering, College of Engineering and Computational Sciences, Colorado School of Mines, 1610 Illinois Street, Golden, CO

Motivation for electrical energy storage:
- Integrating intermittent renewable energy sources ($46\text{ Billion}^*$)
- Reduce ramping and capacity from conventional sources ($39\text{ Billion}^*$)
- Transmission and distribution (T&D) congestion relief ($7\text{ Billion}^*$)
- Time-shifting energy within a time-of-use utility pricing structure ($79\text{ Billion}^*$)

Energy storage with reversible solid oxide cells
A solid oxide flow battery (SOFB) is proposed as an electrical energy storage system employing reversible solid oxide fuel cell technology.

Objective
Determine favorable system configurations and operating conditions for a novel electrical energy storage system utilizing reversible solid oxide cells.

Reversible SOC characteristics
- Overpotential in both modes (high $V_{oc}$, low $V_{oc}$)
- Counter flow
- Ensure good rSOC durability
- No pressure drop in components
- Economic analysis on application specific EES
- One − Gas delivery: Pumps
- Thermal management

Operating conditions analysis
Operating conditions must be selected to:
- Promote methanation for thermal management
- Allow high stack efficiency (low overpotential)
- Ensure good rSOC durability − cooling, air drying

Using rSOCs for energy storage
In addition to rSOC stack...
- Gas storage: Tanks
- Gas delivery: Pumps
- Thermal management

Operating parameter variation
As stack pressure increases...
- Stack efficiency increases
- System efficiency decreases
- Stored methane fraction increases
- Evaporator load decreases
- Compressor power increases

As hydrogen-to-carbon ratio increases...
- Stack and system efficiency decrease
- Dry methane fraction decreases
- Evaporator load increases

Conclusions
1. Reversible solid oxide cells can be used to efficiently store electrical energy in the form of methane gas
2. High performance is achieved with high system complexity
3. The energy storage application will determine the level of complexity required based on the performance requirements

Future work
- Economic analysis on application specific EES

Acknowledgments & References

References

System modeling assumptions:
- Thermodynamically modeled components
- Adiabatic components
- 85-90% isothermal turbomachinery efficiency
- No pressure drop in components
- Multi-stage compressor

Stack modeling assumptions:
- One-dimensional, cell level
- Counter flow
- Planar, anode supported Ni/YSZ/YSZ/LSM
- Area-specific resistances $<< 0.20 \text{ cm}^2$
- Current density $<< 0.05 \text{ A/cm}^2$

Baseline system modeling results

Advanced system configurations
- Multi-stage compressors reduce auxiliary power

Methanation reactor increases storage energy density

Transmission and distribution (T&D)
- Reduce ramping and capacity from conventional sources
- Integrating intermittent renewable energy

Roundtrip energy storage system utilizing reversible solid oxide cells

Distributed and grid-scale applications

1. Gas delivery: Pumps
2. Thermal management

System roundtrip efficiency
To achieve competitively high system efficiency (~70%):
- Small overpotential in both modes (high $V_{oc}$, low $V_{oc}$)
- Low balance of plant (BOP) power

In addition to rSOC stack...
- Gas storage: Tanks
- Gas delivery: Pumps
- Thermal management

Operating parameter variation
As stack pressure increases...
- Stack efficiency increases
- System efficiency decreases
- Stored methane fraction increases
- Evaporator load decreases
- Compressor power increases

As hydrogen-to-carbon ratio increases...
- Stack and system efficiency decrease
- Dry methane fraction decreases
- Evaporator load increases

Conclusions
1. Reversible solid oxide cells can be used to efficiently store electrical energy in the form of methane gas
2. High performance is achieved with high system complexity
3. The energy storage application will determine the level of complexity required based on the performance requirements

Future work
- Economic analysis on application specific EES

Acknowledgments & References

References