Optimizing the operational efficiency of a PEM hydrogen fuel cell for applications in a hybrid electric vehicle

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Background

- Duke Electric Vehicles competes in the Shell Eco-Marathon annually.
- 1st place Battery-Electric Prototype at 2017 competition.
- 296 ml/kWh
- Equivalent to 9.976 MPG-e
- Expanding to hydrogen fuel cell category for 2018.
- Eco-Marathon is competition for efficiency.
- Previously: optimize aerodynamics, rolling resistance, weight, motor controller, battery management system.
- New considerations with hydrogen fuel cell (H2FC) implementation in the electric vehicle.

Objective

Goal: optimize H2FC to maximize efficiency
- Variables: humidity, temperature, pressure, purging frequency, fan speed, short circuit.
- Change operating conditions of commercial fuel cell by controlling variables.
- Reduce variability in load to fix operating point.
- Vehicle power has significant spikes in load during acceleration or climbing hills, while is constant and low while driving on flat roads.

Methods

Optimize H2FC operational efficiency
- Generate IV curve for the fuel.
- Derive power curve as a function of load.
- Use flowmeter to determine efficiency vs. load.
- Change variables, determine impact on efficiency.
Setup:
- Compressed hydrogen tank + pressure regulator.
- Flowmeter attached between tank and H2FC.
- Slide resistors to manually change load.
- 2 multimeters to determine voltage and current at each load value (voltmeter connected in parallel with fuel cell, ammeter in series).
- Energy in with flowmeter, energy out by IV curve.

Determine best way to vary controllable variables:
- Humidity, temperature, pressure, purging frequency, fan speed, short circuit.
- Focused on pressure, purging frequency, fan speed: have biggest impact on efficiency.
- Pressure: inlet pressure of hydrogen.
- Purging: commercial fuel cell purges excess hydrogen + humidity every 10 s.
- Fan speed: cools fuel cell and provides air.

Energy Storage

- Car speed kept constant to minimize aerodynamic losses.
- Motor is off for majority of lap due to track elevation profile.
- Power demanded in short, powerful bursts.
- Energy storage system developed to allow FC to store energy in supercapacitor bank.
- Motor draws directly from this bank in bursts.
- Power converter is fully controllable.
- Operates at 96% efficiency.
- Allows fuel cell to be run at its optimal point.

Fuel Cell Optimization

- Decreasing purge frequency improved efficiency.
- No significant decrease in efficiency over time.
- Reducing fan speed rapidly dropped power.
- Change in temperature over time.
- Increasing pressure improved efficiency.

Fuel Cell Characterization

- Commercial Horizon 100W PEM fuel cell.
- Rated for 40% at 100W.
- Standard operating points:
  - 7.5 psig inlet hydrogen pressure.
  - 10s purging frequency for 100ms.
  - 10s SCU frequency for 100ms.
  - Fan speed PWM 12% on at 12 V.

Conclusions and Next Steps

- Planning to run fuel cell at constant 50W.
- Predicted efficiency is 53.5%.
- Significant improvement over varying fuel cell load: 22% more efficient.
- Optimal running parameters:
  - No purging, fan on, pressure 7.5 psig.
  - Next step: Experiment with inlet humidity effects.
  - Isolate air flow from temperature.
  - Implementation of H2FC in vehicle (redesign).

References