Sustainable Energy
Mod. I: Fuel Cells & Distributed Generation Systems

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Lesson VIII: fuel cell systems (power conditioning)
Fuel Cell Power System Scheme

- Synthesis gas
- Hydrogen reformate
- Natural gas or SNG
- Low-sulfur distillate
- Naphtha
- Methyl fuel
- Heavy oils
- Coal
- Solid waste

Fuel processor

- Water

Fuel cell power section

- DC power

Power conditioner

- AC power

Heat

Cogeneration or bottoming cycle
Power Conditioning Basis (1/2)

- Power conditioning is an enabling technology that is necessary to convert DC electrical power generated by a fuel cell into usable AC power.
- The DC voltage generated by a fuel cell stack varies widely and is low in magnitude (<50V for a 5 to 10kW system, <350V for a 300kW system).
- A step up DC-DC converter is essential to generate a regulated higher voltage DC (400V typical for 120/240V AC output).
- A DC-AC inverter is essential to provide the DC to useful AC power at 60Hz or 50Hz frequency.
- An output filter connected to the inverter filters the switching frequency harmonics and generates a high quality sinusoidal AC waveform suitable for the load.
Power Conditioning Basis (2/2)

✓ DC/AC converter working principle.

IGBT = Insulated Gate Bipolar Transistor
Fuel cell power conversion for a 10 kW stand-alone load is an example for distributed generation.

- The power conversion must be capable to deliver rated power while regulating output voltage (less than 5% total harmonic distortion).
- Peak power must be supplied from some other energy source such as a battery.
Fuel cell output DC (say 29V to 39V) is converted to a regulated DC output (say 50V) by means of a simple DC-DC boost converter.

The output of the DC-DC converter is processed via a pulse width modulation (PWM) DC-AC inverter to generate a low voltage sinusoidal AC.

A line frequency isolation transformer with a turns ratio of 1:3.5 is then employed to generate 120V/240V AC output as shown.

42 to 48V battery is connected to the output terminals of the DC-DC converter to provide additional power at the output terminals for start-up and load change phases.

Assuming a motor-starting current of 3 to 5 times the rated value, the DC-AC inverter rating will be in the 15 kVA to 25 kVA range.
Fuel Cell Supplying a Dedicated Load (3/8)

Power conditioning: line frequency transformer (2/3)
Fuel Cell Supplying a Dedicated Load (4/8)

Power conditioning: line frequency transformer (3/3)

Efficiency calculation example:

- DC-DC converter efficiency = $\eta_1 = 0.95$
- DC-AC inverter efficiency = $\eta_1 = 0.95$
- Line frequency isolation transformer efficiency = $\eta_3 = 0.98$
- The overall efficiency of the power conditioning: $\eta = \eta_1 \times \eta_2 \times \eta_3 = 0.88$
Fuel Cell Supplying a Dedicated Load (5/8)

Power conditioning: high frequency isolation transformer (1/4)

✓ In this design, the low frequency isolation transformer has been eliminated by employing an additional DC-DC conversion stage.
✓ The 50V to 400V DC-DC conversion stage includes a high frequency isolation transformer.
✓ The fuel cell and the first DC-DC converter are rated for steady state conditions.
✓ The second DC-DC converter, along with the DC-AC inverter, is rated for steady state and transient conditions.
✓ This approach suffers from three power conversion stages in the power flow path, which contributes to reduced efficiency.
Fuel Cell Supplying a Dedicated Load (6/8)

Power conditioning: line frequency transformer (2/4)
Fuel Cell Supplying a Dedicated Load (7/8)

Power conditioning: high frequency isolation transformer (3/4)

- Power conditioning unit with fewer power conversion stages in series
- A push-pull type boost converter with a 1:10 gain employing a high-frequency isolation transformer is used.
- The output of the push-pull DC-DC converter is set to 400V.
- The DC-DC converter output is connected to two half bridge dual voltage DC-AC inverters to obtain 120/240V AC output.
- Assuming conversion efficiency of the DC-DC and DC-AC stages to be 96% each, an overall efficiency of 92% can be realized with this approach.
Fuel Cell Supplying a Dedicated Load (8/8)

Power conditioning: high frequency isolation transformer (4/4)
Conventional uninterruptible power supply (UPS) systems employ engine generators and batteries for backup.

Among the various kinds of fuel cells, proton exchange membrane fuel cells (PEFC) are compact and lightweight (apt for this purpose).

Two commercially available PEFC fuel cells (25 to 39V, 500W) along with suitable DC-DC and DC-AC power electronic converter modules.
FC: Load and Local Utility (FC is UPS) (2/3)

### Fuel cell data

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Output (Continuous)</td>
<td>500 W</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>25 to 39 DC</td>
</tr>
<tr>
<td>Fuel Source</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>7.0L/min @ 500W (&lt;1.0L/min @ no load)</td>
</tr>
<tr>
<td>System Start Time</td>
<td>5 minutes @ room temperature</td>
</tr>
<tr>
<td>Turndown Ratio</td>
<td>500W to no load, infinity</td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>41°F to 95°F (5°C to 35°C)</td>
</tr>
<tr>
<td>Dimension (W x D x H)</td>
<td>22.3” x 24.2” x 13.6” (0.056m x 0.615m x 0.345m)</td>
</tr>
<tr>
<td>Weight</td>
<td>97 lbs w/c with 44kg w/cartridge</td>
</tr>
</tbody>
</table>

Two fuel cells to supply a load via a line frequency isolation transformer
FC: Load and Local Utility (FC is UPS) (3/3)

Two fuel cells using a higher voltage (400V) DC-link
FC in Parallel With a Local Utility

- The peak power (as well as the inrush current) demanded by the load is provided by the utility.
- A constant fuel cell power level can be set.
- In the event of a utility failure, the fuel cell system does not have the ability to supply inrush current to loads such as for motor starting etc.
- Special circuit breakers to isolate loads up to the capacity of the fuel cell are necessary.
The fuel cell power connected to the utility must be disconnected immediately in case of utility failure. The DC-DC converter and the DC-AC inverter are controlled separately. A line frequency isolation transformer is shown to match the output AC voltage of the fuel cell unit with that of the utility.
Power Conditioners for Automotive FC (1/2)

- Fuel cell vehicle main components: (a) fuel processor; (b) fuel cell stack, and (c) power conditioning unit (DC-DC or DC-AC) to power a traction motor (AC or DC).
- A fuel cell system for vehicles must have weight, volume, power density, start-up, and transient response similar to the present internal combustion engine-based vehicles. PEFC is the best solution (low temperature, high power density, high efficiency).
Power Conditioners for Automotive FC (2/2)

- Three Phase variable speed AC traction motor load.
- Battery is necessary for start-up and load peaks.
- Fuel cell accessory loads are powered from the battery.
MCFC and SOFC are ideal candidates for hybrid systems.
Pressurized SOFC with a micro-turbine generator (system with a nominal capacity of 250 kW): power generating efficiency higher than 60%.
The SOFC will produce about 80% of the electrical power and the micro-turbine will produce the remaining 20%.
An alternative solution may be based on a shared DC link. The SOFC DC-DC converter and the micro-turbine PWM rectifier stages output are parallel to form a common DC-link. The main advantage of this approach is that only one common DC-AC power conditioning unit is necessary.
FuelCell Energy Inc. (FCE) is developing an ultra-high efficiency fuel cell/turbine hybrid power plant. System development is being conducted under the Department of Energy and managed by the National Energy Technology Laboratory (NETL). The project objectives include the design of a 40 MW system. Two fuel cell/turbine hybrid systems with common DC-link are connected in series via their respective DC-DC converter stages to form a high voltage dc-link (6,000V).