Power-GEN Asia

60 Million Hours of Learning: Increasing Gas Turbine Operability and Flexibility Through DLN Experience

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All relative statements are with respect to GE technology unless otherwise noted.
Outline

• GE Dry Low NOx (DLN) experience
• Combustion challenges
• Combustion system evolution
• DLN enhancements and real world examples:
  – E-class: reduced emissions and increased turndown
  – F-class: expanded hydrocarbon and liquid capabilities
• Evolution of the HA combustion system
• Summary
GE Power & Water

Power Gen Products
Over 4,400 heavy duty gas turbines globally

Distributed Power
Over 30,000 aeroderivative turbines and gas engines globally

Renewables
Over 22,000 wind turbines

Diverse technology and services solutions ... over 1,000GW installed globally
Proven DLN combustion systems

• 28 million fired hours on GE’s DLN1/1+ combustion systems on B and E-class gas turbines

• 46 million fired hours on GE’s F-class DLN2.X combustion systems, which includes the DLN2.6 and DLN2.6+ combustors

• 200,000 fired hours on GE’s H-class DLN2.6+ combustion system
Combustion Challenges
Gas turbine combustion challenges

The flame must be anchored in the equivalent of a 100 mile per hour wind

Chemical reactions must occur in a fraction of a second as air and fuel flow rush through the combustor
DLN operability is the optimization of multiple parameters.
State of the art combustion test facility
A key to developing advanced technology

• Lab capabilities:
  – Full pressure, temperature, and flow
  – Fuel blending capability for H2, N2, CO, CO2, H2O, and a variety of non-methane hydrocarbons
  – Monitoring emissions and operability characteristics at full load & part load conditions
  – Full scale combustion tests allow evaluation of new combustion concepts, and technologies being transferred from one platform to another, over a wide range of operating conditions
Combustion System Evolution
Gas turbine combustion technology evolution

- **B & E**:
  - Standard combustor: Single diffusion nozzle
  - Multi Nozzle Quiet Combustor: Multiple diffusion nozzles

- **F**: DLN1: Diffusion + Premixed nozzles (1989 - present)

- **HA**: DLN2.0: Premixed (5 nozzles) (1990's - 2000's)

- **Late 1990's - 2000's**
  - DLN2+ Swozzles: Late 1990's - 2000's
  - DLN2.6: Center nozzle (1995 - present)

- **2005 - present**
  - DLN1+: Diffusion + Premixed (2005 - present)
  - DLN1: Axial fuel staging (2012 - present)

- **2014 - ?**
  - DLN2.6+: Axial Fuel staging (2014 - ?)

- **2006 - present**
  - DLN2.6+: Swozzles + center nozzle (2006 - Present)
Merging combustor technology

- Increased fuel flexibility
- Axial fuel staging

B/E (DLN1/1+)
- DLN2.6+
- Combustion system
- F (DLN2.6, DLN2.6+)

HA (DLN2.6+AFS)
E-Class Expanded Capabilities
Customers continue to use highly reliable E-class gas turbines to support the need for reduced emissions and increased fuel flexibility.
Evolution of E-class emissions

**NO\textsubscript{x} (tons) / MW-year**

- 42 PPM
- 15 PPM
- 5 PPM
- 4 PPM

**Water Injected**

**DLN fleet experience**

<table>
<thead>
<tr>
<th>Frame</th>
<th>DLN1</th>
<th>DLN1+</th>
</tr>
</thead>
<tbody>
<tr>
<td>6B.03</td>
<td>220+</td>
<td>6</td>
</tr>
<tr>
<td>7E.03</td>
<td>420+</td>
<td>23</td>
</tr>
<tr>
<td>9E</td>
<td>200+</td>
<td>2</td>
</tr>
</tbody>
</table>

More than 730,000 fired hours on DLN1+
Increased fuel flexibility for B and E-class gas turbines

Supporting refinery, petrochemical and shale gas applications

• New fuel flex capabilities demonstrated using GE’s full scale combustion test facility in Greenville, SC
  – 10 full scale test cells
  – Full flow, temperature and pressure
  – Enhanced gas blending capability, including: H2, C2H6, C3H8, etc.

• Expanded fuel capabilities reflect needs for operability on a wider range of non-methane hydrocarbons

<table>
<thead>
<tr>
<th>Fuel components</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen (H₂)</td>
<td>In excess of 30%</td>
</tr>
<tr>
<td>Ethane (C₂H₆)</td>
<td>Up to 60%</td>
</tr>
<tr>
<td>Ethylene (C₂H₄)</td>
<td>Up to 49%</td>
</tr>
<tr>
<td>Propane (C₃H₈)</td>
<td>Up to 100%</td>
</tr>
<tr>
<td>Propylene (C₃H₆)</td>
<td>Up to 35%</td>
</tr>
<tr>
<td>Butane (C₄H₁₀)</td>
<td>Up to 100%</td>
</tr>
</tbody>
</table>
F-Class Expanded Capabilities

- Expanded higher hydrocarbon limits
- Arabian Super Light crude oil
Expanding non-methane hydrocarbon fuel limits

- Leveraging learnings from E-class combustion systems through field experience and combustion testing
- Increasing the maximum allowed levels of non-methane species in gas fuels in F-class DLN combustion systems
- Pushing the allowable Modified Wobbe Index* range from 20% up to 30% based on specific frame and required emissions - this increase can support a variety of fuel applications, including increased ethane content (i.e. shale gas), switching between NG and LNG sources, etc.

* Modified Wobbe Index = Lower Heating Value/√(specific gravity of the fuel* fuel temperature)
OpFlex* AutoTune DX

- The controls on GE’s F-class gas turbines are based upon a Model-Based Control (MBC) system.
- These control systems couple a full thermodynamic model of the gas turbine that includes a detailed combustor models with a variety of sensor inputs.
- The result is real time, closed-loop tuning of the DLN combustion system, which is able to adapt quickly to changes in the operating environment.

Model based control (MBC) turbine thermodynamic cycle model (ARES) plus closed-loop DLN control module.
Example: Response to shale gas transients
(Site in Ohio, May 2013)

Monthly Gas heating value variability
(May 1-31, 2013)

By adjusting GT operating parameters, the AutoTune system maintained stable gas turbines output.

- ~70 Btu/SCF (~7% MWI) change in ~30 min
- ~90 Btu/SCF (~9% MWI) change in ~45 min
Due to changing fuel requirements in Saudi Arabia, GE evaluated the potential to use Arabian Super Light (ASL) crude oil in a F-class DLN combustor. Based on the successful results of this evaluation process, GE offered ASL as a back-up fuel for multiple projects in Saudi Arabia. GE will have more 27 7F gas turbines in Saudi Arabia capable of operating on ASL.
Evolution of the HA Combustion System
Breaking the flame temperature/NO\textsubscript{x} paradigm

• To meet needs for increased output and efficiency, gas turbines must operate with increased firing temperature – However, this leads to an increase in NO\textsubscript{x} emissions

• One way to prevent this concern is to have separate heat release zones to distribute temperature rise through the combustor
Summary

• GE’s combustion test facility enables evaluation of almost any fuel composition at full-scale conditions. This enables GE’s heavy-duty gas turbines to have industry leading fuel flex capabilities.

• Combining GE’s extensive DLN field experience with state-of-the-art combustion test capabilities allows GE gas turbines to have industry leading performance with lower emissions, and better operability over a wide range conditions.