H-class Technology update

REDEFINING RELIABILITY AND EFFICIENCY

Marcus Scholz

March 21, 2014 | Singapore
Lloyd’s of London – Insurance Seminar

GE provides Insurance community bi-annually with updates on New products, F-fleet status, issues & resolutions.

Informative sessions take place with Brokers, Engineers, Underwriters and Advisers.

Historic Venue: Lloyd’s Library, Lime street

Lloyd’s coffee house began 325 yrs ago as marine insurance for ships and cargo. This bell is still rung when a ship capsizes.
Agenda

- Advanced GT naming & status
- F & H Gas Turbine Fleet: experience & evolution
- HA Gas Turbine technology: heritage and capability
- FlexEfficiency* plant design
- Validation and testing: full scale test facility
- Summary

* Trademark of General Electric Company
### F & H-class gas turbine naming update

Align the FlexEfficiency* 50 & 60 Hz portfolio

Link scaled & parallel technologies between 50 and 60 Hz

Simplify ... eliminate FA and FB designation

Continue the ‘H’-class heritage with over 10 years operating experience.

H – class indicates: >2600F Tfire and 4-stage turbine.

<table>
<thead>
<tr>
<th>Previous</th>
<th>Current</th>
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<tbody>
<tr>
<td>7F/7FA.03/7FA.04 7FB/7F Syngas</td>
<td>7F.03</td>
</tr>
<tr>
<td>7FA.05</td>
<td>7F.05</td>
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<tr>
<td>7FA.06</td>
<td>7F.07 7HA</td>
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<tr>
<td>9F/9FA.03/ 9F Syngas</td>
<td>9F.03</td>
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<tr>
<td>9FB.03</td>
<td>9F.05</td>
</tr>
<tr>
<td>9FB.05</td>
<td>9F.07 9HA</td>
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FlexEfficiency* Portfolio

**HA denotes: ‘Air-cooled’**

Responding to customer requests & ‘H’-heritage

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Manufacturing 1<sup>st</sup> unit 9HA – Nov. 2013

Fully assembled casing

Fully assembled rotor

1<sup>st</sup> unit 9HA is fitted with additional instrumentation for the Full Load test in 2014
9HA Final assembly

Technical Data

<table>
<thead>
<tr>
<th>Model</th>
<th>GT output</th>
<th>1x1 CC output</th>
<th>2x1 CC output</th>
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</thead>
<tbody>
<tr>
<td>GE GT-9HA</td>
<td>397 MW</td>
<td>592 MW</td>
<td>1181 MW</td>
</tr>
</tbody>
</table>

A 41%+ efficient Gas Turbine supporting 61%+ Combined Cycle Efficiency
9HA transport to Full Load Testing

Convoy dimensions:
- 390 tons
- 100 m length
- 6.6 m width
- 5.7 m height

Road ➔ Barge ➔ Ship ➔ Test stand
Unique Full Load test facility

World class, full-scale gas turbine and compressor validation facility

- Disconnected from grid
- Variable speed, variable load
- Adjustable pressure control
- Massive data bandwidth

More comprehensive data than any 8000 hour field tests
Technology heritage
Experience matters …

GT installed base ~1,300 GW
More than half is GE

4600 units  Global installed base

173 M hours  Fired hours

2.3 M starts  Fired starts

More experience & better reliability than all others combined

<table>
<thead>
<tr>
<th></th>
<th>GE fleet</th>
<th>All others</th>
<th>Δ</th>
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<tbody>
<tr>
<td>Reliability</td>
<td>98.2</td>
<td>97.0</td>
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<tr>
<td>Availability</td>
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<tr>
<td>Start Reliability</td>
<td>98.0</td>
<td>97.0</td>
<td>+1.1</td>
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</tbody>
</table>

Source: ORAP®, All rights to Underlying Data Reserved: SPS®, Modified by GE. Rolling 12 Month Data Apr’12-Mar’13.
GE Gas Turbines... largest installed fleet

- Largest installed base of any gas turbine provider ... >4,600 units in operation
- Low installed & lifecycle cost with high reliability and availability
- Industry leader in operational and fuel flexibility ... start time, ramping, turndown

GT Rating

- 43 MW: 6B
- 89 MW: 7E
- 130 MW: 9E
- 78 MW: 6F
- 171 - 216 MW: 7F
- 250 - 300 MW: 9F
- 240*/350* MW: 7/9H

* estim. Simple cycle
F & H platform evolution – 50 & 60 Hz

GE’s leading role in Industry:

- Invented ‘F-class’ turbine in 1986 (60 Hz)
- Pioneered ‘H-class’ turbine in 2003 (50Hz)
- First with single digit DLN
- First OEM to ship >1000 large units (>150MW)
Industry-leading ‘H’-class experience

> 10 years ‘H’-class operating experience


- 4-stage turbine operation
- multiple VGV compressor operation
- steam cooling integration experience
- DLN 2.5H ultra low emissions operation
- 6x units in operation with over:

200,000 fired hours on ‘H’-class gas turbines
Gas turbine technology evolution

- 7F.04: 3 Stage Hot Gas Path
- 7F.05: 14 Stage Compressor
- 9HA: 4 Stage Hot Gas Path
- 7HA: DLN 2.6+ Combustion

Modular progression of proven technology

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7 & 9HA Gas Turbine platform

41%+ simple cycle efficiency, air-cooled

14-stage compressor built off the 7F.05

Air-cooled 4-stage hot gas path

DLN 2.6+ combustion platform for wide fuel capability & low turndown
Compressor heritage

Heritage
- GE90 & GEnx
- 7F 5-series compressor validated in August 2011

Performance
- 3D Aero, 14 stages
- Hybrid radial diffuser
- Non-integral bearing
- Oversized for grid code

Maintainability
- Field replaceable blades
- Improved borescope access
- Blade health monitoring
- Automated water wash

3D aerodynamic airfoil

10-stage, 23:1
14-stage, 20:1
DLN 2.6+ combustion system

Combines attributes of DLN 2+ and DLN 2.6 combustion systems

- Six fuel nozzles instead of five - increases control
- Advanced coatings and materials - provides increased durability
- Asymmetric fuel flow control – provides operational flexibility
- Emissions < 25ppm NOx & CO
- Dual fuel capable

DLN2.6+ combustion system experience:

- 65 Operating 9F Gas turbine units
- >900,000 Fired hours
Power turbine features

Performance and improvements
Hot gas path evolution
3D aerodynamic
Improved clearance management
3 and 4 stages experience
Lessons learned

Hot gas path materials
Single crystal (SX) technology
Aero technology transfer 2002
Largest operating fleet, FB & H

Super-alloy wheels
Proven Ni-Fe Alloys
Aero-engine cyclic duty design
Applied to FA, FB & H gas turbine fleets

GE’s material selection supports the longest rotor life in industry!
GE Single Crystal Experience

Single crystal components
- Longer overall life
- Higher availability
- Proven repairs

Introduced in late 1980
- >30 gas turbine models
- >31,500 gas turbine engines
- >100,000,000 hours of operation
- >180 qualified repair types
- 13 qualified repair shops

GE Turbines with single crystal material
- CFM56, CF6, GE90, GENx: 30,600+
- LM2500+, LM6000, LMS100: 980+
- 7F 3-series, 7F & 9F 5-series: 100+
- 7H, 9H: 6
FlexEfficiency* 50 plant design concept
Value of FlexEfficiency*50 & 60

Introducing the FlexEfficiency Portfolio

Record breaking Efficiency

Proven Reliability

Unmatched Flexibility

Lifecycle value

Unprecedented Validation

plants + gas turbines + steam turbines + generators + plant controls = FlexEfficiency Portfolio

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Flexibility ... a complete plant approach

Plant features
- HRSG/ at temperation
- Steam bypass
- Temp & pressure control

Gas turbine features
- Rotor architecture/clearances
- Casings & cooling designs

Steam turbine features
- Architecture & clearances
- thermal transient capability

Controls features
- Digital fieldbus architecture
- Physics based plant modeling
- OpFlex* software utilization

All plant components contribute to flexible operating concept
FlexEfficiency 50 – an integrated plant

D-650 Steam Turbine
- 3-Casing HP/IP/2-Flow LP
- Enhanced 42” or 33+” LP sections
- Single side exhaust – reduced centerline
- >40% shaft efficiency

W84 Generator
- Water cooled stator
- Reduced site assembly
- Sliding feature for maintenance

9HA - Gas Turbine
- Advanced compressor & turbine design
- >40% SC efficiency

3-Pressure drum HRSG w/reheat
- Fast start capability
- Cyclic capability
- Modularized construction

Optimized plant layout & design
- Elect., mech., centerline separation
- Improved maintenance access
- Pier foundation design – CC ST valves
- Best in class Power Density

Flexible plant design
- 33 pre-designed options
- Standard interfaces

2.5 year NTP to COD
- Pre-commissioned skids
- Fieldbus – 60% less wire
- Flexible installation schedule

GE Confidential & Proprietary
Validation & testing
Traditionally, new Gas Turbine technology was tested and validated at customer site, due to the GT size and test stand operating costs. (GE’s 7/9 FA’s, FB’s & 7/9H’s)

Testing could only be conducted with limitations due to grid connection and commercial constraints. (fixed speed, low risk trials, insufficient instrumentation)

Long term costs of development and site change-out are significant and further represent a revenue risk for customer.

Time frame to mature technology acceptance was in excess of 2-3 years.

Substantial benefits for Customers, OEM (Engineering) and Insurance / Finance community, GE invested over $185 MM in a purposely designed test bed for large Gas Turbines.

⇒ Full scale & full load validation
Gas Turbine testing - “a decade of validation”

Jet engine test cell ➤ GE off grid test stand

- Full speed... 1 RPM to >3900 RPM
- Full load... 1 MW to 110% MW
- Full scale... >300MW
- Full instrument... we saw it all
- Full risk...well beyond grid stresses

World class validation... inspired by aviation testing
Test Cell Configuration 2011-2014

Full Speed Full Load Power Train using compressor as load-bank

Advanced Gas Turbine
Advanced Compressor
Gear Box Assembly
Drive & Starter Motor System
Facility can test 50Hz & 60Hz

Unique test facility to explore full load & beyond operating conditions
Off Grid Testing Benefits

Benefits

• Allows testing without grid restrictions ... no “speed limit”

• Thorough product mapping ... insurer and customer acceptance

• Comprehensive technology validation prior to first fire in the field, w/ ‘inducing age’.

• Reduces onsite commissioning time for new technology

• Flexible speed range allows for 50Hz & 60Hz designs

Testing beyond normal site conditions increases confidence in new products
GE test stand Industry acceptance

Customers and industry partners, such as insurers and consultants, have reviewed test stand features and test data of the 7F-5 test to confirm the following:

- Exceptional loading capability with many speed and ramp rate transient variability.
- Comprehensive data acquisition and real-time assessment.
- Validation of test data results in superior understanding of turbine operational envelope and its limits.

Rapid commercialization of the product, following the 1st unit testing.
7F-5 production (2012 FSFL)

30+ units sold - 8 units have left factory
8 sites under construction
1st unit COD Q2 2014

Advanced 14-stage compressor in full production
9HA program

1\textsuperscript{st} unit test – 2014

2\textsuperscript{nd} unit COD – 2016
### Advanced Gas Turbines 50 & 60 Hz status

<table>
<thead>
<tr>
<th>Year</th>
<th>9F-7 launch</th>
<th>Compressor Test</th>
<th>7F-5 GT Test</th>
<th>7HA launch</th>
<th>9HA GT Test</th>
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<tbody>
<tr>
<td>2011</td>
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<td>Intro rating</td>
<td>Analysis &amp; Modeling</td>
<td>F &amp; H platform alignment</td>
<td>Verifying 9HA final design</td>
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**Modular design & technology alignment:**
- Lessons learned
- Identifying growth potential
- Leveraging 9F & H design
- Commercial Commitments for FlexEfficiency technology:
  - 30x 7F-5 committed (1st COD 2014)
  - 6x 7HA committed
  - 3x 9HA committed

>61% efficient technology platform
9HA - 2nd unit site construction
EdF Bouchain: - site works ongoing

EDF Bouchain: FlexEfficiency*50 from model to reality COD 2016
GE’s Gas turbine validation: Greenville

Full speed, full load, non-grid-connected
✓ Advanced compressor validation
✓ 7F-5 full load validation
• 9HA full load validation 2014
• 7HA full load validation 2015

7F-5 validation results
✓ 3800 sensors, 250+ fired hours
✓ Performance, operability & lifecycle
GE’s advanced ‘H’-class technology

- >61% Combined cycle efficiency for the lowest cost of electricity
- Merging of ‘H’-technology (pioneered by GE) and over 1100 ‘F-tech’ units experience.
- Air cooled with proven materials
- Industry leading validation facility to support reliable operation over the lifecycle of the turbine
- Unit#1 and Load compressor shipped to Test Facility (Feb. 2014)
- Continuous pipeline of technology development for sustained industry leadership
Thank You !