Innovative Technology for Installed Gas Turbine Power Plants in a Renewable Energy World

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Agenda

Gas Turbine Drivers in a Renewable Market Place

Hydrogen Commercial Install Case Study

Flexibility Extension

Digital Maintenance Enhancement

Conclusions
Offerings for Multiple OEM Platforms

3 Engine Classes

13 OEM Frames

F-Class

Advanced Frame

B/E Fleet

Ansaldo HGP Repair

Siemens and Mitsubishi

Rotors, LTE, Discs

Cases

General Electric

M&D

Full Service and Maintenance

Total Lifetime Support

Field Service

Reconditioning
Market Challenges Facing Gas Turbines
Renewables Changing Power Generation

Declining Revenue + Increasing O&M Costs =

- Lower Marginal Prices
- Reduced Capacity Factors
- Aging Assets
- Added Starts & Stops
- Ramping of Conventional Units

Increasing Renewable and Distributed Generation and Energy Efficiency driving need for Flexible Power Supply
Taking Advantage of a New ENERGY Balance

NEW WORLD
RENEWABLE GENERATION

OLD WORLD
CONVENTIONAL GENERATION
• Includes gas turbines

THE WILD WEST
STORAGE
• Batteries?
• Hydrogen fuel for gas turbines

Building on our fighting foundation … and look to the Wild West
Fuel Flexibility
Energy Storage through Fuel – Power to Gas

- **Energy Storage Source:**
  - Over generation in renewable penetrated markets
  - Overnight wind curtailment = ‘Free’ electricity to make hydrogen

- **Energy Storage Consumption:**
  - Use existing Gas Turbine Asset
  - Retrofit combustor to switch seamlessly from natural gas to hydrogen blends
  - Increase plant capacity factors
  - Reduce operating cost
  - Compete with Storage Devices

Hydrogen produced from renewables can be viewed as a battery to store energy from renewables, and then generate/distribute using existing infrastructure

**Levelized costs of storage, 2015 vs 2030 [EUR/MWh, 2014 Price level]**

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LEC-III® Upgrade to Fuel Flexible Low Emissions

- LEC-III® dry low emissions combustion systems installed on more than 70 machines
- 32,000hr between inspections
- Capable of achieving sub 5 ppm NOx emissions guaranteed
- Turndown to ~50% load

- Addition of optimized fuel air mixing Secondary Fuel Nozzle allows low emissions operation with hydrogen mixtures in natural gas

Low emissions combustion system with hydrogen capability
AutoTune Enhanced Tuning Package

AutoTune System Overview

• Key Benefits:
  o Eliminates seasonal manual tuning
  o Reduced risk of Lean Blowout (LBO) Trips
  o Improves emissions control year round
  o Improved turndown
  o Improves hardware life
  o Power+ option improves power output
  o Improved fuel flexibility including HYDROGEN

• Cross platform solution – 6B, 9E, 9F, 701F, GT26, 64.3, 94.2, 94.3

• Multiple control platforms
  o TC-7, Mark V & VI, TXP, T3000, Ovation™, Netmation

Patented Logic: AutoTune without Need for Control System Upgrade

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Rheden, The Netherlands, 26th of April 2018
AES Elsta Perspective – Voice of Customer

- Steam + Electrical capacity = 630MW
- 3 x GE9E MS9171E gas turbine
- 1 x GE steam turbine
- 3 x Ansaldo HRSG with additional duct firing

- How to stay competitive in a changing Electricity Market within the contractual boundaries?
- Increase of production and fuel flexibility
- Availability of “Sitegas” a mix of methane and hydrogen, byproduct of a neighbouring facility
- Usage of low cost fuel and positive effect on emissions
- In January 2011 first proposal to stakeholders for increasing the H₂ percentage in the fuel mix to the gas turbines, from 10% to ..
- Begin 2017 final approval to execute the project
• PSM’s LEC-III® combustion equipment installed in 2009/2010
• Modify the current installation with:
  • Fin mixer secondary fuel nozzles
  • CDMS and AutoTune system
• Additional equipment changed or modified:
  • Gas control valve fuel mixing station, H\textsubscript{2} analyzers and flame scanners
• Results of the project:
  • Maximum of 25% H\textsubscript{2} over the full operating range, 55 – 123 MW, tested up till 35% H\textsubscript{2}
  • Low emissions, CO is on the edge without H\textsubscript{2} on minimum load
• Challenges of the project:
  • Connecting AutoTune system to the MK V control system
  • Position of the CDMS probes on the combustion cans
• Last gas turbine will be modified in week 22/23 2018

Execution of the modification of three gas turbines and test and commissioning
Fuel Flexibility
Storage Fuels and Cost Offset

- Waste gas and refinery by product gas use substantially reduces the fuel bill
  - **Example:** For natural gas priced at ~4.5€/MMBTU (or 4.75€/GJ), a 9% energy savings on a base loaded Frame 9E.03 combined cycle would save ~€3million/year

- Low emissions gas turbine combustor is the cleanest way to consume waste gas

Significant Saving Potential by Using Alternative Fuel Source – Refinery, Wind, Solar
Dry Low NOx Operation with Hydrogen Across the Load Range Saving Significant $$$
Stable, robust and flexible sub 9ppm operation from 0% to 35% hydrogen

E-class Fuel Flexibility – Netherlands
9E Demonstrated Engine Operation with Hydrogen

Base Load 30% H₂

Min Load 35% H₂

Patented Automated Tuning with changing fuel constituents
Fuel Flexibility
9E Commercial Engine Operation with Hydrogen

AutoTune Safely Operates while Keeping Dynamics Low
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Operational Flexibility / Start-up Optimization

Fully Integrated CCGT Start-Up:
- Simulate start cycles for GT / HRSG / ST
- GT Start Profile
  - Optimized to ST requirements,
  - Hold points removed, etc.
- ~50% Fuel Savings
- ~30% Start-up time reduction

500k to 750k extra revenue based on 230 starts per year

Significant savings with AutoTune / Controls upgrade
Gas turbine power generation in an increasingly renewable market:

- Operational flexibility – rapid load changes over a wider range in load
- Fuel flexibility – ability to burn waste/off gases and lower carbon fuels
- Always with reduced emissions
- Providing a simple retrofit solution

One combustor for many Applications

FlameSheet™ Combustion Systems for:
- GE: 6F, 7E, 7F, 9E, 9F
- Siemens / Mitsubishi: 501F, 501G, 701F, 701G
- Siemens: 501B/D

60-90% more profit with 20% greater turndown
Maintainability Advantages
9FB FlameSheet Combustion System

GE 9FA/B 2.6+ / 2.0+

PSM 9FA/B FlameSheet

Added benefit for 9F FlameSheet installation is higher output and improved engine efficiency, due to lower combustor pressure-drop

FlameSheet™ Lower ΔP Design = Higher efficiency and More Output
Operational flexibility - FlameSheet™
Optimize combined cycle for extended low load operation

Operational Highlights

- Developed new, cold part load firing curve → improve unit specific heat recovery steam generator (HRSG) robustness
- Additional 15-20% load turndown demonstrated on cold part load firing curve
- Reliable 3+ years of sub 9ppm NOx and CO of operations on AGC using improved turndown capability

Ensuring no HRSG incremental damage and no upgrade required to HRSG

Max Isotherm
Reduced Isotherm

Emissions/Turndown Performance Met with Reduced Exhaust Temperature
Operational Flexibility – FlameSheet™

- Two 7F FlameSheet™ installations in 2015 – Eastman Chemical
- Simple, drop-in installation completed 1 week ahead of schedule
- Extended operational range achieved
- On track for 32,000 hour durability targets, with +25,000 hours on Fleet leader

FlameSheet™ Installed into Two Commercially Operated 7F Engines – Additional Installations Happening Now!
**Operational Flexibility - FlameSheet™**

Commercial Engine Installation – NOx Performance

- Demonstrated Sub-5ppm NOx over normal operating range 40% - 100% load
- Demonstrated Sub-10ppm NOx above 20% load
- Demonstrated 6ppm NOx at +28°C Overfire, beyond base load
- Technology applicable to E, F and H/J-class

*F-class FlameSheet™ substantially reduces start-up and normal operating NOx Emissions advantage from start-up to peak fire*
Robust Operation at all Fuel Temperatures and Over a Wide Range of Fuel Constituents

Enhanced Fuel Flexibility

<table>
<thead>
<tr>
<th>Fuel Constituent Comparison (Premix Operation, %Vol)</th>
<th>501F DLN</th>
<th>FlameSheet™</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4 (min)</td>
<td>90%</td>
<td>40%</td>
</tr>
<tr>
<td>H2 (max)</td>
<td>0%</td>
<td>40%</td>
</tr>
<tr>
<td>C2 (max)</td>
<td>5%</td>
<td>40%</td>
</tr>
<tr>
<td>C3 (max)</td>
<td>2.5%</td>
<td>20%</td>
</tr>
<tr>
<td>C4 – C6 (max)</td>
<td>0.5%</td>
<td>10%</td>
</tr>
</tbody>
</table>

- FlameSheet™ able to operate with a variation in Modified Wobbe Index (MWI) of up to 30%
- FlameSheet™ insensitive to fuel temperature

\[
MWI = \frac{LHV}{\sqrt{(MW_{gas}/28.996) \times T_{gas}}}
\]

Hydrogen Blending

- Demonstrated capability to run with 65% blended hydrogen by volume at baseload, and more recently up to 80% hydrogen
Development
Next Steps on the Hydrogen Path

- Benchmark analysis to high hydrogen test result
- Used advanced analytical techniques to demonstrate 100% hydrogen capability
- Complete atmospheric rig tests to show further improvement from the already demonstrated 80% hydrogen to achieve the 100% hydrogen goal
- Complete high pressure (full scale conditions) to verify robust 100% hydrogen operation
- Perform engine demonstrator, with combustor retrofit on an existing E or F-class machine, with fuel switching from 100% natural gas to 100% hydrogen

Ongoing development to support retrofit upgrades
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Digitalization Providing Cost Effective on Demand Only Maintenance,
Optimized for the High Cycling Renewable Environment

CLS (Consolidated Life Statement) is used for **reliable**
Technology and innovation product development

- Autotune system maintains healthy operation and/or enhanced operational performance
- Plant monitoring provides ability to build self learning systems for safe operation

Combination of Design and Big data for digital assessment and condition based maintenance
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Gas turbines have ultimate flexibility … BUT they must be relevant for the market they serve

Existing gas turbine power plants have unique abilities to provide support critical to the renewable grid … they just need to be re-configured to support this new goal

Gas turbines must be cost effectively re-packaged for the demands of a renewable market place

Case study presented showing what can be achieved with a retrofit to existing asset

Decades of gas turbine power plant retrofit experience can be applied to upgrades for competiveness in the renewable market

Renewable Retrofit Solution considers not just the gas turbine but also all the accessory equipment, including steam cycle where applicable
Next Steps

- Process established to perform a full power plant ‘retrofit for renewables’, identifying specific solutions to address:
  - Start time reduction*
  - Turndown*
  - Maintenance
  - Energy storage
  - Fuel flexibility*

* Immediately available

- First step is the site walk down followed by provision of detailed upgrade assessment, documenting applicable modular upgrades to achieve profit

Upgrade for Renewables Today
Thank You!