F-class OpFlex controls advancements
Bob Bellis, F-class/OpFlex Controls Product Manager
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Operational Flexibility ...

Advanced controls technology to ...

- Get the most out of plant equipment
- Expand operating envelopes
- Adapt operation to changing conditions

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OpFlex* solutions suite

**Gas Turbine**
- Start-Up NO\textsubscript{x} / Low Visible Emissions (LVE)
- Fast Start
- Purge Credit
- Variable Load Path

**Steam Turbine**
- Steam Turbine Agility

**HRSG**
- Adv. Attemperation
- Adv. SCR Control*
- AutoBlend*
- Adv. Drum Control*

**Combustion Versatility**
Robust operation during weather, fuel, and grid variations
- Fuel flexibility
- Fewer trips
- Longer intervals

**Load Flexibility**
Load range expansion, efficiency, responsiveness and customization
- Higher output
- Deeper turndown
- More efficient

**System Reliability**
Enhancements for reliable, cost effective operations
- Liquid/HFO reliability
- Fewer system trips
- Less downtime

**Automated Tuning**
- AutoTune MX
- AutoTune DX
- AutoTune LT
- Ambient Select

**Grid Stability**
- Enhanced Transient Stability

**Reliability**
- AutoRecover

**Output**
- Variable Peak Fire
- Variable Airflow
- Cold Day Performance

**Responsiveness**
- Fast Ramp
- Grid Services Package

**Turndown**
- Extended Turndown

**Efficiency**
- Variable Inlet Bleed Heat

**Advanced controls technology for all modes of power plant operation**

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* Under development
April 2015
### OpFlex* solutions suite

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#### Turndown
- Extended Turndown

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### Operational Packages
- Start-Up Reliability  
- Diagnostics/Productivity  
- Trip Prevention

### Fuels Packages
- Liquid Fuel Reliability  
- Heavy Fuel Oil

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April 2015
OpFlex Variable Load Path
Conventional combined cycle plant starts too slow and costly to compete in real-time power markets ... cost, time to dispatch, and load profile.

Combined cycle plant challenge: How to generate more power sooner and more efficiently without damaging HRSG and steam turbine?

Need near-simple cycle load profile ... while controlling exhaust temperature to manage plant stress.
Variable Load Path objective & start-up strategy

**Objective:**

Move up the dispatch order by making start profile and start cost more attractive to grid operator:

- Shorter start
- Reduced fuel burn, more efficient start
- Reduced load imbalance, more aggressive start profiles
- Reduced start emissions

**VLP start-up strategy:**

Maximize exhaust energy and load during start-up subject to:

- Constraints of plant equipment operating limits
- Grid permit and environmental emissions permit requirements, and
- Maintaining desired load profile for dispatch to grid
What is OpFlex* Variable Load Path (VLP)?

- Gas turbine control feature
- Allows independent control of load and exhaust temperature within the gas turbine boundaries ... true GT flexibility product
- Simple interfaces for integrating into existing plant operation
- Requires OpFlex AutoTune MX to manage combustor operability
Why is AutoTune MX & Model-Based Control Required?

Ability to utilize the full capability of DLN2.6+ combustor limited with prior split schedule approaches:

- Requires scheduling parameter to increase with load
- Requires significant margin to boundaries, especially with wide variations in ambient, fuel, and now exhaust conditions/load path

AutoTune uses detailed combustor models developed from extensive field characterization testing

80,000 data points collected from six units dating back to 2012

AutoTune uses detailed combustor models developed from extensive field characterization testing
Comparison of conventional versus VLP combined cycle start-up curves (predicted)

With VLP:
- Near simple cycle load profile ... higher load sooner
- Near simple cycle full load heat rate

With VLP:
- Exhaust temperature still controlled to limit equipment stress
- Reduce maximum exhaust temperature during start
Impact of VLP – HRSG heat balance comparison

At same output

Cold path “pushes” more heat energy to IP and LP sections of HRSG, reduces heat in HP/reheat section

Cold path redistributes and nearly doubles energy input to HRSG without increasing temperature

At same exhaust temperature

Cold path enables GT to deliver more output, results in more overall heat energy into HRSG, particularly in IP & LP sections ... more than 100% of baseload value
VLP control interface

1. Control selections
   - VLP enable/disable
   - Setpoint priority
   - Local or remote DCS control

2. Setpoint control
   - Load setpoint and rate
   - Exhaust temperature setpoint & rate

3. Boundary control
   - Emissions
   - Exhaust flow

4. Operating space chart

Plant control interface signals for all new functionality enables control locally on gas turbine HMI or via plant DCS

Refer to GEK121057 “OpFlex Variable Load Path Operation User Guide”
### Benefits of Variable Load Path

#### Plant A Hot Start Comparison

<table>
<thead>
<tr>
<th></th>
<th>Pre-VLP</th>
<th>VLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start-up Fuel Cost Savings</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Start Time</td>
<td>c.130 mins</td>
<td>c.65 mins</td>
</tr>
</tbody>
</table>

#### Plant B Hot Start Comparison

<table>
<thead>
<tr>
<th></th>
<th>Original Unit</th>
<th>VLP Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compare Op</td>
<td>143 Starts</td>
<td>233 Starts</td>
</tr>
<tr>
<td>Jun’14 – May’15</td>
<td>1,900 Hours</td>
<td>3,100 Hours</td>
</tr>
<tr>
<td>Time to 150MW</td>
<td>55 mins</td>
<td>10 mins</td>
</tr>
</tbody>
</table>

**Combined cycle plant delivered near-simple cycle start capability:** More MW, less time, less fuel

**Changed plant dispatch ...** VLP unit sees more run time, starts, hours

**Just now learning how to best take advantage of new found capability to further “optimize”**
Backup
<table>
<thead>
<tr>
<th>OpFlex offering</th>
<th>Brief Description</th>
<th>Mark* V</th>
<th>Mark Ve, VI, VIe</th>
<th>Product pre-requisites</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start-up Agility suite</strong></td>
<td>Fast, reliable, repeatable starts with low emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Start-up NO\textsubscript{x}</strong></td>
<td>Low visible emissions above (~\sim) 20% load, reduced cumulative start-up NO\textsubscript{x}</td>
<td>X</td>
<td></td>
<td>None</td>
</tr>
<tr>
<td><strong>Fast Start / Purge Credit</strong></td>
<td>Conduct purge during prior shutdown; isolate fuel manifold; skip purge on start; “Fire-on-the-fly”; faster accel/loading (if applicable)</td>
<td>X</td>
<td>None; Liquid fuel systems must be disconnected; Duct burners require separate purge credit system</td>
<td></td>
</tr>
<tr>
<td><strong>Start-up Reliability package</strong></td>
<td>Redesigned start permissives, automated system pre-start checks (various pumps, fans, valves), improved start-up HMI screens</td>
<td>X‡</td>
<td>X‡</td>
<td>None‡; Not all features available on Mark* V</td>
</tr>
<tr>
<td><strong>Steam Turbine Agility</strong></td>
<td>Automated start-up, revised permissives and rotor stress limits, fast hot starts</td>
<td>X‡</td>
<td>X‡</td>
<td>A- or D-series GE steam turbine; ‡Not all features available on Mark* V</td>
</tr>
<tr>
<td><strong>Advanced Attemperator</strong></td>
<td>Model-Based Control of attemperation flow to better regulate steam temperature</td>
<td>X</td>
<td>X</td>
<td>Most HRSG attemperation systems; compatible with GE or non-GE DCS</td>
</tr>
<tr>
<td><strong>Variable Load Path</strong></td>
<td>Independent GT load and exhaust temp. control to customize start-up &amp; op load paths</td>
<td>X</td>
<td>AutoTune MX; DLN2.6+ combustor (expected available in late 2016)</td>
<td></td>
</tr>
<tr>
<td><strong>Combustion Versatility suite</strong></td>
<td>Robust operation during weather, fuel, and grid variations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Enhanced Transient Stability (ETS)</strong></td>
<td>Model-Based Control (MBC) architecture with grid stability software package</td>
<td>X</td>
<td></td>
<td>None; Meets grid codes worldwide (NERC standard PRC-024-1 in US)</td>
</tr>
<tr>
<td><strong>Ambient Select</strong></td>
<td>Standard scheduled-based turbine control plus dual DLN fuel split schedules</td>
<td>X</td>
<td></td>
<td>None</td>
</tr>
<tr>
<td><strong>AutoTune LT (ex. Ambient Adapt)</strong></td>
<td>MBC/ETS plus continuous DLN fuel split biasing</td>
<td>X</td>
<td></td>
<td>ETS</td>
</tr>
<tr>
<td><strong>AutoTune DX (ex. “Wide Wobbe”)</strong></td>
<td>MBC/ETS plus closed-loop DLN control module</td>
<td>X</td>
<td></td>
<td>ETS; Combustion Dynamics Monitoring system</td>
</tr>
<tr>
<td><strong>AutoTune MX (a.k.a. All Load AutoTune)</strong></td>
<td>Full automated DLN tuning at all loads</td>
<td>X</td>
<td></td>
<td>AutoTune DX; DLN2.6+ combustor (expected available in late 2016)</td>
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<tr>
<td><strong>Load Flexibility suite</strong></td>
<td>Load range expansion, efficiency, responsiveness and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>customization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Variable Peak Fire</strong></td>
<td>User or AGC adjustable overfire for more output (+4 MW with</td>
<td>X</td>
<td>X</td>
<td>None (automated emissions-compliant peak possible with AutoTune DX)</td>
</tr>
<tr>
<td></td>
<td>2.2:1 Maint. Factor &amp; &lt;15 ppm NOx)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Variable Airflow</strong></td>
<td>Online, user adjustable max IGV setting for better output or</td>
<td>X†</td>
<td>X</td>
<td>ETS, AutoTune DX (†offline max IGV change avail. for Mark V)</td>
</tr>
<tr>
<td></td>
<td>better CC heat rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cold Day Performance</strong></td>
<td>Remove cold weather firing temperature suppression for</td>
<td>X</td>
<td></td>
<td>ETS, AutoTune DX</td>
</tr>
<tr>
<td></td>
<td>higher output (+5MW at 30F)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fast Ramp</strong></td>
<td>Enable 2x up/down ramp rate in DLN Mode 6 (16.6%/min</td>
<td>X</td>
<td></td>
<td>ETS (3x may be possible with AutoTune DX)</td>
</tr>
<tr>
<td></td>
<td>versus 8.3%/min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Extended Turndown</strong></td>
<td>Revise DLN Mode 6 transfer out to lower loads (enable 8-10%</td>
<td>X</td>
<td>X</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>turndown improvement)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Variable Inlet Bleed Heat (IBH)</strong></td>
<td>Replace static IBH schedule with icing model; enables</td>
<td>X</td>
<td></td>
<td>ETS</td>
</tr>
<tr>
<td></td>
<td>part load heat rate benefit (1%+)</td>
<td></td>
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<td><strong>System Reliability suite</strong></td>
<td>Enhancements for reliable, cost effective operations</td>
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<td><strong>Start-up Reliability package</strong></td>
<td>Redesigned start permissives, automated system pre-start</td>
<td>X‡</td>
<td>X</td>
<td>None</td>
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<tr>
<td></td>
<td>checks (various pumps, fans, valves), improved start-up</td>
<td></td>
<td></td>
<td>‡Not all features available on Mark* V</td>
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<tr>
<td></td>
<td>HMI screens</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Trip prevention package</strong></td>
<td>Enhanced protection logic to avoid “nuisance” alarms and</td>
<td>X‡</td>
<td>X</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>trips related to exhaust conditions (spreads, over temp.,</td>
<td></td>
<td></td>
<td>‡Not all features available on Mark* V</td>
</tr>
<tr>
<td></td>
<td>over press., IBH control, fuel pressure, GCV calibration,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>etc.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diagnostics / Productivity package</strong></td>
<td>Software to more quickly &amp; efficiently diagnose system</td>
<td>X‡</td>
<td>X</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>issues, reducing downtime (System Reset, expanded Alarm</td>
<td></td>
<td></td>
<td>‡Not all features available on Mark V</td>
</tr>
<tr>
<td></td>
<td>Help files, “online P&amp;ID”, first-out logic, etc.), and to</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>efficiently execute systems tests and procedures, particularly those not done frequently (Overspeed, DC lube oil pump, motor run time, cooling water fan, water wash, etc.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Liquid fuel operability</strong></td>
<td>Enhanced control logic to avoid trips during fuel transfers,</td>
<td>X‡</td>
<td>X</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>improve Atomizing Air sequencing, and reduce recirculation</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>system parasitic loads</td>
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