Flexible Power Generation for Grid Support utilizing the Aero-derivative Gas Turbine Technology

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• Aero-derivative Gas Turbines
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The Energy Trilemma

- Environment
- Security of Supply
- Price of Electricity
Changing Market Requirements

• Lowest Cost of Electricity still the key driver

• High penetration of intermittent Renewable Power Generation

• Decentralisation

• New operating regimes for fossil fuels
Changing demands on Power Plants

Flexibility

Fast Response

Request Cycling
Aero-derivative gas turbines meet today’s market demands

- Fast start
- High cyclic life
  - Multiple daily starts
- No lock-out on shutdown
- Fast ramp rates
- High efficiency
- Modular plant designs

(The ISO's Building A Sustainable Energy Future; 2014-2016 Strategic Plan)
Siemens Gas Turbine portfolio
Now even stronger with Aero-Derivative products

Heavy-duty gas turbines
Industrial gas turbines
Aeroderivative gas turbines

<table>
<thead>
<tr>
<th>50Hz or 60Hz</th>
<th>50Hz</th>
<th>60Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Industrial Trent</strong></td>
<td>SGT-800</td>
<td><strong>Industrial RB211</strong></td>
</tr>
<tr>
<td><strong>SGT-800</strong></td>
<td><strong>SGT-750</strong></td>
<td><strong>SGT-600</strong></td>
</tr>
<tr>
<td>48 to 53 MW</td>
<td>37-40/38-41 MW</td>
<td>24/25 MW</td>
</tr>
<tr>
<td><strong>SGT-700</strong></td>
<td><strong>SGT-400</strong></td>
<td><strong>SGT-500</strong></td>
</tr>
<tr>
<td>33/34 MW</td>
<td>13 to 14/13 to 15 MW</td>
<td>19/19 MW</td>
</tr>
<tr>
<td><strong>SGT-600</strong></td>
<td><strong>SGT-300</strong></td>
<td><strong>SGT-200</strong></td>
</tr>
<tr>
<td>24/25 MW</td>
<td>8/8 MW to 9 MW</td>
<td>7/8 MW</td>
</tr>
<tr>
<td><strong>SGT-100</strong></td>
<td><strong>SGT-200</strong></td>
<td><strong>SGT-100</strong></td>
</tr>
<tr>
<td>5/6 MW</td>
<td>5/6 MW</td>
<td>4 to 6 MW</td>
</tr>
<tr>
<td><strong>SGT-5-8000H</strong></td>
<td><strong>SGT-6-8000H</strong></td>
<td><strong>SGT-6-2000E</strong></td>
</tr>
<tr>
<td>400 MW</td>
<td>296 MW</td>
<td>117 MW</td>
</tr>
<tr>
<td><strong>SGT-5-4000F</strong></td>
<td><strong>SGT-6-5000F</strong></td>
<td><strong>SGT-6-2000E</strong></td>
</tr>
<tr>
<td>307 MW</td>
<td>242 MW</td>
<td></td>
</tr>
<tr>
<td><strong>SGT-5-2000E</strong></td>
<td><strong>SGT-6-8000H</strong></td>
<td></td>
</tr>
<tr>
<td>187 MW</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SGT-6-8000H</strong></td>
<td><strong>SGT-6-5000F</strong></td>
<td></td>
</tr>
<tr>
<td>242 MW</td>
<td></td>
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<td><strong>SGT-6-5000F</strong></td>
<td></td>
</tr>
<tr>
<td>117 MW</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Derivation of the Industrial Trent

Aero Trent 800

Industrial Trent
Industrial Trent Gas Turbine: 3 independent shafts for flexibility

LP Compressor (2 Stage)
IP Compressor (8 Stage)
HP Compressor (6 Stage)
HP Turbine (1 Stage)
IP Turbine (1 Stage)
LP Turbine (5 Stage)

LP Compressor blade number creates 50/60Hz

25000 hours operation / 5500 Cycles: 3 starts/day for 4 ½ years
Designed for Maintainability and Quick Installation

- Compact footprint: < 30m x 15m (100’ x 50’)
- Installation possible < 75 days
- Engine change-out within 48 hours
- Engine less than 15 tonnes: air freight
- Low maintenance costs
  - < $5/MWh total (continuous operation)
Decentralised Power Generation

• High Energy Efficiency

• Competitive Installed Costs
  • US$700 – US$900/kW

• Power enhancement through ISI
  • +10MW at ISO

• Synchronous condenser possibilities

![Graph showing typical overall Energy Efficiency for Industrial Trent options (in %)]
Fast Start-up of Gas Turbines

- **OEM 2 Dual Fuel Engine Ultra-Fast Start**: 501-KB7
- **OEM 3 Dual Fuel Engine Fast Start**: 13MW Class Industrial GT Fast Start
- **OEM 4 Gas Engine Fast Start**: Industrial Trent (35MW/min ramp)
- **OEM 1 Gas Engine Regular Start**: Industrial Trent (21MW/min ramp)

* Ultra fast start requires specific pre-start conditions to be met.

**Industrial Trent 100% Load** - more than 50MW - from cold in less than 10 minutes.
Part-Load Efficiency and Ramp Rate

Multiple Units allow:

- Operational Flexibility
- High efficiency across wide operating range
- Low power plant turndown
  - approx. 5% rated output while maintaining emissions compliance
- Rapid response to grid demand
  - 20% power increase per unit in <20 seconds
- Low station power loss during GT maintenance outage

Plant Efficiency Curve

1. Open cycle, natural gas fuel, ISI
Industrial Trent: High stress operating cycle – no maintenance penalty

Operation over 2 day period – US location
<table>
<thead>
<tr>
<th>High efficiency, fast response Combined Cycle possibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Industrial Trent:</strong> &gt; 53% net efficiency, full load &lt;40 minutes</td>
</tr>
<tr>
<td>• Low exhaust temperature ➔ low pressure, low temperature HRSG</td>
</tr>
<tr>
<td>• reduced thermal stress allows improved cycling performance</td>
</tr>
<tr>
<td>• Fast / multiple start capability with OTSG</td>
</tr>
<tr>
<td>• Duct firing for further flexibility</td>
</tr>
<tr>
<td>• 2 + 1 with duct firing: 20% to 110% rated station load</td>
</tr>
<tr>
<td>• ‘Water-free’ possibilities: Organic Rankine Cycle</td>
</tr>
<tr>
<td>• &lt; 20 minutes to full load of combined cycle plant possible on warm start</td>
</tr>
</tbody>
</table>
Pulse Load Operation

4 hour pulse

14 hour pulse

Time from beginning of Pulse (mins)

Plant Load (% of nominal)
## Pulse Load Operation

<table>
<thead>
<tr>
<th>100MW Power Plant</th>
<th>ICE</th>
<th>CC ICE</th>
<th>Trent DLE OC</th>
<th>Trent DLE CCGT</th>
<th>Trent + ORC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Load Net Efficiency</strong></td>
<td>%</td>
<td>44</td>
<td>49.2</td>
<td>41.87</td>
<td>53</td>
</tr>
<tr>
<td><strong>Start-up time</strong></td>
<td>Mins</td>
<td>5</td>
<td>50</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td><strong>Shut-down time</strong></td>
<td>Mins</td>
<td>1</td>
<td>20</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td><strong>O&amp;M costs (2000 hrs/yr operation)</strong></td>
<td>$/MWh</td>
<td>5.5</td>
<td>5.5</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Start-up costs</strong></td>
<td>$/MW</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Aero-derivative Gas Turbines offer a competitive solution....

Cost per pulse (US$)

- Ice
- Ice CC
- Trent DLE
- Trent DLE CCGT
- Trent DLE + ORC
And a clean one too….

Combustion Emissions Comparison (tonnes/year)

- **ISO, zero loss**
- **Natural Gas fuel**
- **250MW Plant Output**
- **700 Hours/year operation**
- **Open cycle**
- **No post-combustion clean-up**

**Environmental Benefits of Gas Turbines**

- > 70% NOx reduction
- > 85% CO reduction
- > 98% UHC reduction
- > 35% Particulates reduction
- > 90% VOC reduction
… with low GHG Emissions

CO$_2$ Eq Emissions (Tonnes/hour) for 250MW Power Plant according to efficiency

3.2 g/kWh methane slip almost eliminates CO2 savings by switching to gas from diesel
- 48% efficient power plant emits CO$_2$ eq to 36% efficient power plant with no methane slip
- 0.05 g/kWh methane slip has negligible impact on CO$_2$ eq
Industrial Trent Ultra-Flexible combined cycle

Warm start, DLE operation

Start-up after up to 8 hours standstill

- Gas Turbine at full load in 7 minutes
- Steam Turbine in 22 minutes.
Hybrid Power Plant

Combine GT / CCGT with BESS for even faster response

- BESS moves Plant response to within 1 second
- 80 MW, 30 MWh BESS capacity - 15 MWh used
Conclusions

Aero-derivative Gas Turbines offer fast, flexible and efficient despatchable power generation to address the Energy Trilemma

- Low environmental impact
  - GHGs, Combustion Emissions, Water

- Enhances security of electricity supplies
  - Voltage and Frequency support

- Competitive economics for low cost electricity needs in a high intermittent renewables scenario
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Thank you.
Any questions?

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