MITIGATION OF SEASONAL PRODUCTION LOSS FOR THREE PARALLEL 4.7MMTPA LNG TRAINS

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RasGas acts as the operating company for and on behalf of the owners of the LNG projects RL, RL (II), RL 3, AKG Projects and Barzan Gas Company Limited (Project Owners)

RasGas has developed world-class facilities for the extraction, storage, processing and export of LNG, and a global portfolio of customers

RasGas produces approximately 37 million tonnes per annum (MMTPA) of LNG from 7 LNG trains

RasGas delivers LNG via a fleet of long-term chartered LNG vessels

Major Shareholders:

- Qatar Petroleum (QP): 70%
- ExxonMobil: 30%
PROJECT BACKGROUND AND OBJECTIVE

Background:
• Train 3 is designed for rich LNG and Trains 4/5 are designed for rich and lean LNG production of 4.71 MMTPA
• Due to seasonality impact, LNG production reduces during summer by ~5%

Project Objective:
To remove the seasonality impact

The project consisted of three main aspects:
1. Revision of process conditions
2. Design for more gas turbine power LP/MP-MR string
   • Gas turbine power reduced due to ambient air temperature and hot air recirculation
3. Design a restaged propane compressor
LNG PRODUCTION SEASONALITY

LNG Train Seasonal Production Profile

- **Annualised LNG Production %**
- **Average Monthly Temp, °C**

Seasonal production profile from January to December:
- January: 99.6%
- February: 100.0%
- March: 99.6%
- April: 98.8%
- May: 97.7%
- June: 96.5%
- July: 95.6%
- August: 95.4%
- September: 95.6%
- October: 96.5%
- November: 97.7%
- December: 98.8%

Average monthly temperature peaks in July and August, affecting production.
PROJECT TEAM ORGANISATION

Project Team:
- RasGas (Company)
- Elliott Group (Compressor OEM)
- General Electric (GT OEM) and
- APCI (Refrigeration Licensor)
- Chiyoda Corporation (EPC Contractor)

Project Management:
- RasGas Venture Planning department acts as focal point for RasGas
- Chiyoda Corporation acts as focal point for various vendors
STUDY FOCUS AREAS

1. Hot air recirculation to GT
2. Cooling water system
3. Cryogenics
4. Power augmentation
5. PR re-staging
HOT AIR-RECIRCULATION ANALYSIS
COOLING WATER CAPACITY EVALUATION

- Existing sea water (SW) and fresh cooling water (FCW) system subject to additional heat duty

- SW & FCW system has capacity to handle the additional heat load to remove seasonality impact

- Assessment concluded that it is feasible to select centralised or local IAC
## CRYOGENICS – ANALYSIS SUMMARY

### Liquefaction Process Licensor Study Results: (Train 4 & 5 – Lean LNG)

<table>
<thead>
<tr>
<th>Case</th>
<th>LP-MP MR Required MW</th>
<th>LP-MP MR Available MW</th>
<th>Power from IAC MW</th>
<th>IAC, USRT</th>
<th>PR Required MW</th>
<th>PR Available MW</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>84.30</td>
<td>80.26</td>
<td>4.04</td>
<td>800</td>
<td>78.14</td>
<td>79.55 3636 rpm</td>
<td>Minimum LNG required to remove seasonality</td>
</tr>
<tr>
<td>Summer - max (August)</td>
<td>84.67</td>
<td>80.26</td>
<td>4.40</td>
<td>960</td>
<td>78.34</td>
<td>79.55 3636 rpm</td>
<td>Maximum LNG with 960 USRT Chiller</td>
</tr>
<tr>
<td>Winter</td>
<td>88.16</td>
<td>88.94</td>
<td>0</td>
<td>None</td>
<td>64.8</td>
<td>85.50 3534 rpm</td>
<td>Current Winter LNG rate</td>
</tr>
<tr>
<td>Winter-max (May)</td>
<td>88.26</td>
<td>82.49</td>
<td>5.77</td>
<td>960</td>
<td>74.26</td>
<td>81.18 3616 rpm</td>
<td>LNG production limited by 7% stonewall margin on Propane Compressor</td>
</tr>
<tr>
<td>Extreme Summer</td>
<td>76.17</td>
<td>73.81</td>
<td>2.36</td>
<td>800</td>
<td>69.58</td>
<td>70.31 3551 rpm</td>
<td>LNG production limited by power available to Propane-HPMR compressor.</td>
</tr>
</tbody>
</table>

Train 4 Re-rating Cases 1, 2 and 3 with modified propane compressor and inlet air cooling on LP/MP-MR turbine.
LNG TRAIN MAJOR COMPRESSION STRINGS

**PR/HP-MR String**
- MS7121EA
- DLN1, 79 MW Site Rated
- PR Compressor
- HP/MR Compressor
- Helper Motor, 12 MW Rated

**LP/MP-MR String**
- MS7121EA
- DLN1, 79 MW Site Rated
- LP/MR Compressor
- MP/MR Compressor
- Helper Motor, 12 MW Rated

**NGL String (Train 4 & 5)**
- FR52D
- GB
- DLN1, 27 MW Site Rated
- RGC Compressor
- Gear Box
- Helper Motor, 9.7 MW Rated
LP/MP-MR STRING POWER AUGMENTATION
GT Air Inlet Filter-house with Cooling Coils
• 88M Centrifugal Compressor
• Horizontally Split Casing
• 3 Sideloads
• 4 Stages
• 5 Impellers

• Pressure Rise 1.1 to 16.3 bara
• Temperature Rise -38 to 63 degC
• Discharge Mass Flow 637 kg/s
• Total Power Consumed 56.2 MW
PROPANE COMPRESSOR RESTAGE

Flow Limitation & Previous Impeller Failures

RasGas has suffered 4 identical failures between 2007 and 2012.

Restaging:

Reason 1 – to remove the restriction on LNG production

Reason 2 – to enhance the reliability of the compressor and therefore, LNG Train
PROPAINE COMPRESSOR RESTAGE

HHP (4th) Stage Results

C3 Compressor HP Stage
SUMMARY

• Seasonality production loss was identified to be caused by:

  1. LP/MP-MR string power constraint during summer (Trains 3, 4 & 5)
  2. Propane Compressor HHP (4th) Stage Stonewall (Trains 4 & 5)

• A total investment of approximately 150M$ was estimated, producing an IRR of ~33%.

• Overall project schedule of 42 months

• Retrofit of the propane compressor was estimated to require approximately 20 shutdown days to complete
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- General Electric
- Turbine Air Systems
LP/MP-MR STRING POWER AUGMENTATION

GT Power Output and Chiller Temperature Reduction
Performance and Mechanical Integrity Validation:
• Detailed CFD study by OEM
• Impeller Modal Frequency Tests
• Cold Eyes Review by independent 3rd party
• Regular contact with OEM and preliminary design review
Redesigned Components:
- Stage 2 - diaphragm and return channel
- Stage 3 - diaphragm, return channel, side load wall and impeller
- Stage 4 - diaphragm, return channel, side load wall, 2 impellers and volute wall
- Discharge volute
- Balance piston