Efficient Power Augmentation with Dry Air Injection

By
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TurboPHASE Module – Revolutionary Technology
15-30% output at all Ambient Temperature

TurboPHASE
15-30% output and 8-10% heat rate on Aero-derivative GTs
TurboPHASE eliminates elevation effects

![Diagram showing atmospheric pressure and altitude relationship](image-url)

*Correction Factor*
Turbophase provides missing mass flow

- Increased GT Output
- Increased Mechanical drive torque
- Increased Exhaust Mass Flow at lower exhaust temperatures
- Increased Steam Production, Steam Turbine Output
TurboPHASE T-S diagram, 7000’ elevation, 80F

1. Stage 1 exit: 2 bar
2. Stage 2 exit: 3 bar
3. Stage 3 exit: 6.6 bar
4. Stage 4 exit: 13 bar
5. GT compressor exit: 410°C, 12 bar
6. Ambient Pressure: 0.8 bar

**TurboPHASE Intercooled compression work required to compress 1 kg air to 13 bar**

**GT axial compressor work required to compress 1 kg air to 12 bar**
**Heat and Mass Balance of TurboPHASE**

- **Injection Air Out to GT**
  - 6.35 kg/s @ 315°C
  - 12.8 bar
  - 350°C

- **Exhaust Air Out to Atmosphere**
  - 2.72 kg/s @ 140°C
  - 1.2 bar
  - 150°C

- **Water Out**
  - 180 m³/hr @ 40°C

- **Natural Gas In**
  - 16.3 mmbtu/hr
  - 350 mBar
  - 30°C

- **Electrical In**
  - 35kW, 480 VAC

- **Water In**
  - 180 m³/hr @ 30°C

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**Out**

- **Injection Air**
  - 6.35 kg/s @ 315°C
  - 2,224 kJ/sec

- **Engine Exhaust**
  - 2.72 kg/sec @ 140°C
  - 476 kJ/sec

- **Vent air**
  - 6.8 kg/sec @ 32°C
  - 357 kJ/sec

- **Cooling Water**
  - 200 lpm @ 44°C
  - 12,430 kJ/sec

**Total energy out**

- 15,487 kJ/sec

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**In**

- **Fuel in**
  - 16,300,000 (BTU/hr)
  - 4,776 kJ/sec

- **Ambient air**
  - 15.87 kg/sec @ 26°C
  - 740 kJ/sec

- **Cooling Water**
  - 200 lpm @ 29°C
  - 9,971 kJ/sec

**Total energy in**

- 15,487 kJ/sec
TurboPHASE is 32% more efficient

- 11 N2 compressor consumes 109.4 MW and the Turbine produces 192.3 MW, with 82.9 MW as shaft work for generator output
- 11N2 GT is approximately 10,264 simple cycle efficiency (33%)
- 11N2 compressor exit flow is 259 kg/s
- 109,400 kw/259 kg/sec = **422 kw/kg/sec of air generated**

- TurboPHASE compressor consumes 2000 kw of power to produce 6.35 kg/sec of air
- The reciprocating engine is 42% thermally efficient: 16.3 MBTU/2 MW = 8,150 simple cycle efficiency (42%)
- 2,000 kw/6.35 kg/sec = **315 kw/kg/sec of air generated**

- TurboPHASE compression process is 25% more efficient than the GT axial compressor
- Considering the relative efficiency of the GT compared to the Reciprocating engine
  - \[ 25\% \times \frac{.42}{.33} = 32\% \]
Standard Products improve reliability

- Standard commercial off the shelf components
- MTU 20V engine, 2000kW, 2750 BHP
- Hyundai 4 stage intercooled compression
- Sound & Weather enclosure
- Fully assembled and factory acceptance
Modular Turbophase System fits within existing plant

- TPMs connected to common header
- Common header feeds all GTs
- Air can be directed to any combination of GTs
- Integrated into existing cooling loop
- Small footprint
TurboPHASE is modular and scalable
Minimal Footprint
Install TurboPHASE without GT modification

- New Tee welded into IBH, Rotor Air cooler lines
- External to enclosure
Turbophase controls integrated to DCS

- No changes to GT Controller, Gas turbine controls are completely unaffected
- DCS provides Output demand to TPM
- TPM converts output demand to pressure and flow, internal PLC
- Permissives and trip functions aligned with GT operations
22% power increase, 10 seconds to max power

GE MS6001B Combined Cycle
4.5MW incremental, constant across ambient

![Graph showing GT output (MW) vs. GT inlet temperature (deg F/C) for one TPM and two TPMs, with Baseline comparison for GE 7FA.03 Simple Cycle.]
3.5% HR improvement with 5TPMs

![Graph showing heat rate improvement with different temperatures.]

- GE 7FA.03 Simple Cycle
- Baseline
- One TPM
- Two TPMs

Heat Rate (BTU/kWh)

GT Inlet Temperature (deg F/C)
Only 100k Maintenance Cost over first 5 years

Year 1-5: 5.50 $ per operating hour

* 4000 OH per year
## TPM Performance Summary

<table>
<thead>
<tr>
<th>Frame</th>
<th>TPM Incremental Output</th>
<th>TPM Incremental Heat rate</th>
<th>No. of TPMs per GT</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE Fr5</td>
<td>3.5</td>
<td>8700</td>
<td>1 TPM</td>
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<tr>
<td>GE 6B</td>
<td>4.4</td>
<td>7300</td>
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<td>5.0</td>
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<td>GE 7E/EA</td>
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<td>7200</td>
<td>3 TPM</td>
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<tr>
<td>GE 7FA</td>
<td>27.0</td>
<td>6700</td>
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<tr>
<td>SW / MHI 501F</td>
<td>27.0</td>
<td>6600</td>
<td>5 TPM</td>
</tr>
</tbody>
</table>

- Combined Cycle Performance @ 35C Ambient, except Fr5
- Firing temperatures at latest OEM values
- Heat Rates are BTU/kWh (LHV)
Benefits of TurboPHASE

**FAST RESPONSE**
- Eliminates spinning reserve
- 60 seconds start
- Dynamic signal capable

**OUTPUT INCREASE**
- Increase power to ISO day output
- Temp, Humidity, Elevation Independent

**ENVIRONMENTALLY FRIENDLY**
- No Water Consumption
- SCR, CO Catalyst

**IMPROVE EFFICIENCY**
- GT efficiency improvement

**NO MAINTENANCE PENALTY**
- No water, steam
- No change to firing temperature

**RETURN ON INVESTMENT**
- Capacity & Energy
- Reserve Margin
- Ancillary