

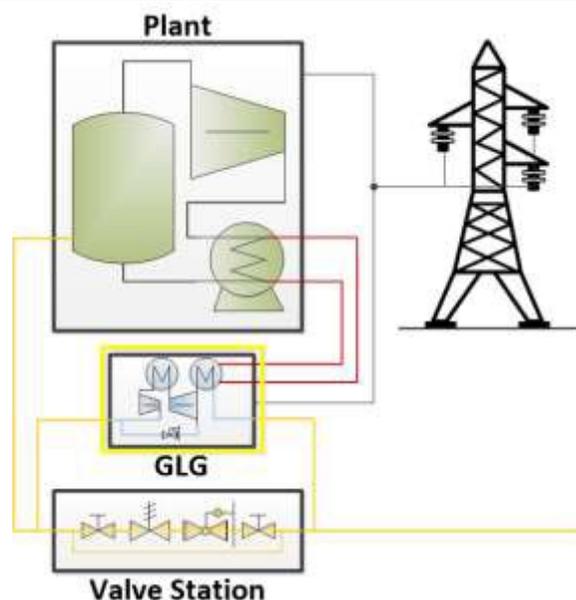
Anax Star Turbo Expander ASTE 250 HP-L250 kW Test Brief

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Technology Overview

A turbo-expander generates power through pressure reduction in a high-pressure natural gas pipeline. Natural gas enters through an expander section of an axial flow turbine that reduces the gas inlet pressure to a usable pressure downstream. A generator connected to the turbine generates AC current at 500-600 HZ, and an inverter converts the high frequency current to useable 60 HZ alternating current. The system, referred to as a gas letdown generator (GLG), can be installed in parallel with conventional pressure regulating devices such as city gates or customer pressure reducing valve stations.

As natural gas expands, it can cool to low temperatures without the addition of external heat. Thus, GLGs are configured with means of absorbing waste heat from other processes into the gas. In applications that generate waste heat via other processes, the heat can be used to control the temperature of the GLG and condition the leaving gas. GLGs can be used in natural gas pipeline applications to recover lost energy due to large-scale pressure reduction and deliver electricity onsite or to the electric grid.



Anax-Star ASTE250



Anax Holdings, a US investment group, and Star Refrigeration, an engineering company in the United Kingdom engineered and built the Anax-Star Turbo Expander (ASTE250). The ASTE250 is a packaged 7'x7'x13' skid-mounted 250kW system that conforms to US industry standards and employs several novel GLG design features. The design includes staged gas expansion using twin-turbines operating at up to 25,000 RPM. The turbines are shafted to a permanent magnet rotor that powers a generator. Gas from the inlet-side of the turbo-expander pressurizes oil-free fully enclosed gas-lubricated bearings that do not need shaft-seals. Staged liquid-to-gas heat exchangers control system and gas temperatures. A high-frequency inverter rectifies generator electricity converting it to standard 480V, 60Hz AC power. A pressure control valve regulates gas inlet pressure, and a bypass valve regulates mass flow through the turbo-expander in order to maintain stable gas outlet pressure and power generation. Dual fast-acting shutoff valves isolate the GLG and protect the gas pipeline during controlled and fast stop scenarios such as shaft over-speed/imbalance, loss of utility grid power, loss of external heat supply, loss of bearing pressure, and loss of instrument air. In all, there are nearly 100 controlled and fast stop control sequences in order to maintain system safety and integrity.

Anax-Star ASTE250 Applications

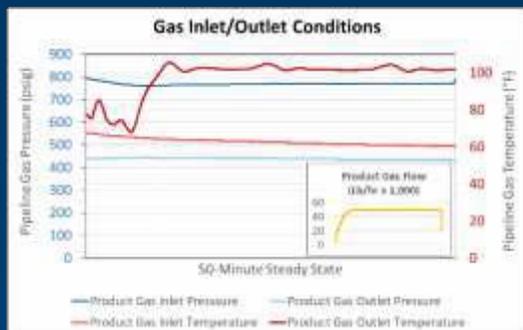
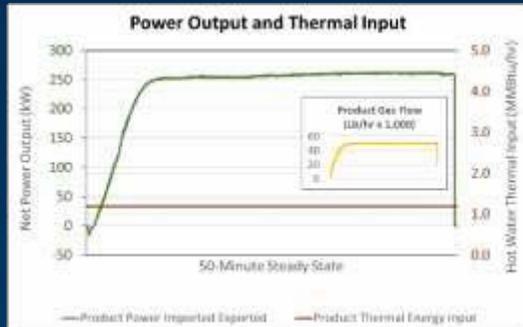
The ASTE250 is a packaged modular plug-and-play design for grid-parallel and off-grid zero-emissions power generation in compliance with UL1741 and IEEE1547 for distributed generation, and can be installed in seismic zones 1 to 4. It is designed to operate at gas inlet pressures of about 400 to 900 psig with at least 250 psig pressure reduction. Its safety relief pressure is 975 psig. In order to achieve 250kW power output at those pressures, gas throughput needs to be about 6,000 to 25,000 scfm, and a waste-heat process needs to provide low-grade heat at about 150°F and at least 1.2 million Btu/hr.

A guiding principal in development of the ASTE250 was to create a renewable energy source for public utilities, pipeline operators, and major industrial users (MIUs). Target applications include natural gas power plants with abundant gas flows and State and Federal mandates for clean energy; City gates and other pipelines junctions between high-pressure long distance networks and low-pressure local networks; and MIUs with significant inbound natural gas volume, high electricity consumption, and available waste heat streams.

Summary of GTI Test Results

Steady State Performance at Maximum Power:

- Average power output: 254 kW
- Average gas flow rate: 49,600 lb/hr
- Average gas inlet pressure: 768 psig
- Average gas outlet pressure 438 psig
- Maximum gas temperature rise: 44°F



Successful Controlled Stop Simulations:

- Loss of external heat supply
- Low instrument air pressure
- Inverter overcurrent
- High generator winding temperature
- High first stage gas inlet temperature

Successful Fast Stop Simulations:

- Loss of utility grid power
- Loss of gas bearing pressure
- Manual emergency stop at panel
- Loss of gas pipeline inlet pressure
- Loss of inverter control
- Shaft over-speed
- High shaft orbit (imbalance)

Pressure Test: 1.5x Maximum Allowable

Anax-Star ASTE250 Turbo-expander

Test Facility

The ASTE250 HP-L250kW was tested at a high-pressure natural gas flow facility at DNV-GL Flow Centre in Ferryhill, England. An onsite boiler supplied external heat to the GLG, and a portable generator simulated utility power for grid interconnection.



GTI Test Summary and Observations

GTI was commissioned by Anax Holdings to identify a test facility with adequate gas pressures and flows for full-scale GLG testing; to develop appropriate test protocols based on the Anax-Star test plan; and to participate in onsite testing.

Primary goals for the tests included full-scale proof of concept, verification of performance mapping, and in-service data collection as detailed in the test protocols GTI develop. The diagram below shows the general schematic of the GLG system and the test boundaries defining the components that were part of the device tested and the components that were not part of the device, but were part of the system to make it fully functional. The diagram specifies controls and measurement locations defined in the test plan.

GTI provided an independent evaluation of the test results using Anax-Star's test plan as a basis for assessment. The adjacent summary of test results show steady state performance of the GLG when operated at full power for an extended 50-minute duration. In addition, a battery of controlled and fast stop sequences were successful. The performance and safety tests conducted at the test facility in accordance with the test plan demonstrated technical feasibility and safe operation of the ASTE250 GLG.

