Anax-Star Turboexpander ASTE Safety & Performance Test Brief

Performed by: Gas Technology Institute, GTI Project Number 22189

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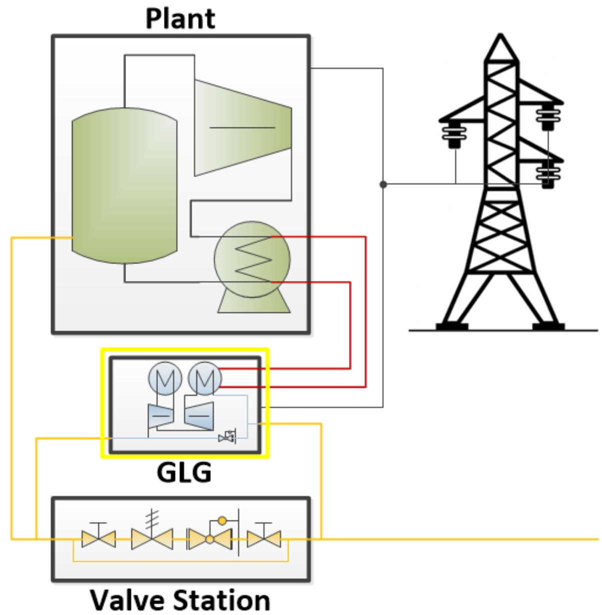
Technology Overview



A turboexpander generates power through pressure reduction in a high-pressure natural gas pipelines. 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 at city gates, such as pressure regulating valves.

Without the addition of external heat, natural gas cools to a low temperature as it expands – whether through a turboexpander or a pressure regulating valve. Thus, GLGs must absorb waste heat from other processes into the gas to control the temperature and condition the outlet 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 Turboexpander

Anax Power, a US company, along with Star Refrigeration, an engineering firm in the United Kingdom have engineered and built the Anax-Star Turboexpander (ASTE). The ASTE is a packaged 7’x7’x13’ skid-mounted 250kW system that conforms to US industry standards and employs several 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 magnetic rotor that powers a generator. Gas from the inlet side of the turboexpander pressurizes the 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 and converts it to standard 480V, 60Hz AC power. A pressure control valve regulates gas inlet pressure, and a bypass valve regulates mass flow through the turboexpander 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 grid power, loss of 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.

ASTE Applications

As a modular, plug-and-play package, the ASTE is designed for grid-parallel and off-grid zero-emissions power generation in compliance with UL1741 and IEEE1547 for distributed generation. The machine 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 and a safety relief pressure of 975 psig. In order to achieve 250kW power output at pressures, gas throughput needs to be about 6,000 to 25,000 scfm, though this can vary. Additionally, waste-heat should be available to provide low-grade heat at about 150°F and at least 1.2 million Btu/hr.

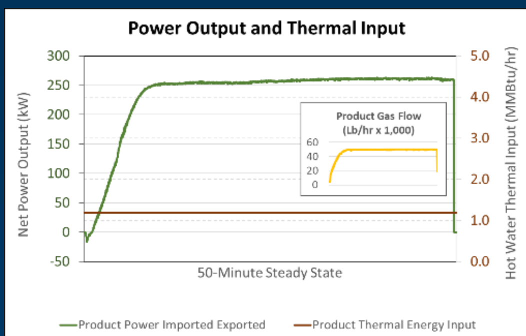
The ASTE’s goal is to deliver renewable energy to public utilities, pipeline operators, and major industrial users (MIUs). Target customers include natural gas power plants, MIUs with significant inbound natural gas volume, city gates, and other pipeline junctions between high-pressure networks and low-pressure networks. Furthermore, the ASTE qualifies for several state and federal renewability incentives around clean energy.

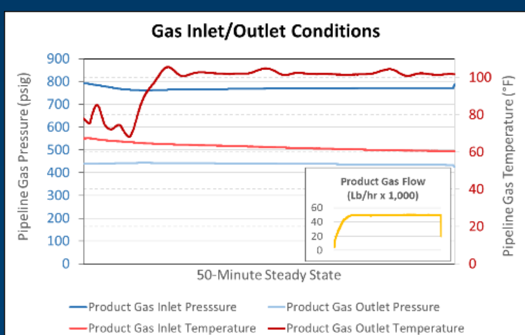
Summary of Test Results

Sample Steady State Performance:

Parameter	*Design*	*Tested*
Inlet Pressure (psig)	*750*	*751*
Outlet Pressure (psig)	*450*	*447*
Diff. Pressure (psid)	*300*	*304*
Power Output (kW)	*250*	*253*

- *Peak power output: 260+ kW*
- *Approx. gas flow rate: 50,000 lb/hr*
- *Heat input at 250 kW: 850 kW*





Successful Controlled Stop Simulations:

- *Loss of external heat supply*
- *Inverter overcurrent*
- *High generator winding temperature*
- *High first stage gas inlet temperature*

Successful Fast Stop Simulations:

- *Low instrument air pressure*
- *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 (shaft imbalance)*

Pressure Test: *Tests conducted by Star Refrigeration at 1.5x maximum allowable pressure per PHMSA requirements.*

Anax-Star Turboexpander Testing Report

Test Facility

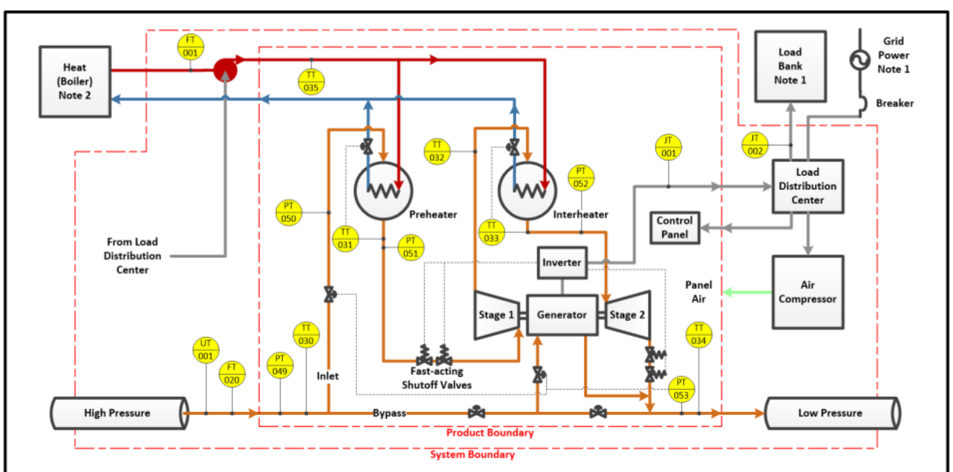
The ASTE was tested at a high-pressure natural gas flow facility at DNV-GL Flow Centre in Ferryhill, England. An onsite boiler supplied external heat to the GLG, and a portable generator simulated utility power for grid interconnection.

GTI Test Summary & Observations

GTI was commissioned by Anax Power to identify a test facility with adequate gas pressures and flows for a thorough, full-scale GLG test. After identifying a site, GTI developed appropriate test protocols based on the Anax-Star test plan. Once the site and testing protocol were established, GTI participated in the on-site testing.

Primary goals for the test included full-scale proof of concept, verification of performance mapping, and in-service data collection as detailed in the GTI test protocols. The diagram below shows the general ASTE schematic, as well as the test boundaries, which define the components that were a part of the test and the components that were not a part of the test. 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 shows steady state performance of the GLG when operated at full power for an extended 50-minute duration. Furthermore, a plethora 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 ASTE. **NOTE: This document constitutes an overview of the full 65-page report.**



Note 1: Tests for the gas letdown generator use a generator to simulate grid power. A load bank is used to simulate Power Load and measure power output of the gas letdown generator.
Note 2: Tests for the gas letdown generator use a boiler to simulate waste heat produced by a facility process or generated by another means such as a supplemental combined heat and power system.

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