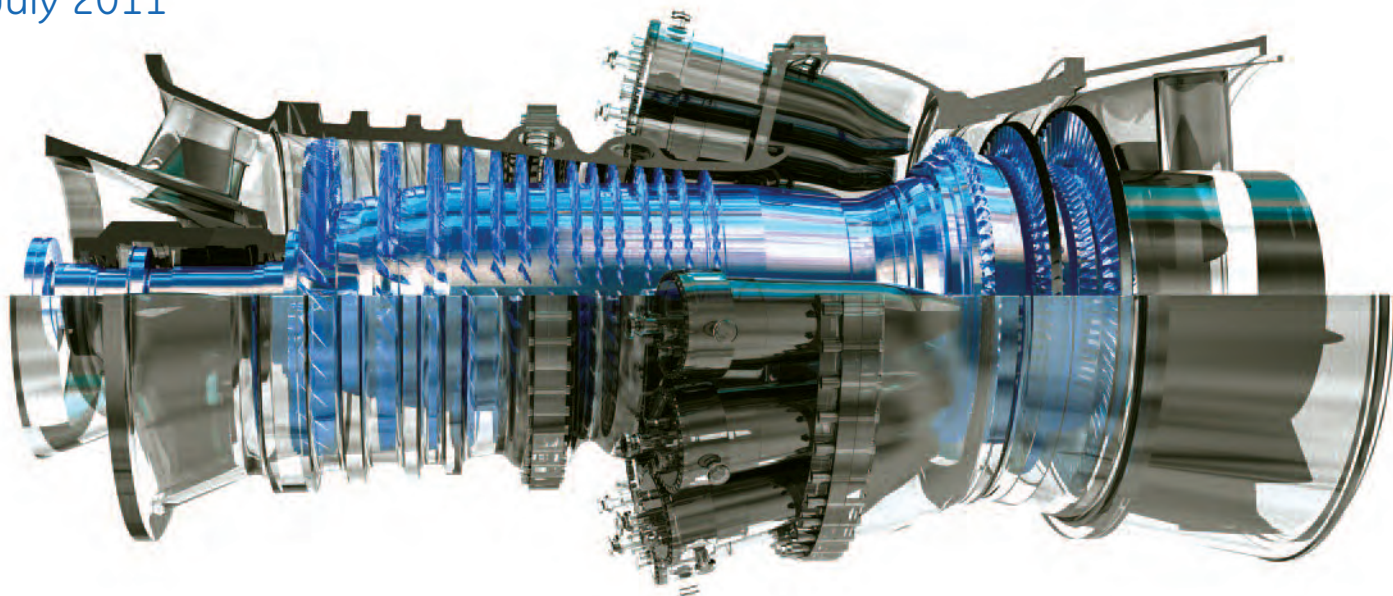


GE's Next 7FA Gas Turbine "Test and Validation"

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GE's Next 7FA Gas Turbine "Test and Validation"

I. Introduction

Today's power generators find themselves in an uncertain world. Greenhouse gas legislation, fuel prices, renewable portfolio standards, and financing constraints are but a few of the concerns they face. In response to these demands, GE has continued to evolve its F-class technology, which has been an industry standard for reliable, flexible, and economical power generation for almost two decades.

In 2009, GE Energy introduced its upgraded Frame 7FA gas turbine to meet growing performance requirements for power plant operators. The upgraded turbine is designed to help power plant operators reduce their total cost of ownership and environmental impact by allowing them to use less fuel to generate power.

The newest addition to GE's F-class gas turbine portfolio, the 7FA.05 version, delivers greater output and efficiency while maintaining leadership in reliability, availability and the operational flexibility power generators need to achieve greater revenue in all operating modes. In developing the 7FA.05 gas turbine, GE has mined the wealth of knowledge that comes from the largest and most experienced F-class fleet in the industry and combined it with proven technology from across GE's broad portfolio of heavy duty and aeroderivative gas turbines, as well as GE's aircraft engine models.

A key part of the technology validation for this new turbine is the construction of a full speed, full load-capable test stand facility at GE's Greenville facility. The first system to be tested in this facility will be the advanced compressor in early 2011. Using a unique and proprietary power train, GE will be able to fully characterize the performance of the compressor, including aeromechanics, performance, and surge line mapping. Following characterization of the compressor, GE will perform a Full-Speed Full-Load test of the complete gas turbine. This testing will utilize extensive instrumentation to demonstrate performance, aeromechanics, combustion dynamics, off-frequency capability, and dual-fuel capability. This validation approach will enable GE to fully characterize the next 7FA under real-life conditions.

This paper describes how GE has developed and successfully validated several enhancements for F-class gas turbines, with special focus on the validation testing for the next 7FA to be introduced in 2012.

II. GE's Next 7FA Gas Turbine

Value Proposition

GE Energy's newest 7FA heavy duty gas turbine delivers greater output and efficiency while maintaining leadership in reliability, availability and the operational flexibility power generators need to achieve greater revenue in cyclic and peaking operation.

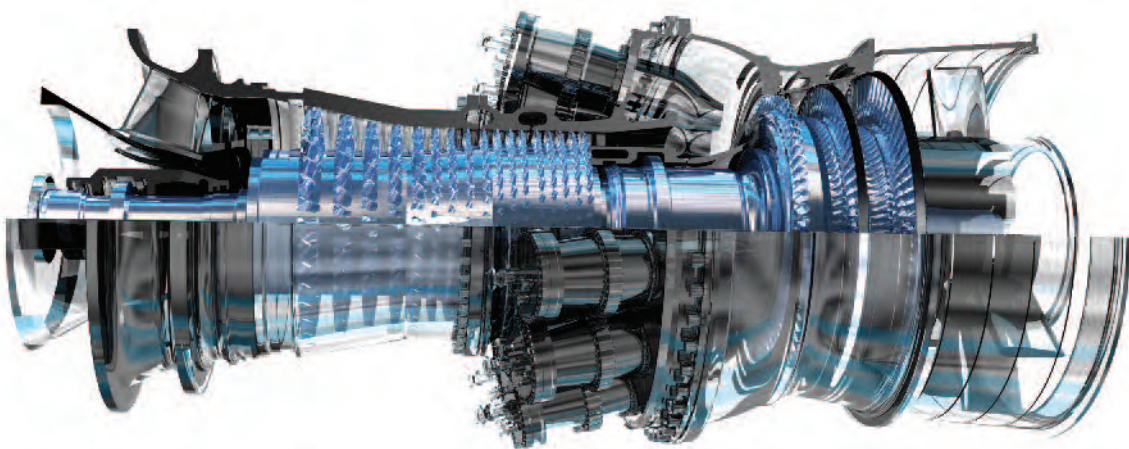


Figure 1. 7FA.05 gas turbine

To help meet customers' growing need to generate more power more efficiently, GE Energy introduces the next evolution of its industry-leading 7FA heavy duty gas turbine for the 60 Hz power generation regions. By merging a host of proven technologies leveraged across our product lines, the next evolution of the 7FA gas turbine now offers improvements in output, thermal efficiency, operability and lower life cycle costs, all without compromising the high degree of reliability, availability, and maintainability (RAM), and operational flexibility historically delivered by GE's F-class fleet.

Using proven technology from earlier GE models, the latest 7FA gas turbine is coupled with a highly advanced 14-stage axial compressor, providing enhanced performance, operability, and maintainability, in simple and combined cycle configurations.

Largest Fleet Heritage and Experience

GE's F gas turbine technology was initially developed in the 1980s. GE's first F-technology unit entered commercial service on June 6, 1990, at Virginia Electric & Power Company's Chesterfield site. As of November 2010, there are more than 743 7FA/B gas turbines in service with a cumulative operating experience of more than 23 million fired hours and more than 612 thousand starts. The hours-based fleet leader has logged more than 130 thousand hours while the starts-based fleet leader has logged more than 3,600 starts.

7F technology has been scaled to the 50 Hz 9FA machine and the 50/60 Hz 6FA machine. It has also evolved to GE's advanced FB and F Syngas technology. A grand total of 1061 GE F technology units are now in service with more than 35.6 million fired hours and 746 thousand starts.

Table 1. GE F-class operational experience

This experience includes operation in duty cycles ranging from peaking to daily start/stops to base load operation as shown in Figure 2.

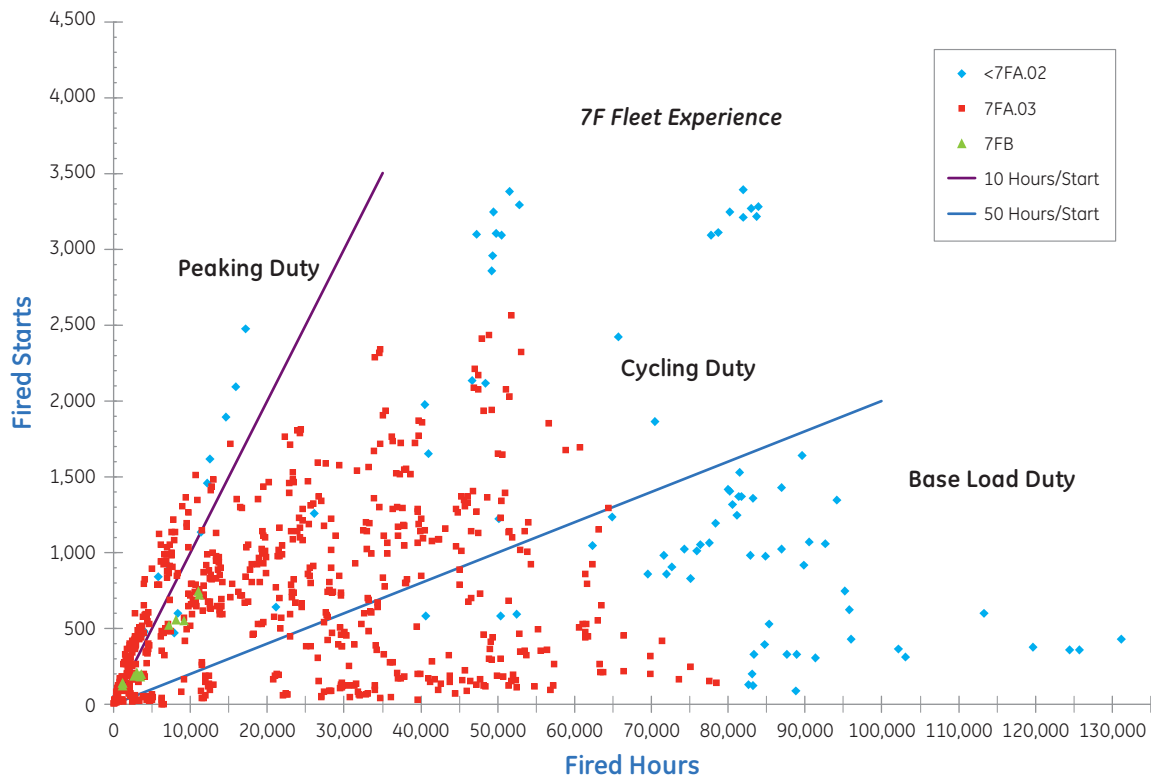


Figure 2. 7FA duty cycle for 2009 (base load, cyclic, peak)

To summarize, GE can confidently say its F technology has the:

- Largest fleet
- Most operational experience
- Most reliability¹

Incremental Proven Technology

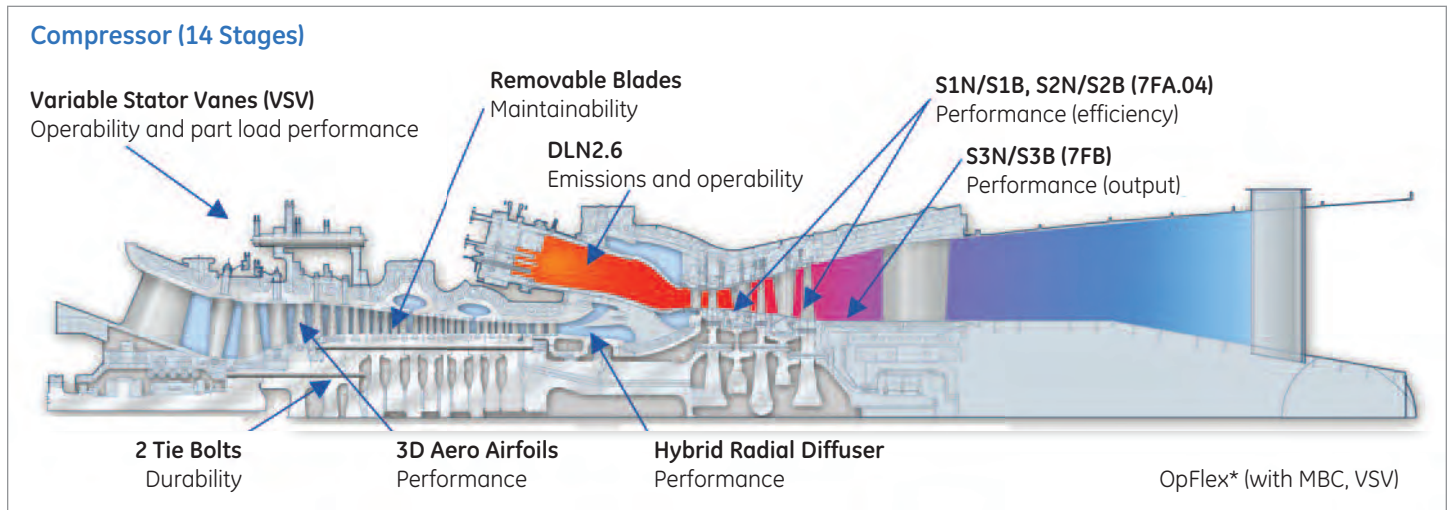


Figure 3. 7FA.05 model evolution

GE has employed an incremental approach for the evolution of the 7FA.05 gas turbine. Only existing proven technologies are being utilized.

- Aviation heritage compressor design utilized on heavy duty gas turbines (GE5, GE10, 5002E, 6C)
- Heavy duty gas turbine compressor mechanical rotor structure
- Successful DLN2.6 combustor
- Evolution of the validated 7FA Advanced Hot Gas Path (HGP) turbine section

It is important to note that no unproven technologies have been introduced with the 7FA.05 platform.

Compressor

GE's most advanced high efficiency compressor technology, based on prior heavy duty gas turbine platforms, has been incorporated into the 7FA.05 gas turbine. The compressor is based upon GE Aviation compressor technology practices. The 7FA.05 gas turbine technologies consist of 14 stages specifically modeled for a higher flow rate, enabling greater output. The airfoil design is based on the proven aerodynamic configuration of the GE5, GE10, 5002E and 6C platforms. The airfoils utilize a proprietary, three-dimensional aerodynamic shape for improved efficiency. The first three stages of the compressor contain variable stator vanes that provide the gas turbine with a wider operating envelope. The compressor flow path has been planned to accommodate inlet conditioning with improved leading edge erosion tolerance. The rotor is bolted steel construction with two sets of durable concentric tie bolts specifically planned to improve the aerodynamic flow path. The rotor blades and wheels incorporate a circumferential dovetail plan that permits removing the blades without pulling the rotor from the casing, thereby improving maintainability. The compressor casing has been built to match the rotor and the existing DLN2.6 combustor interface. The casings accommodate an advanced Blade Health Monitoring (BHM) system for stages 1 through 3. Additional borescope holes have been included for enhanced inspection coverage.

1. Source: ORAP®; All rights reserved: SPS® (2Q'09-1Q10)

The higher temperature-capable materials still operating in FA firing temperatures will further improve the successful experience of the 7FA wear modes for low cycle fatigue, oxidation and creep, thus supporting longer life and reduced repair costs.

Component	Comment	7/9FA	7/9FB	6C	7/9H	GE10

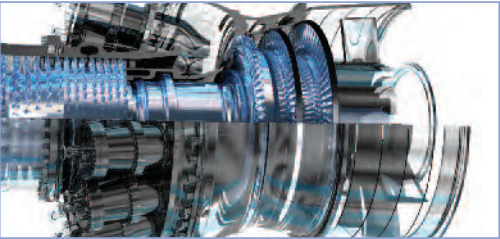


Table 4. 7FA.05 gas turbine experience

The first and second stages of the turbine section will consist of minor modifications to the 7FA Advanced Hot Gas Path hardware to increase the flow passing capability. The third stage will utilize the 7F Syngas design. The turbine casing remains unchanged.

III. GE’s Next 7FA Gas Turbine – Validation Program

World Class Validation Program

The energy industry today counts on new products being thoroughly validated prior to first unit shipment.

Although the next 7FA employs proven technology, GE recognizes that robust configurations depend upon a rigorous program of testing to ensure all components are tested under the conditions they will see in service. It is recognized that full validation requires that the proven technologies utilized come together and be validated successfully as a system. Prior to delivering the first unit to a customer, the 7FA.05 gas turbine will undergo a series of component level, subsystem level, and system level tests. No field-testing effort is expected other than the testing normally done during normal plant commissioning. The initial units are only expected to have normal remote monitoring and diagnostics along with planned borescope inspections.

The development of the Test Stand Validation Facility will not only allow for the most thorough full-scale compressor validation in the world for GE’s newest 7FA model, but it will also provide the opportunity to run a Full-Speed Full-Load test for this unit on both NG and distillate fuels prior to first unit shipment. This will allow for full validation of the complete gas turbine system.

GE’s high level 7FA.05 platform validation objectives are:

- Gas turbine performance
- Inlet flow distortion
- Compressor mapping (up to surge line) for performance, aerodynamics and aeromechanics
- Compressor IGV / VSV schedule optimization
- Compressor exit diffuser geometry
- Combustion operability / dynamics / profiles
- Gas turbine exhaust profiles
- Rotor / HGP life (thermals and stresses)
- Gas turbine grid code response (aeromechanics and controls)
- Transient operation w/fast start
- Natural gas / liquid fuel
- OLWW nozzle positions

- Accessory (system pressures, cooling and sealing)
- Controls

Validation Plans

Component level testing is required to ensure boundary conditions are well understood in order to articulate sub-system design and system level interactions. The following are key subsystem test rigs that have been completed to support component level validation to ensure system level program success:

- Inlet rig – inlet flow profile for R1 blade durability, performance
- VSV rig – vane arm mechanical durability
- Combustion lab and rig – combustion dynamics and profiles for life, emissions
- Compressor diffuser rig – hybrid radial diffuser design for performance
- Turbine aero rig – performance
- Exhaust diffuser rig – performance and exit profiles

System Level Testing will be required for the full validation of the 7FA.05 gas turbine and will rely on three key systems level tests.

- Compressor test – full scale compressor characterization
- 7FA.04 HGP field test – successfully instrumented field rotor test (completed in May 2009)
- 7FA.05 FSFL test – Factory FSFL test of the 7FA.05 gas turbine

Compressor Testing

The compressor vehicle test of the 7FA.05 Gas Turbine is planned to start in the early to mid 2011 timeframe. This test is expected to be two-to-three months in duration. The test will be comprised of over 2600 data streams that will be supplied through an advanced slip ring. The data achieved by this test will support the validation of the following objectives:

- Aerodynamics mapping for performance
- Compressor blade and stator aeromechanics
- Compressor rotating stall effects during start-up
- Optimize the IGV / VSV schedule
- Measure expected inlet flow distortions
- Measure bleed valve sensitivities
- Compressor sub-system operation of the compressor exit diffuser
- Compressor tip clearance robustness
- IGV / VSV mechanisms
- Finalize VSV linkage lengths
- On-line water wash operation
- Flow and heat transfer assumptions

- Transient operation with fast start
- Torque measurement system

System Testing

The gas turbine test of the 7FA.05 Gas Turbine is planned to start in the late 2011 timeframe. This test is expected to be three-to-four months in duration. The test will be comprised of over 2800 data streams that will be supplied through two advanced slip rings. The data achieved by this test will support the validation of the following objectives:

- Gas turbine performance
- Compressor aeromechanics (as a result of compressor learning from rig test)
- Compressor to combustor interface
- Combustion operability and dynamics
- Combustion and gas turbine exhaust profiles
- Rotor / HGP life (thermals and stresses)
- Grid code response
- Transient operation with fast start
- Natural gas and liquid fuels
- OLWW nozzle positions
- Accessory (system pressures, cooling and sealing)

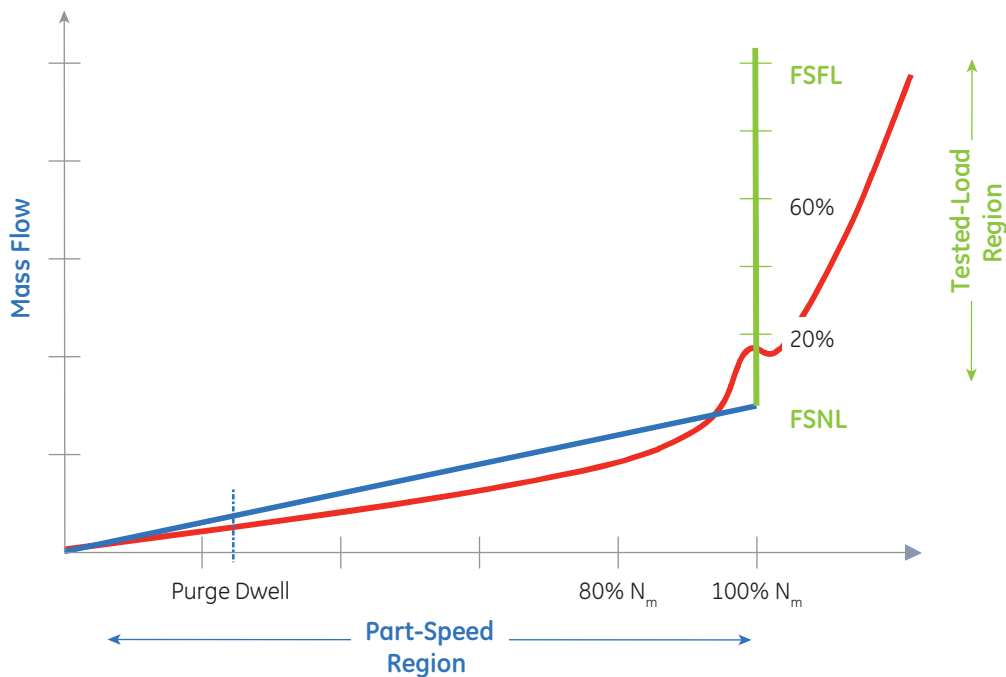


Figure 4. 7FA.05 gas turbine test plan

- Controls

The gas turbine will be tested over the test plan illustrated in *Figure 4* in terms of mass flow, physical speed, and load.

IV. GE Factory Test Facility

Overview

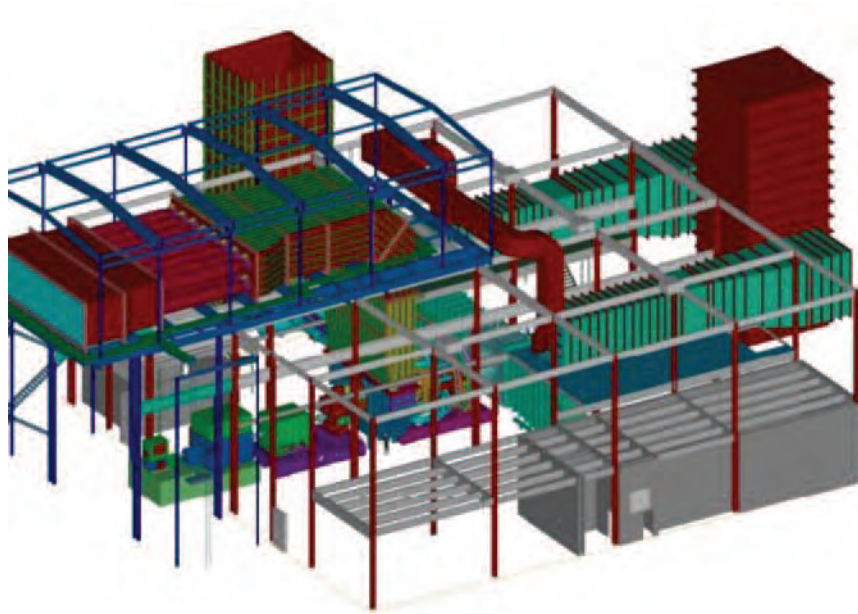


Figure 5. GE Factory Test Facility (Greenville, SC) – View 1

GE has invested in a Full-Speed Full-Load world class test facility that is being constructed at the Greenville, SC manufacturing location.

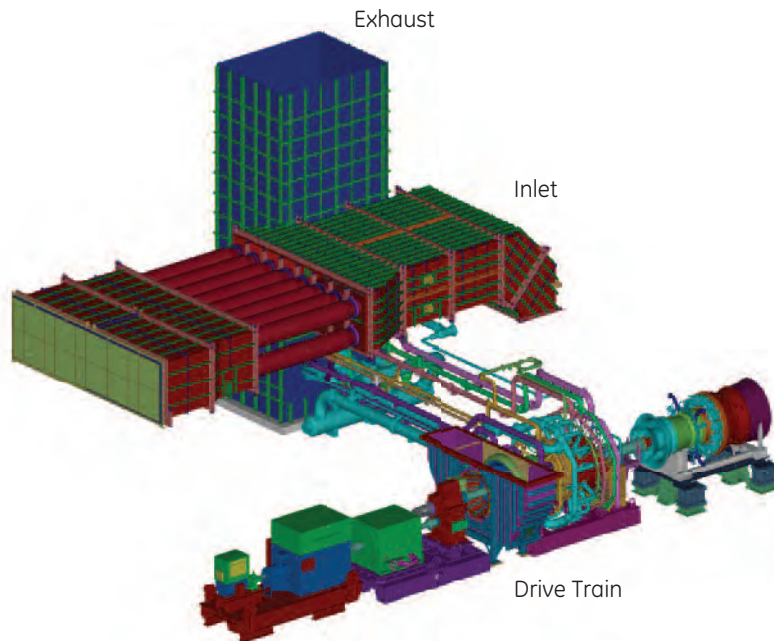


Figure 6. GE Factory Test Facility (Greenville, SC) – View 2

This test facility will enable GE to fully characterize the 7FA.05 compressor and gas turbine under real-life conditions, but in a controlled laboratory setting. The unique capability of the test facility will allow for testing far beyond the normal expected operating conditions that would be expected in the field.

Configuration and Drive Train

The drive train configuration consists of:

- Starter motor
- 58 MW motor (supplemental drive train power source)
- EL 19 electric drive torque converter
- FD90 gear box

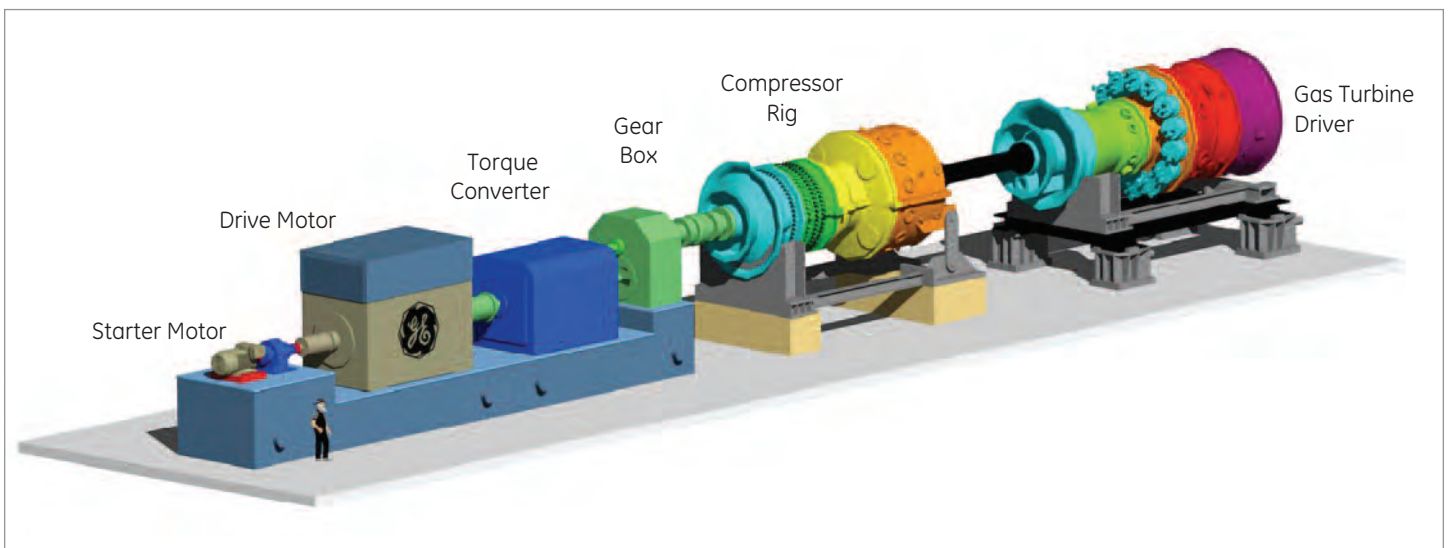


Figure 7. GE Factory Test Facility drive train configuration

- Load compressor (test article)
- Driver gas turbine (used as a power source or test article)

With this unique test stand configuration, GE will have the capability to fully validate and test heavy duty gas turbines as follows:

- Full scale compressor test rig that will allow for steady state and transient aeromechanics, performance and operability testing of the compressor subsystem.
- Variable speed/variable load capability of the gas turbine that allows for simulating off frequency operation and importance of grid code compliance response.
- Full-Speed Full-Load capability of the gas turbine. This allows for simulating the conditions and load environment and of the gas turbine with electrical grid load.
- Ability to test far beyond the expected field operation of a gas turbine.

World Class Test Capability

Careful thought was considered in the design of the test facility from the drive train configuration to features needed to fully validate a gas turbine.

Table 5 highlights some of the key capabilities of GE's new test facility.

Flexible Configuration	<ul style="list-style-type: none"> • Capability to independently and simultaneous test a compressor rig and gas turbine
Modular Design Capability	<ul style="list-style-type: none"> • Rapid development, quick configuration change, modules on rail
Full Scale Compressor	<ul style="list-style-type: none"> • Eliminates the uncertainty of scale effects
Full Load Capability	<ul style="list-style-type: none"> • Simulates the operation of a gas turbine as expected in the field
Variable Speed Capability	<ul style="list-style-type: none"> • Capability to test beyond grid code requirements in terms of aeromechanics and controls • Test ambient temperature effects relative to the compressor
Compressor Rig Throttling Capability	<ul style="list-style-type: none"> • Ability to fully map compressor especially to surge line and beyond at full scale SS conditions • Inlet throttle – flow measurement accuracy especially at low flows, ASME flow nozzle and 36" valve • Exit throttle – ability to back pressure compressor to target any desired op-line point
Ability to Run at Sub-atmosphere Inlet Conditions	<ul style="list-style-type: none"> • Can pull inlet vacuum <0.5 atm, reduces impact of surge • Reduces work required to achieve highest pressure ratio points on compressor map

Table 5. Capabilities of GE's new test facility

VI. Conclusion

GE's 7FA gas turbine is the most experienced F-class gas turbine in the world. The 7FA fleet has more units in service, and has accumulated more operating hours and starts than any other F-class gas turbine. GE has utilized the wealth of knowledge that comes from this F-class operating experience and combined it with technology from across GE's broad portfolio of heavy duty and aeroderivative gas turbines—as well as GE's aircraft engine models—to develop the 7FA.05 version gas turbine.

The 7FA.05 delivers increased output and efficiency, which are highly valued in today's competitive power generation segment, but does so without compromising the world-class operational flexibility, reliability, and availability of the 7FA. The improved performance and operational flexibility have enabled the 7FA.05 to become part of GE's ecomagination portfolio, a rigorous internal and third party environmental and operational evaluation.

Prior to delivering the first unit to a customer, the 7FA.05 will undergo a comprehensive series of component level, subsystem level, and system level tests, culminating in a Full-Speed Full-Load test in a new world class test facility being constructed at GE's Greenville, South Carolina, gas turbine manufacturing and test center of excellence. This testing will enable GE to fully characterize the 7FA.05 under real-life conditions and beyond.

GE's commitment to the 7FA gas turbine is a testament to the confidence GE has in this industry workhorse to continue to serve the wide-ranging needs of its customers in an ever changing and extremely competitive segment.

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