GE Power

POWERING A NEW RECORD AT EDF

9HA.01 SETS EFFICIENCY WORLD RECORD

GEA32885

August 2016

On Friday the 17th of June 2016, GE and EDF officially inaugurated the first ever combined-cycle power plant equipped with GE's HA gas turbine in Bouchain, France. On that day, GE was also recognized for powering the "world's most efficient combined-cycle power plant" by achieving at Bouchain something never seen before: converting fuel to electricity at a record 62.22 % efficiency rate.

I. INTRODUCTION

1.1. GE 9HA Combined Cycle Plants

From the increasing penetration of renewable energy resources to evolving emissions standards, utilities are in greater need of enhanced efficiency and flexibility to effectively and profitably navigate the fluctuating energy landscape. In response, GE Power has developed the 9HA Combined Cycle Power Plant.
This innovative 600+MW block-size plant is engineered to answer the current and evolving energy production needs of the globe. GE Power has specifically engineered the power plant to give customers a total plant design that is simple and cost effective to install, control and maintain.

1.2. EDF Bouchain... home for the first 9HA

In 2011, GE and EDF signed a strategic partnership for the co-development of the first 9HA power plant in the northern part of France (Bouchain). EDF, one of the world's largest utilities, is at the forefront of innovation. The introduction of the most efficient combined-cycle gas turbine powered by GE's 9HA.01, will complement the mix of power-generating assets.

Bouchain's power plant is an integrated, highly efficient system that includes these key components: the "H-class" 9HA.01 Gas Turbine, a D-650 Steam Turbine that runs on the waste heat produced by the gas turbine, an advanced W86 Generator, a Mark* Vle control system that links all of the technologies and a heat recovery steam generator.

II. 9HA.01 EFFICIENCY WORLD RECORD

2.1. Tests Objectives

The purpose of the test conducted on the 28th of April 2016 was to verify the Combined Cycle Power Plant efficiency. Bureau Veritas, acting as an independent third party, witnessed and certified the performance tests carried out by GE's internal testing organization. Bureau Veritas is a global leader in Testing, Inspection and Certification, and is well recognized and accredited by major national and international organizations.

2.2. Performance test protocol

The procedure for carrying out the test was prepared by GE and validated by Bureau Veritas ahead of the tests. The performance test was conducted according to ASME PTC 46-1996 . The objective of this code is to provide uniform and accurate test methods to determine the thermal performance and electrical output of heat-cycle electric power plants and cogeneration facilities.

Fuel samples collected during the tests were analyzed per ISO6974 standard and ISO6976 was used for the calculation of calorific values of gas, Wobbe Index and density.

Bureau Veritas was involved throughout the test sequence:

Prior to the test:

- Bureau Veritas checked and validated the test procedure developed by GE, and the availability and functionality of all measurement devices needed for the performance test
- The calibration certificates of the station and precision instruments were checked by Bureau Veritas
- The cycle isolation was done by GE and EDF under the supervision of Bureau Veritas

During the test, Bureau Veritas supervised the performance test:

- Witnessed and verified data recordings and plant conditions
- Witnessed gas sample collection and verified heating value calculations
- Witnessed the auxiliary load measurements
- Verified performance test calculations and accuracies

After the test:

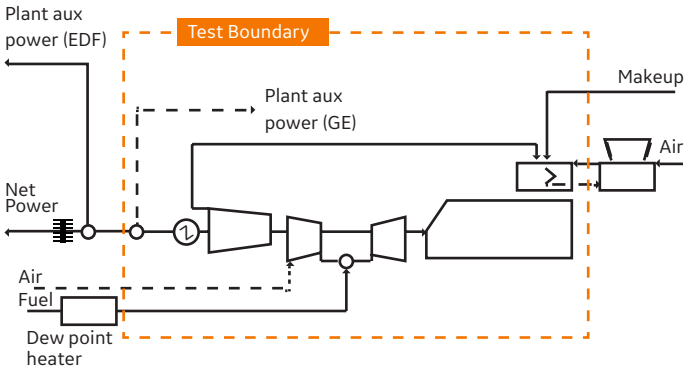
- Bureau Veritas validated the GE measurements transmitted by GE
- Generated a final test report including the test data and results certification, and including post test uncertainties analysis

2.3. Combined Cycle test boundaries & specific conditions

The following schemes present the combined plant test boundaries:

Specific test conditions:

- The combined cycle plant test boundaries include the entire power island. As such the published combined cycle efficiency is a net performance level
- The combined cycle efficiency calculation was based on the LHV of the fuel gas



2.4. Tests results and corrections

2.4.1. Reference conditions

The combined cycle efficiency test was performed on April 28, 2016. The reference conditions taken into account for the calculation are detailed in the table below:

Parameter	Unit	ISO conditions GE auxiliaries
Ambient temperature	°C	15
Barometric pressure	Bar,a	1.0133
Relative humidity	%	60
Generator frequency	Hz	50
Power factor	-	0.85
Condenser cooling water temperature	°C	15.0
Condenser cooling water flow	t/hr	28,983
Fuel Wobbe Index at 15°C and 1.01325 bar,a	MJ/Nm^3	50.724
Fuel composition	(mole %)	CH_4 =100

2.4.2. Measured and calculated parameters during the test without corrections

Parameter Measured	Item Reference	Unit	Value
Ambient temperature	-	°C	11.17
Barometric pressure	-	Bar,a	1.010
Relative humidity	-	%	40.64
Condenser cooling water temperature	-	°C	15.03
Condenser cooling water flow	-	t/h	27026
Generator frequency	-	Hz	50.00173
Gas composition	-	% mole	CH_4 = 89.302 C_2H_6 = 5.457 C_3H_8 = 1.378 iC_4H_{10} = 0.274 nC_4H_{10} = 0.171 iC_5H_{12} = 0.057 nC_5H_{12} = 0.03 C_5H_{14} = 0.086 He = 0.015 N_2 = 1.548 CO_2 = 1.683
Wobbe Index	-	MJ/Nm^3	49.67
Gas fuel flow rate	W FG	kg/h	75,397
Fuel lower heating value at constant pressure	LHV	kJ/kg	46,344
Heat consumption	Q	kJ/h	3,494,265,346

Parameter Measured	Item Reference	Unit	Value
HP steam pressure 1	P	Bar,a	173.3
HP steam pressure 2	P	Bar,a	173.3
HP steam temp 1	T	Deg C	578.8
HP steam temp 2	T	Deg C	578.4

2.4.3. Correction factors and uncertainty calculations
The correction factors and uncertainty calculations have been calculated using the correction curves and equations provided by GE and validated by Bureau Veritas

2.4.4. Test conclusion
The following table shows the performance reached during the test run for the different sets of reference conditions (described in section 2.4.1)

Parameter	Unit	ISO conditions GE auxiliaries
Corrected power island net output	kW	593,880 +/- 2, 176
Corrected heat consumption	kJ/h	3,435,887,202 +/- 16,403,495
Corrected heat rate	kJ/kWh	5,785.5 +/- 34.8
Corrected efficiency	%	62.22 +/- 0.37

In addition, the first 9HA combined cycle power plant independently demonstrated a maximum output of 605 MW on a power island net output basis. Collectively, the 9HA has proven it was designed to meet the flexibility, power, and efficiency needs of our customers.

III. BOUCHAIN WORLD RECORD …. ONE MORE STEP IN THE 9HA DEVELOPMENT & VALIDATION PROCESS

3.1. Step 1… 9HA Gas Turbine validated from a fleet perspective
In 2008, GE developed the world's largest and most comprehensive full-speed, full-load (FSFL) gas turbine test facility located in Greenville, South Carolina, U.S. The objective of this significant achievement is to be able to support, prove, and accept the accuracy of the technical parameters of our gas turbine fleet. Therefore, this off-grid, world-class, $200 million facility provides full-scale validation of 50 and 60 Hertz gas turbine systems. Here, GE performs comprehensive off-grid testing with superior load response and full over/under frequency testing capability beyond the typical grid-connected installations.

The 9HA product validation took place from October 2014 to March 2015. Extensive mapping of all systems and controls was performed with variations made to rated speed, ignition to load, and ambient temperatures. This testing was observed by many customers and industry partners (i.e., insurers, grid operators, investors, and EPC's).

The range of operating conditions and data obtained from the gas turbine and its systems exceeds the bandwidth of the entire F-class installed fleet operating data, and is equivalent to multiple units running over 8,000 hours with full instrumentation.

This testing not only demonstrated gas turbine systems and control capabilities, but also confirmed the design methods and tools, along with the growth potential of the HA platform.

For additional information on the 9HA validation tests, please refer to GEA32109 (09/2015).

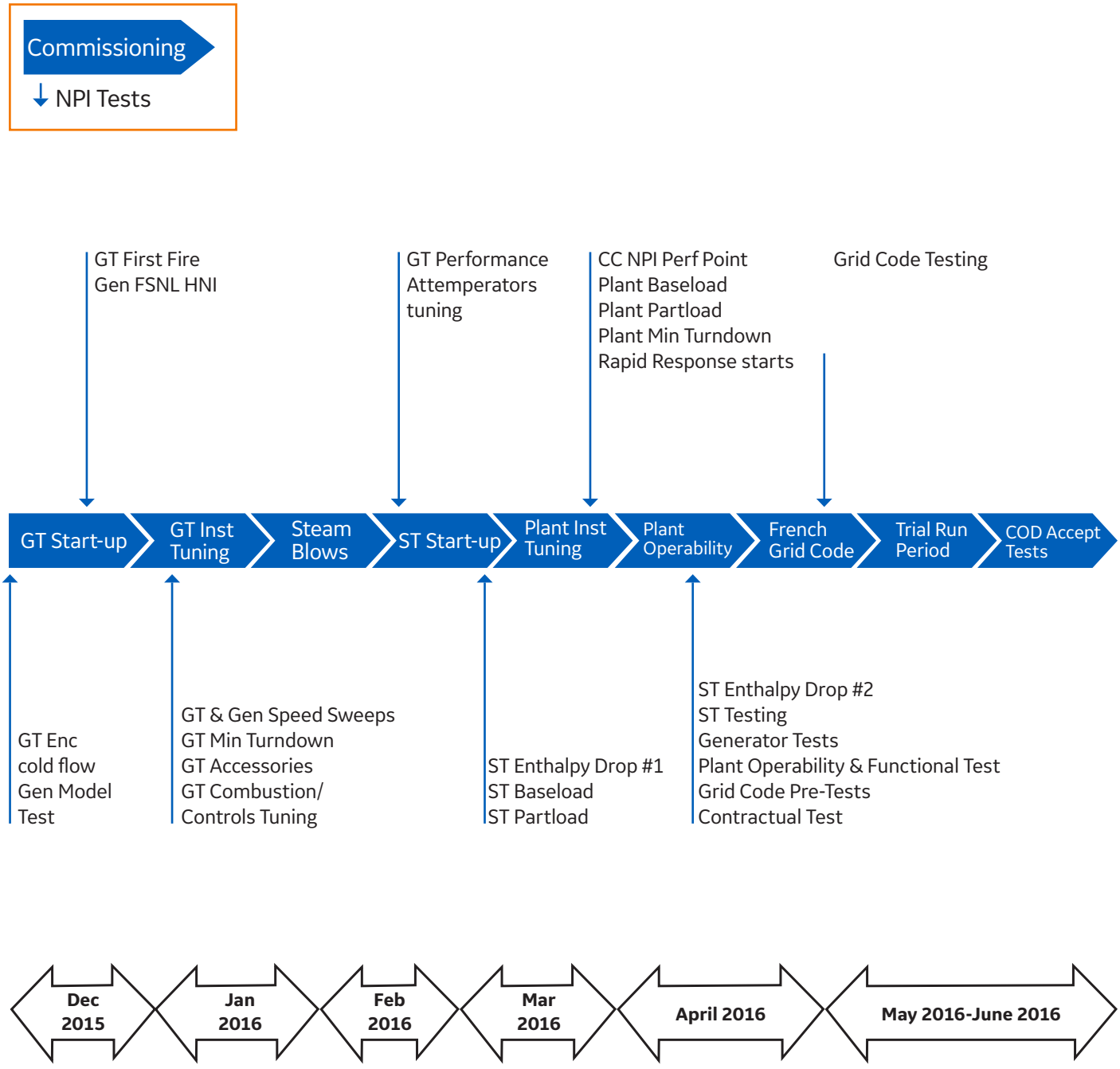
3.2. Step 2… First 9HA commercial unit complementary tests
Integrated into the commissioning operations were a limited number of New Product Introduction (NPI) tests to further gather engineering information on the first 9HA.01 installed in the field, as well as the gathering of information on the generator, steam turbine and SSS Clutch. These tests included monitoring station instrumentation and temporary engineering instruments to validate the installed effects associated with the inlet, gas turbine enclosure and single shaft drive train. A summary of these activities are presented in the illustration below.

3.3. Next Steps… Towards 65% Combined Cycle Efficiency
GE sees continued efficiency gains in the years to come. Advances in materials, additive manufactured geometries, ceramic matrix composite materials, combustion, and steam cycle conditions and efficiency should enable GE to reach 65% combined cycle efficiency by the beginning of the next decade. These advances will enable higher temperature operation with less cooling and less emissions.

IV. OTHER KEY ATTRIBUTES DEMONSTRATED DURING THE BOUCHAIN COMMISSIONING PHASE

The 9HA gas turbine was designed from the ground up to be extremely flexible. This includes high ramp rates and fast start up times to meet fluctuating demand, the ability to be turned down to low part loads while maintaining low emissions, to burn a wide range of gas compositions and the ability to respond to increasingly unstable grids, or to gain revenue from ancillary services.

FE50 Plant Integrated Validation Plan

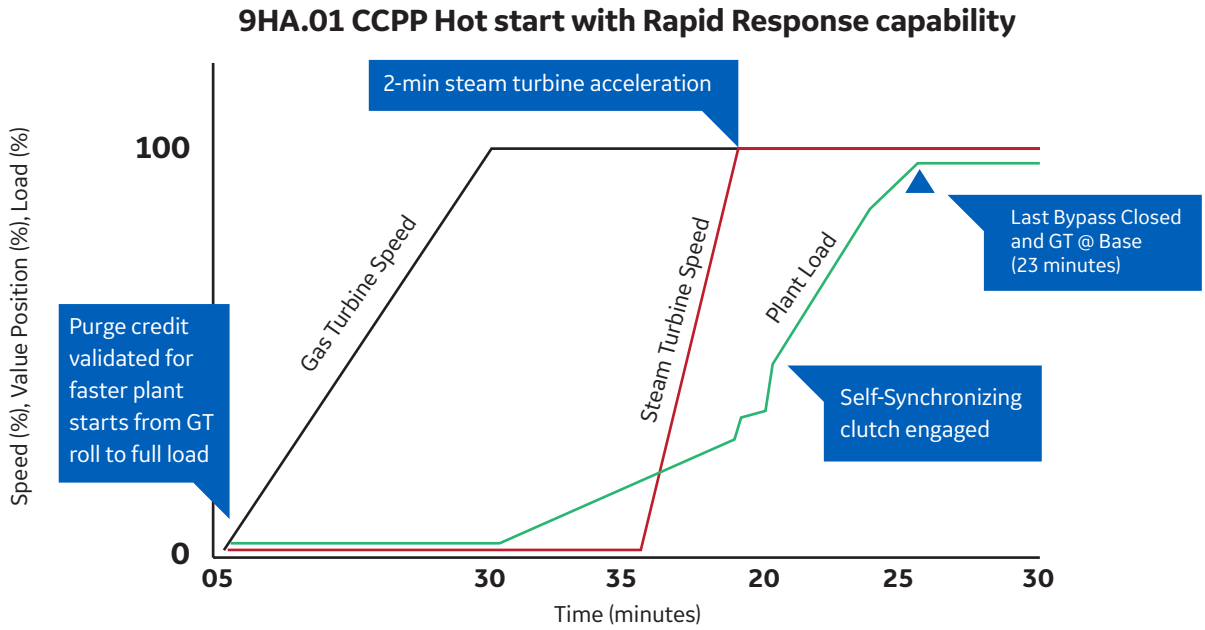


During the EDF Bouchain commissioning phase, all these parameters have been tested to demonstrate world class performances.

4.1. Demonstrated Combined Cycle performances

9HA.1Performance Criteria	Test conditions	Validated Capability
CC Output	Net / ISO conditions	> 605 MW
CC Efficiency	Net / ISO conditions	62.22%
CC MECL in Emissions Guarantee	NOx < 25ppm / CO<15ppm	31% of CC Baseload
Start-up time to Full Plant Load	Hot Condition	24 Minutes
Time from Turning Gear to FSNL		<11 Minutes
Time from FSNL to FSFL		<12 Minutes
Gas Turbine ramp rate		> 8.33% per min
Gas Variation (Modified Wobbe Index)		Up to +/-15% (Rich to Lean Gas Fuel)

The Below graph shows the 9HA hot start with rapid response as demonstrated during the EDF Bouchain commissioning. The HA Rapid Response Combined Cycle Plant is a GE plant level solution providing customer's highest operational flexibility with the capability of highly efficient steady state operation and rapid delivery of power to the grid with drastically reduced startup emissions.



4.2. Grid code capability

Frequency stability is one of the prevailing concerns of a Transmission System Operator (TSO), whose aim and duty is the reliable operation of the grid. Operation of electrical grids must be robust, handling future generation mix, whilst often being constrained by existing infrastructure. To help meet these challenges, TSOs have developed grid codes. Among other requirements, grid codes define minimum performance requirements of generating units connected to the grid.

GE has designed solutions for the HA plant to match or exceed grid requirements, even the most challenging environments (small grids such as islands or industrial sites). Combining excellence in unit design and site tests beyond reality at the FSFL test facility has secured the compliance with these challenging needs and extended the ancillary services and profitability that can be offered by the plant.

At Bouchain's site, the unit demonstrates a fast plant ramp rate at nearly +/- 70 MW/min, as per dispatch command. The plant plan boasts a rapid response to frequency ramp (49.5 Hz in less than 15 s) injection, with more than +90 MW in around 10 s" and "nearly +150 MW power change in around 30 s. It also demonstrated unique capability to handle grid split events, with swift plant load rejection from base to part load (nearly -275 MW in around 5 s), and fast and robust reaction against combined grid event, being consecutive extreme high/low frequency incidents. Bouchain's plant can provide rapid frequency support at any load, and the test demonstrated its ability to quickly go beyond baseload power or minimum environmental load to adapt its power output to the demand.

The plant is also by design capable of running through a transient loss of power supply of all its auxiliary systems. This robustness has been proven via tests executed at full load, connected to the French grid.

4.3. Plant controls w/ digital fieldbus validated

- Digital control architecture for operability & reliability
  - ◊ Field bus technologies - 60% less wire
  - ◊ Easy install and commission – one TA
  - ◊ Skid validation & commissioning at supplier
- Advanced control and modeling
  - ◊ Performance seeking algorithms - MBC
  - ◊ Increased diagnostics, proactive maintenance
  - ◊ OpFlex, performance management
- Total plant solution – customer focus
  - ◊ Analytics, Outage schedule
  - ◊ Integrated asset management
  - ◊ Full plant Auto-start, various start-up modes
  - ◊ Reduced commissioning cycle

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With a generating capability of more than 605MW, the 9HA turbine developed and produced by GE is the world's most efficient gas turbine, achieving an efficiency rate during commissioning performance tests of up to 62.22%. These record-breaking efficiency levels have created the world's most efficient combined-cycle power plant at Bouchain, which was officially recognized in April as a world record holder. In addition, the 9HA is highly flexible, is capable of reaching full power in less than 30 minutes, and captures maximum revenue stream associated with ancillary services to the grid. EDF and GE are the first companies to introduce such a flexible and energy efficient gas turbine.

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