POWERING FORWARD:
GE'S RECORD SETTING HA GAS TURBINE IGNITES A NEW ERA OF POWER GENERATION

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A NEW ERA OF POWER GENERATION

On June 17, 2016, General Electric Company began a new era of power generation with the inauguration of its first high-efficiency air-cooled (HA) gas turbine combined cycle power plant. Now three years later, GE has 100 HA turbine orders, more than half of which have shipped to our customers. Today, 40 HA gas turbines have entered commercial operation, accumulating 415,000+ fired hours of operation as of September 2019. And this advanced HA technology has powered not one but two world records by delivering 62.22% net efficiency at a 50 Hz plant and 63.08% gross combined cycle efficiency at a 60 Hz plant.

The launch of the HA fleet—grounded upon GE's rigorous validation testing and 70 million+ hours of experience with advanced turbines—has delivered the world's most reliable, lowest cost of electricity gas turbine and has resulted in one of the industry's most successful new products to date.

GE HA FLEET

100 UNIT ORDERS | **40** COD UNITS

415,000+ OPERATING HOURS

FLEET LEADERS

20K+	15K+	18K+
9HA.01 FRANCE	7HA.01 JAPAN	7HA.02 USA

Met/Exceeded
PERFORMANCE ON ALL HA GT UNITS

We're very proud of our HA technology, and we've never stopped pushing the boundaries of what it can do. Our goal is to always make the best better. GE's HA gas turbine has been recognized for powering the world's most efficient power plants in both the 50 Hz and 60 Hz energy segments. We take pride in knowing we are helping to make an impact on people around the world who don't have access to reliable, efficient power. And the impact of the HA is clear: compared to earlier technology, creating power more efficiently directly results in lower customer fuel costs, less environmental emissions, and competitive and affordable electricity rates for the public.

PERFORMANCE BEYOND EXPECTATIONS

The performance of the HA combined-cycle power plants has exceeded both GE's and our customers' expectations. This has been proven by comparing the actual tested output and efficiency to the contractual guarantee. The first 40 HA gas turbine plants have met or exceeded performance guarantees and are successfully generating electricity at various site conditions on their respective grids around the world.

EXCEPTIONAL PERFORMANCE = FIRST TO DISPATCH

The HA fleet has quickly accumulated over 415,000 hours of operation and is expected to top 450,000 hours by the end of 2019. The 9HA fleet has already surpassed 132,000 fired hours and the 7HA fleet 284,000 fired hours. This rise in expected operating hours can be attributed to the HA's higher overall performance. By helping our customers generate more power at the highest efficiency, their power plants have moved up in dispatch order. The power plants that make up the HA fleet cover a wide range of configurations and applications, including simple cycle and combined cycle, single shaft and multi-shaft (1x1, 2x1 and 3x1), and straight power generation, as well as combined heat and power. Following are highlights of some of GE's initial HA power plants in commercial service.

PROJECT HIGHLIGHTS

EDF Bouchain Power Plant, France. 1x1 SS, COD July 2016

The first 9HA.01 entered commercial operation (COD) in the summer of 2016 at EDF's Bouchain plant, located in the Nord Pas-de-Calais region of France. Efficiency of this plant is 62.22% on a net combined cycle basis while producing more than 605 MWs of electricity. Operational flexibility of the 9HA.01 gas turbine enables the plant to respond quickly to fluctuations in grid demand, providing opportunity for increasing usage of renewable energy in France. The high efficiency coupled with the operational flexibility puts Bouchain at the top of the thermal plant merit order and the plant has dispatched over twice its expected hours. The plant continues to operate exceptionally well today, with reliability at over 99.7% for the power island. The plant was named by Power Magazine as one of their 2017 Top Gas Plants (September 2017).[1]

Figure 2: EDF Bouchain 9HA Power Plant.

This plant is recognized as the world's most efficient 50 Hz combined-cycle power plant, as verified by independent third-party Bureau Veritas[1]

Kazan CHPP-3 Power Plant, Russia. 1x1 MS, COD June 2017

The 9HA.01 gas turbine commenced operation in a combined heat and power plant in June 2017 at the JSC TGC-16 CHPP-3 plant in Kazan, Russia. The CHPP-3 plant creates a total CHP plant efficiency of approximately 80% while doubling the previous electrical capacity.[2] It is also reducing the region's power shortage, created in part by increased power consumption from Kazan's large number of petrochemical industries and refineries. GE provided the turnkey solution, partnering with GAMA Power Systems on engineering and construction of the plant.[4]

Figure 3: CHPP-3, Kazan.

Tatarstan President Rustam Minnikhanov stated that the new gas turbine power unit launched at Kazan improved the power supply reliability and the plant has surpassed the contract capacity and efficiency.[3]

Futtsu Power Station, Japan. 1x1 SS, COD September 2017

Tokyo Electric Power Company added a 9HA.01 to their existing Futtsu plant in the Chiba prefecture. Since the commercial operation date of the 9HA in September 2017, the plant has been operating in continuous operation, already accumulating over 14,000 fired hours by September 2019.

Figure 4: Futtsu Power Station.

Bhikki, Haveli Bahadur Shah, and Balloki Power Plants, Pakistan. 2x1 MS, COD June–July 2017 / CC, COD 2Q 2018

GE is proud to have delivered six 9HA.01 turbines in Pakistan and worked with our engineering, procurement and construction (EPC) partners to build three separate power plants over the last few years. The gas turbines operated in simple (open) cycle mode on natural gas fuel during 2017, and now all three plants have reached combined cycle commercial operation. On May 10, 2018 Haveli Bahadur Shah officially announced all commissioning activities were complete as did Bhikki on May 20 and Balloki on July 30.

The three plants deliver up to 3,600 MWs of power—the equivalent power needed to supply up to 7.3 million Pakistani homes—making a meaningful difference in the everyday lives of the people of Pakistan.

Figure 5: Bhikki Power Plant.

7HA fleet led by Exelon Wolf Hollow/Colorado Bend, Texas, USA. 2x1 MS, COD June 2017

The 7HA gas turbine combined cycle fleet has rapidly grown in the 60 Hz regions with 29 gas turbines in commercial operation accumulating over 284,000 fired hours. The fleet leaders for the 7HA.02 are Exelon's Wolf Hollow and Colorado Bend power stations in Texas, U.S.A. Both plants are configured as 2x1 multi-shaft with total plant output greater than 1,000 MW at each site, with all units at each site accumulating over 16,000 hours. In December 2017, Exelon Wolf Hollow II was honored as Power Engineering's Best Gas Fired Project of the year.[5]

Figure 6: Exelon Wolf Hollow Power Plant.

Chubu Nishi Nagoya, Japan. 2 blocks of 3x1 MS, COD September 2017

GE and Toshiba collaborated to install six 7HA.01 gas turbines and two steam turbines at the Chubu Electric Company's Nishi Nagoya thermal power plant in Aichi Prefecture, Japan. The first block of three units reached commercial operation in September 2017. Block 1 has achieved a gross combined cycle efficiency level of 63.08%, which set the world record for highest gross efficiency.[6] The second block of three units reached commercial operation in March 2018. Details of the power plant installation, commissioning and technology are in the following video: https://youtu.be/cmA39yG5h34.

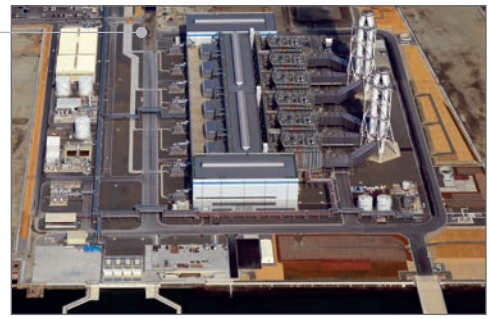

Figure 6: Chubu Electric's Nishi Nagoya Power Plant.

BUILT ON A LEGACY OF PROVEN TECHNOLOGIES AND EXPERIENCE

The HA gas turbines were developed with an evolutionary approach, combining experience from GE's original H-class architecture with field experience from its F-class gas turbine fleet. GE continuously updates and refines its design practices based upon the hundreds of millions of hours of experience across its heavy duty, aviation and aeroderivative gas turbines. The HA features the Advanced Compressor first developed for the 7F.05, which has accumulated over 575,000 fired hours of experience across 46 units. This modern compressor features a 14-stage design with 3D aerodynamic, field replaceable airfoils, and 1 stage of inlet guide vanes with three stages of variable stator vanes. The combustor is the Dry-Low-NO_X (DLN) 2.6+ combustor with over 3 million fired hours and over 10 years of experience. The turbine for the HA evolves from the proven, original H-class 4-stage gas turbine (7/9H) with simplification by eliminating steam cooling of the first turbine stages. The HA design utilizes passive cooling and proven alloys from its F and H-class with over 70 million fired hours of experience[7]—it does not rely upon externally cooled air nor the associated heat exchangers that other OEMs require for their advanced gas turbine offerings. This greatly reduces plant capital cost, space requirement and schedule needs during installation. It also allows for a simpler design that increases reliability and availability.

UNPRECEDENTED FULL-SPEED, FULL-LOAD VALIDATION TESTING

In 2008, GE developed the largest and most comprehensive full-speed, full-load gas turbine test facility in the world. Known as "Test Stand 7" at GE's Greenville, South Carolina, USA manufacturing facility, this off-grid, world-class facility provides full-scale, full-load validation of 50 and 60 hertz gas turbine systems. No other gas turbine manufacturer offers a test stand that can test both 50 and 60 Hz products with this level of rigor. The facility has enabled the most thorough possible validation of GE's new heavy-duty gas turbines, in advance of the first units' commercial operation.[7]

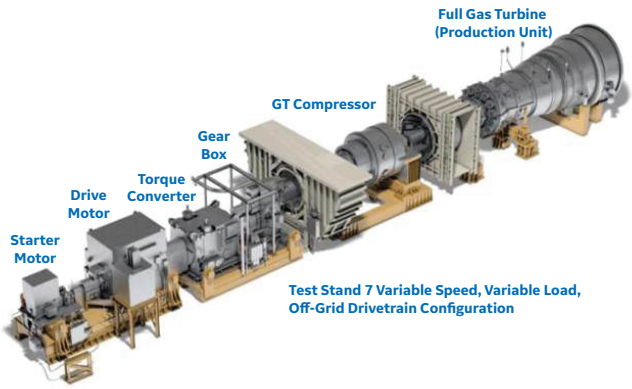

Figure 7: Test Stand 7 Validation Testing in Greenville, South Carolina USA.

Test Stand 7 operates the gas turbine independent from the restriction of the power grid, enabling a much wider testing envelope than an on-grid facility. The facility uses a separate stand-alone compressor as the load sink, which allows GE to focus on both the compressor validation and the entire gas turbine validation as test articles. This level of testing validation of the gas turbine and its systems is comparable to a gas turbine operating well beyond 8,000 hours connected to a grid. Isolation from the grid facilitates off-speed (90%-110% speed) operation at a range of equivalent loaded conditions. Variable speed also enables testing at ambient temperatures equivalent to a range from -37°C to 85°C. Figure 8 shows a comparison of the compressor mapping of the test stand unit to the entire year of units[8]. Since 2008, this rigorous test has been employed on the 7F.05, 9HA.01, 7HA.01, and 7HA.02. The 9HA.02 began validation testing in the test stand on July 17, 2019 and is expected to run in the test stand for 3-4 months. The 7HA.03 is expected to begin validation testing in early 2021. The rigorous testing has allowed GE to fully understand the hardware boundaries and in some cases, make necessary modifications, map the operating limits and identify growth capability.

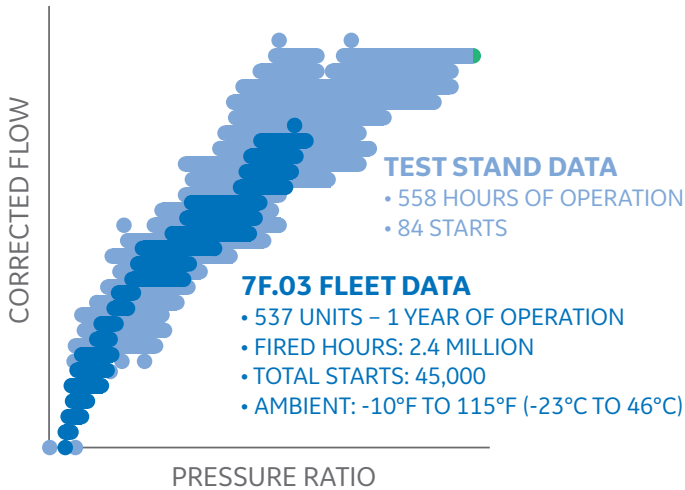

Figure 8: Compressor mapping of Test Stand 7 testing vs. fleet data.

LEARNINGS, IMPROVEMENTS AND THE GE FLEET LEADER PROGRAM

GE's validation test program has greatly accelerated the performance, operability and reliability / quality of its gas turbines by thoroughly validating the core technologies in the laboratory / factory environment prior to introduction in its commercial products. But the validation test program is just the first step to ensuring successful and reliable gas turbine product lines. GE's Fleet Leader Program is an inspection, data collection, and analysis program deployed on new gas turbine technology. The program—which starts at commercial operation and extends through the first hot gas path inspections—is an important second step to carefully monitor, adjust and update the equipment. The program includes increased inspections and monitoring with frequent borescope inspections and mini combustion inspections in addition to full maintenance inspections. This allows GE to collect valuable data and information to enhance hardware for long-term operation with maximum reliability and availability.

The EDF Bouchain facility participated in the Fleet Leader Program, enabling GE to monitor and inspect the power equipment to improve reliability, operability and performance over the plant's life. The plant has run at 99.7% reliability to date and continues to lead the thermal power plant dispatch on the French grid. The gas turbine encountered fewer than 10 events during the commissioning and initial 18-month operation phase of the plant that accounted for less than 25 hours of downtime, lower than what is typical in this industry. These minor events included trips from human error, controls updates and an exhaust joint repair.

Exelon's Wolf Hollow and Colorado Bend projects were the first 7HA.02 sites in the Fleet Leader Program. The four 7HA.02 gas turbines, the largest and most operationally flexible on the Texas grid, logged over 8,500 hours in the 2017 summer months with the highest reliability immediately following the commercial operation dates. The 7HA.02's continued to run reliably during Hurricane Harvey in August 2017 and provided much needed power to the Houston and Dallas metropolitan areas. GE was extremely pleased with the initial inspections results, which confirmed GE's design models and observations were consistent with the full-speed, full-load validation testing. Following the detailed inspections, the units were quickly returned to service to continue to deliver power to the grid.

In Pakistan, monitoring and inspection of equipment enabled GE to make an update on the 9HA gas turbines. During the summer of 2017, GE encountered and resolved a fuel delivery seal issue. The improved seal has been validated in GE's combustion laboratory and the 6 units operating in Pakistan have since operated with over 74,000 fired hours to date. These units continue to operate at full capacity and have never been de-rated. Furthermore, the updated seal has been implemented across the HA fleet to provide a more robust sealing regardless of site conditions.

Additionally, the modular equipment designs and close collaboration with various EPC partners allowed up to 30% faster installation times when compared to previous designs. Balloki 2 achieved a 64-day schedule from gas turbine on foundation to first fire. Additionally, GE worked with (or under) EPCs to overcome commissioning challenges at the various plants. In one example, GE worked with the plant EPC to correct the situation on a foundation facing lateral vibration at operating speed of the generator. GE worked with the customer and the EPC to identify and correct the root cause and return the equipment to service. GE is committed to working with its partners and stakeholders to ensure the highest reliability and performance of its power generation equipment.

In the fall of 2018, a 7HA.02 unit experienced a forced outage due to an oxidation issue which results in shank distress on the stage 1 turbine blade (S1B). The issue originates from the post-cast and coating processes utilized for the S1B in 9FB, 7HA.01/.02 and 9HA.01 gas turbines. GE's solution for this shank distress is the second generation "Gen 2" S1B, which is built upon a previously successful method of post-cast processing. The updated heat treatment achieves the proper microstructure to protect against oxidation and subsequent crack initiation and propagation. All affected HA gas turbines are being updated with the Gen 2 part and all gas turbines manufactured since September 2018 have been assembled with the Gen 2 part. GE has run the updated Gen 2 S1B parts in a 9HA.01 in the fleet reaching over 7,000 fired hours. These S1B have been removed from the gas turbine, analyzed thru destructive testing and have shown no oxidation / shank distress. A Fleet Leader Program will continue to validate the Gen 2 S1B at various intervals up to 32,000 hours.

THE FUTURE OF THE INDUSTRY

Since the beginning, the HA has been the biggest, most powerful, most efficient, most advanced… the list goes on. GE continues to see gas playing a critical role in the world's energy mix, and this innovative gas turbine continues to be the technology leader in the industry, defined by sheer power combined with record-breaking efficiency which set a record of over 63%, and can now be quoted at >64% in combined cycle applications. In fact, by the early 2020s the net efficiency could reach 65%—and each percentage point can translate to tens of millions of dollars for our customers. Together, these attributes deliver the most cost-effective conversion of fuel to electricity and the flexibility to respond quickly to fluctuations in grid demand, helping to pave the way for greater integration of renewable energy.

GE's HA technology is the fastest growing fleet of gas turbines in the world today with over 45 technology selections and 100 units ordered by more than 40 customers in 18 countries, including orders in the US, Mexico, Brazil, Pakistan, Japan, Bahrain, China, Taiwan, Malaysia, Israel, UAE, South Korea, Bangladesh, Thailand, Indonesia, and France. The fleet has accumulated over 415,000 fired hours of commercial operating experience across 42 units, including those in commissioning. In addition, the HA turbine is now available at >64 percent net combined-cycle efficiency, higher than any other competing technology today. We'll see more than 45 HA turbines in operation by the end of 2019 with more than 60 by the end of 2020.

Our power generation experience is filled with industry firsts and impressive milestones culminating in the highly efficient HA gas turbine. Other OEM's have followed suit, but none can offer the outstanding performance, reliability, efficiency, and expertise of the GE H-Class gas turbine. Advanced gas turbine materials and coatings as well as evolving combustor technology are putting our HA gas turbine ahead of the curve with the industry's lowest gas turbine levelized cost of electricity, building on our heritage of continuous improvement and innovation. GE's long-term investments in additive manufacturing play an important role in the HA's efficiency upgrades.

The HA platform—built for industry longevity—is changing the way power is delivered around the world. And we will continue innovating to make the best even better so that we can continue to provide the world's most advanced products and technology for customers in every corner of the globe. More to come as we launch the latest HA product, the 7HA.03.

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