Abstract

The paper presents the evolutionary Siemens HL-class gas turbines and power plants. The HL-class combines best-in-class technology innovations with the rich heritage of Siemens proven SGT-8000H series design resulting in a technology carrier to the next level of performance.

The SGT-8000H series has set the standard in terms of design robustness and reliable operation; it has become a benchmark for clean fossil power generation all over the world. All SGT-8000H gas turbines have been delivered on schedule and have met contractual performance guarantees.

With the development of the HL-class, Siemens continues its leadership in large air-cooled gas turbines by pushing efficiencies beyond 63% with a clear roadmap to efficiency levels of 65%. The HL-class portfolio consists of three engines: The SGT-9000HL engines for the 50Hz and 60Hz markets which are about 25% larger in power output than the present SGT-8000H engines and the SGT5-8000HL for the 50Hz market which has a similar output as the SGT5-8000H at a substantially higher efficiency. The HL-class is designed for highest operational reliability and flexibility to fulfill the requirements of base load units while also being a perfect fit for peaker applications. This makes the HL-class a versatile solution for operators who anticipate energy systems with a rapidly increasing share of fluctuating production by renewables.

The technologies introduced in the HL-class have been thoroughly tested in component and engine tests over multiple years. Siemens testing and validation methodology has proven to be successful with the seamless introduction of the SGT-8000H series and continues to be a cornerstone of Siemens product design philosophy. New technologies are quickly and effectively validated at Siemens own test centers and on customer sites worldwide. The test facilities include off-grid test cells in Siemens Gas Turbine Factory in Berlin (Germany), material testing in Casselberry, Florida (USA), combustion testing at the Clean Energy Center in Ludwigsfelde (Germany) as well as planned full engine on-grid testing in cooperation with Duke Energy (USA) to ensure the validation and demonstration of the HL-class' complete functionality.
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POWER-GEN International in Las Vegas, USA, December 5–7, 2017

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Abbreviations

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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACE</td>
<td>Advanced Combustion Efficiency (system)</td>
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<tr>
<td>CC</td>
<td>Combined Cycle</td>
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<tr>
<td>CCPP</td>
<td>Combined Cycle Power Plant</td>
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<td>CEC</td>
<td>Clean Energy Center</td>
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<td>EPC</td>
<td>Engineering Procurement and Construction</td>
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<td>GT</td>
<td>Gas Turbine</td>
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<tr>
<td>GW</td>
<td>Gigawatts</td>
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<tr>
<td>HCO</td>
<td>Hydraulic Clearance Optimization (system)</td>
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<tr>
<td>HRSG</td>
<td>Heat Recovery Steam Generator</td>
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<tr>
<td>I&amp;C</td>
<td>Instrumentation &amp; Control</td>
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<tr>
<td>IGV</td>
<td>Inlet Guide Vane</td>
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<tr>
<td>IoT</td>
<td>Internet of Things</td>
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<tr>
<td>LCOE</td>
<td>Levelized Cost of Electricity</td>
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<td>LEG</td>
<td>London Engineering Group</td>
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<tr>
<td>MW</td>
<td>Megawatts</td>
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<tr>
<td>NOx</td>
<td>Nitrogen Oxides</td>
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<tr>
<td>p.a.</td>
<td>per annum</td>
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<td>SGT</td>
<td>Siemens Gas Turbine</td>
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<tr>
<td>SCC</td>
<td>Siemens Combined Cycle</td>
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<tr>
<td>SCR</td>
<td>Selective Catalytic Reduction</td>
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<tr>
<td>TB</td>
<td>Terabytes</td>
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<tr>
<td>TBC</td>
<td>Thermal Barrier Coating</td>
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<tr>
<td>TIT</td>
<td>Turbine Inlet Temperature</td>
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<td>USD</td>
<td>US Dollars</td>
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1 Siemens Large Gas Turbine Development

Siemens develops its gas turbine portfolio based on its own design methodology. The Siemens evolutionary design approach ensures competitive products for new unit and service businesses. This development methodology is based on the proven design and the fleet experience of more than 6,900 installed heavy duty, industrial, and aero-derivative gas turbines in more than 60 countries worldwide. Siemens validates new technical developments in a proven three step testing approach. The knowledge gained in each step is fed back into the development process and used to refine and enhance the design methodology.

2 Siemens H-class Heritage

Well perceived by customers all over the world. It is the market leader in the air-cooled H-class with 86 engines sold and more than 500,000 fired hours on four continents. The SGT-8000H achieved unprecedented baseload efficiencies as well as industry leading operational flexibility while maintaining the robustness and reliability of the existing design heritage. Since the first commercial installation, it has reached unprecedented levels of reliability and efficiency to the satisfaction of its customers. All SGT-8000H series gas turbines have been delivered on schedule and have met contractual performance guarantees for both Siemens extended scope power plant solutions and equipment scope of supply projects.
In June 2015, Siemens was awarded its single biggest order ever. This order supported significant expansion of the Egyptian power supply. 18 months after the signing of the contract, Siemens has set a new worldwide benchmark for the execution of fast-track power projects. The first phase of the megaproject in Egypt has been completed. The promised goal of bringing 4.4 GW of new capacity to the grid has even been exceeded with 4.8 GW already connected to the grid. After full project completion in May 2018, the three power stations will be the largest gas-fired, combined cycle power plants ever built and operated in the world.

Together with the local Egyptian partners Elsewedy Electric and Orascom Construction, Siemens is supplying on a turnkey basis three natural gas-fired combined cycle power plants (CCPP). Each CCPP has a capacity of 4.8 GW, for a total combined capacity of 14.4 GW. These power plants – Beni Suef, Burullus and New Capital – will be powered by 24 SGT5-8000H gas turbines which were selected for their high output and efficiency. The scope of supply also includes twelve steam turbines, 36 generators, 24 heat recovery steam generators and three 500 kV gas-insulated switchgear systems. The dimensions of the megaproject are enormous: More than 20,000 workers are engaged at the construction sites during implementation. Over 1.6 million tons of material are being handled.

Figure 3: Key figures of the Egypt megaproject execution
3 Siemens Evolutionary HL-class

Siemens has introduced the HL-class as the technology carrier to the next level of efficiency and output. It is based on the reliable engine architecture of the SGT-8000H series with design features proven over years of operation. With the HL-class, Siemens combines technical evolution with technical revolution.

The Siemens HL-class consists of three engines: SGT6-9000HL, SGT5-9000HL and SGT5-8000HL. In simple-cycle operation, the SGT-9000HL series will provide a capacity of 388MW for the 60Hz version and 567MW for the 50Hz version. The SGT5-8000HL will provide 481MW. All engines exceed 63% efficiency in combined cycle operation with a mid-term goal to reach 65%.

3.1 Reliable Design DNA

The HL-class shares the H-class proven engine architecture that allows for reliable and flexible operation.

Some of the key elements of this architecture include Hydraulic Clearance Optimization (HCO) which reduces degradation through tip-clearance optimization, maintains hardware integrity and eliminates hot restart restrictions.

A single tie-bolt steel rotor with hirth serrations prevents rotor imbalance by allowing self centering of rotor discs. Furthermore, it eliminates the lifetime impact on the rotor brought upon by high load gradients by creating cooling air passages and allows for on-site destack.

The air-cooled four-stage turbine design is reliable and proven and the can annular combustion system with identical burner count for H- and HL-class engines helps to achieve higher firing temperatures and provide operational flexibility.
3.2 Cutting-edge Technologies
For the HL-class, Siemens continued with its proven approach of developing, testing and utilizing key technologies. Siemens engineers developed an Advanced Combustion Efficiency System (ACE) for greater efficiency and reduced NOx emissions at higher firing temperatures. Advanced compressor 3D blading was developed for better aerodynamic behavior and increased performance during part-load operation, and an innovative multi-layer thermal barrier coating (TBC) reduces wear of key components and allows for increased service intervals. Super-efficient internal cooling features for turbine blades and vanes reduce losses caused by cooling air supply and thereby raise efficiency. A free standing, internally cooled turbine blade 4 reduces the exhaust losses of the gas turbine.

3.3 Testing and Validation
Testing and validation is an integral part of Siemens gas turbine development. Upgraded components and technical solutions pass through a series of tests designed to minimize technical and commercial risks. The key technologies developed for the HL-class have been thoroughly tested at Siemens owned test facilities, including component testing at Siemens Clean Energy Center, prototype testing at Siemens Berlin Test Facility and testing and validation under real site conditions in the Siemens operating fleet.

In accordance to Siemens thorough testing and validation philosophy, the SGT5-8000H was tested and validated in open cycle operation from 2007 to 2009 in Irsching, Germany, under a hosting agreement with E.ON SE with subsequent commissioning of the entire combined cycle single shaft unit in 2011. Similarly, the first HL-class engine will be tested and validated in Duke Energy’s Lincoln County site starting in 2019. The Duke Energy testing and validation alliance will be beneficial to both parties. This opportunity allows Siemens to validate the entire gas turbine and generator package on an actual grid as well as verify durability through long-term endurance testing, while enabling Duke Energy to have early access to Siemens’ latest technology.

Siemens’ successful validation approach, proven with the SGT-8000H series and applied to the evolutionary HL-class, has been accepted by the insurance industry, enabling the HL-class to already have LEG 2 insurability. This is the main precondition to achieve bankability and obtain attractive financing conditions.

"This unique arrangement with Siemens offers a significant cost saving to our customers while providing one of the most advanced, efficient gas turbine units in the U.S. This new technology will provide us with flexible peaking power needed to complement intermittent solar energy resources for our customers and lower emissions across our fleet."

David Fountain
Duke Energy’s North Carolina president
### 3.4 Constructability

Siemens has reinvented the methodology for plant construction with a modular Power Core™. The Power Core™ consists of prefabricated Siemens Solution Blocks and prefabricated pipe racks. These plug and play blocks are fabricated and tested in a controlled manufacturing environment and delivered to site as large modules which can be lifted into place for assembly. For the customer, that means increased safety, improved quality, accelerated schedules, less dependence on the availability of skilled local labor, and overall lower project risk. An average lead time reduction between four and eight weeks can be expected in combined cycle projects.

Prefabricated modules offer multiple advantages during construction. Modules are delivered to site and installed in place. This eliminates much of the material handling associated with stick built construction, drastically reduces the amount of work above grade and the associated scaffolding, and improves the safety of the site. Prefabrication enables much of the skilled labor to be moved to a controlled factory environment enabling higher quality, quality control and pre-testing prior to delivery, ultimately reducing schedule risk. Building separate modules also reduces congestion on site, enabling multiple units to be constructed in parallel.

The Siemens Solution Block concept has been successfully implemented at sites around the world. Examples of sites which employed these solutions includes Knapsack II CCPP near Cologne in Germany and La Caridad in Mexico which achieved a reduction of approximately 40,000 man-hours by using a prefabricated pipe rack and resulted in an overall schedule reduction of one month. In addition, a 940MW electric CCPP in Lordstown, Ohio (USA), and Castle Peak Power Company Limited’s new combined cycle unit in its Black Point Power Station in Hong Kong are being built using Siemens Solution Blocks.

![Figure 8: Siemens Solution Block – Prefabricated pipe rack module in numbers](image-url)
3.5 Plant Flexibility

Siemens has been the industry leader in flexible combined cycles for more than a decade and continues that innovation leadership with the HL-class combined cycles. The HL-class is capable of extremely fast start and ramp rates of up to 85MW per minute as well as unrestricted hot restart. The SCC6-9000HL Flex-Plant leverages these capabilities enabling unrestricted gas turbine start-up in simple or combined cycle configurations. With Siemens Co-Start™ technology, combined cycle power can be achieved in as little as 20 minutes.

As part of the Siemens Flex-Plant family, the SCC-9000HL is available with a broad range of flexibility features which can be tailored for each application, including Clean-Ramp™ technology to keep units with SCR technology in emissions compliance while ramping, Siemens Dash™ technology to enable fast duct fired facilities, and Siemens Energy-Control™ system for fast starting air-cooled facilities.

Siemens Flex-Plants are designed to enable reliable operation over the full life of the plant whether the plant is base loaded or frequently cycled. To enable fast, frequent high cycling capability without a service impact, Flex-Plants incorporate Siemens patented Benson or Drum-Plus™ boiler technology and plant design and integration features specifically designed for cycling. Siemens has been successfully designing and building flexible combined cycles for over 18 years with more than 400,000 operating hours and more than 10,000 starts in operating flexible large combined cycles.

Siemens’ extended scope solutions offer a broad range of operations from Power Island to Turnkey Power Plant and includes Siemens new Power Core™ offering. The Siemens Power Core™ introduces unique pre-designed and prefabricated pipe rack and solution modules which reduce plant construction time, increase construction safety and reduce overall project risk.

3.6 Service and Digitalization

The Siemens global service team integrates the collective knowledge and experience of Siemens global fleet of more than 1,300 large gas turbines. This highly professional field service team is located in five service regions and service engineering teams are dispersed globally across 13 offices in eight countries. Along with the multiple service repair shops and warehouses worldwide, the team is able to provide timely maintenance response.

Figure 9: Siemens’ global large gas turbine fleet
The HL-class products are designed to optimize serviceability, leading to highly competitive maintenance intervals for increased engine availability. The maintenance concepts are suitable for various operation regimes including both hours-driven and starts-driven operation. With higher durability capability of key components, HL-class products with optimized operation expense allow maximization of customer long-term value.

Like the SGT-8000H engines, the HL-class engines have a proven single tie-bolt rotor design which allows for easy on-site destack. Entire stage 1 and stage 4 rotating turbine components can be removed and replaced without a cover-lift. All compressor and turbine blades are removable without a rotor lift. The design of the turbine casing enables roll-in/roll-out of stationary parts with the rotor in place. Siemens has implemented innovative field service concepts to optimize outage duration, enhance flexibility and ensure precision and safety.

The HL-class is designed to plug-in to Siemens suite of digital products. Siemens digital offerings are designed to maintain profitable life-cycle operation, increase availability, operability, and flexibility while guaranteeing cyber security. Based on data analytics, plant condition and performance monitoring, Siemens provides intuitive insights in engine operation, plant optimization and decision support for operation and maintenance. Advanced operation simulation for training and risk mitigation and integrated digital asset management are available for quick access to relevant information.

Over the years, Siemens has collected operating data and has monitoring experience of over 25 million operating hours. Building on this experience, the HL-class offers connectivity to MindSphere, the cloud-based Siemens operating system for the Internet of Things (IoT) for advanced analytics and intuitive insights through customizable apps. Connecting turbines and plants to the digital world enables our customers to uncover transformational insights across their entire business.

4 Conclusion

Siemens delivers on promises. Even highly complex projects are finished on time and on value. With its latest development in the gas turbine and power plant portfolio, Siemens demonstrates once again its leadership in innovation and technologies that provide real value to its customers.

The SGT-8000H series is well received by customers as demonstrated in the latest project success in Egypt and has globally collected more than 500,000 fired hours of fleet experience. The same DNA is incorporated in the high-efficiency HL-class.

With the HL-class, Siemens can offer its customers improved performance and availability, higher operational flexibility, improved constructability and serviceability and hence lower LCOE. Siemens is continuing to deliver what it is best known for: reliable, high performing, cutting-edge technologies.
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