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EVOLUTIONARY IMPROVEMENTS OF SIEMENS SGT-A35 GAS TURBINE (INDUSTRIAL RB211)

Cristiano Balestrino

Product Family Owner
Siemens Gas & Power
cristiano.balestrino@siemens.com

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Abstract

Over more than 40 years of technological advancements, the SGT-A35 (Industrial RB211) has become a trusted reference for Gas Turbine clients, earning a dependable reputation with operators worldwide in Oil & Gas and Power Generation alike, proven by well over 40 million hours accumulated in service.

A trusted reputation does not preclude a mission of continuous innovation, however. The urge to minimize the environmental footprint of generating equipment, together with the challenges faced by operators in reducing operating costs, increasing efficiency and extending flexibility of equipment to accommodate changes and uncertainty in market conditions have driven the significant R&D investments made by Siemens in the SGT-A35 product line in recent years.

This paper will present some of the most significant enhancements recently introduced for the SGT-A35. R&D efforts were targeted wisely and incrementally, applying the latest technologies specifically to improve certain value attributes while preserving a strong traceability to the proven technology and its aero-derivative lineage. This results in evolutionary upgrades to benefit new units as well as the operating fleet, with self-contained packages easy to embody as a retrofit.

An example of this is the efficiency enhancement and increased useful life for the RT62 Free Power Turbine, which unlocks significant savings for operators through better fuel efficiency and reduced maintenance cost, by introducing the latest 3D aerodynamics and materials technology for some components in this well proven product.

The RT61 Power Turbine was also significantly improved, with an extension in major overhauls interval and the introduction of a variant optimized for cold climates. Again in this case, the relatively small optimization of a few components provides significant enhancements in fuel efficiency and emissions for applications in cold weather regions such as Canada.

Finally, Siemens' expertise in Additive Manufacturing unlocks yet another level of continuous improvement for proven products such as the SGT-A35, making it possible to optimize components in ways which were previously constrained by conventional manufacturing methods.

The application of Additive Manufacturing to select components in the SGT-A35 combustion system provides ways to simplify manufacturing, improve the availability of spare parts, and at the same time enhance key product attributes such as emissions and fuel flexibility – once more without introducing radical changes in the product, but rather building on its proven track record.

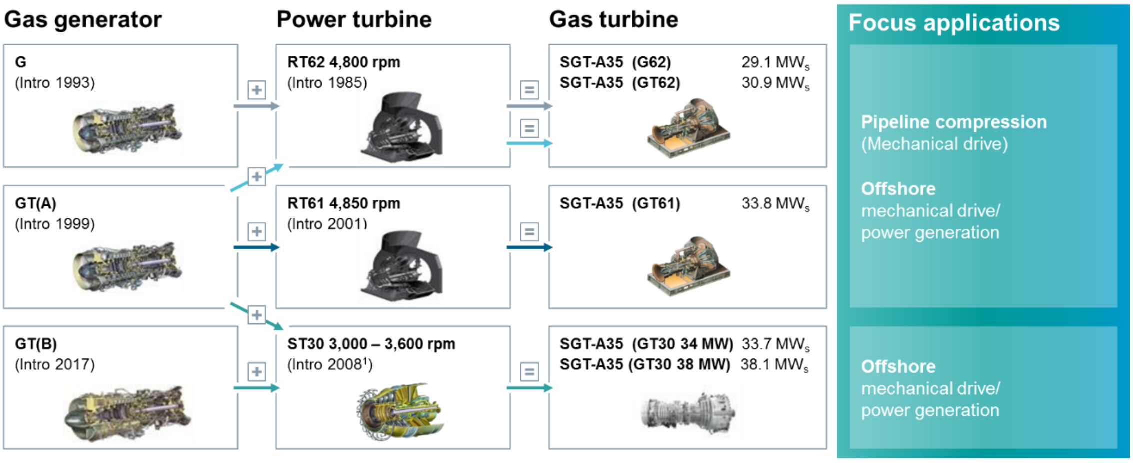
SGT-A35 (Industrial RB211) technology and experience

Originally derived from the Rolls-Royce RB211 in the 1970s, the SGT-A35 has earned the trust of Clients across Oil & Gas and Industrial Power Generation industries, covering a broad range of applications.

Since its acquisition of the Rolls-Royce Energy business in 2014, Siemens has continued to invest significantly in R&D applied to the SGT-A35 product line. At the same time, a long-term commercial agreement facilitates continued access to Rolls-Royce Aero Engine technology, ensuring continuous improvement through the "download" and incorporation of advanced gas turbine technology and upgrades proven in flight.

The acquisition of the Dresser-Rand business further enhanced the portfolio, with access to world-class capability in Oil & Gas Solutions, Compression Equipment and Gas Turbine packaging.

Through these synergies and a consistent strategy based on incremental improvements to a proven and reliable product, the SGT-A35 fleet has continued to grow – now exceeding 650 units sold and over 42 million hours accumulated in operation.



1 ST30 Power Turbine Entry Into Service with Rolls-Royce MT30 Marine gas turbine

Figure 1: Current SGT-A35 Gas Turbine new equipment configurations.

The SGT-A35 portfolio is illustrated in Figure 1 above together with the primary application focus of the different variants:

- Mechanical Drive in pipeline compression stations;
- Offshore Oil & Gas (Power Generation & Compression for offshore production).

In the pipeline segment, Siemens has recently received orders for seven compressor packages with Dry Low Emissions technology to be deployed in Canada within the network of TC Energy (formerly TransCanada) and its subsidiaries. The SGT-A35 (GT61) DLE gas turbines with RFA36 pipeline compressors will support pipeline expansions transporting Canada's natural gas to export markets.

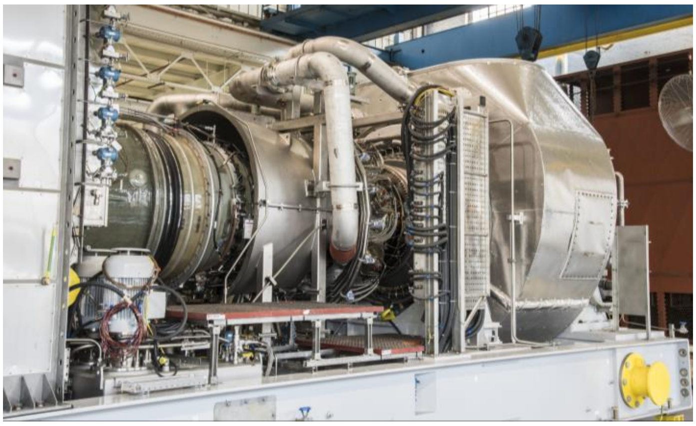


Figure 2: SGT-A35 (GT61) DLE gas turbine on its package base plate during assembly.

In the Offshore Oil & Gas segment, the latest evolution to the SGT-A35 portfolio is the GT30 variant, which incorporates a lightweight, proven aeroderivative free power turbine module optimized to direct-drive an electrical generator at either 60 Hz or 50 Hz frequency without the need for a step-down gearbox. This results in a more compact package with substantial weight and space savings, which are critical in offshore applications.

Figure 3: SGT-A35 (GT30) compact generating set for offshore applications.

In 2018, Siemens supplied six SGT-A35 (GT30) gas turbine packages for the Carioca MV30 Floating, Production, Storage & Offloading (FPSO) vessel, located in the giant "pre-salt" region of the Santos Basin approximately 250 kilometers (155 miles) off the coast of Rio de Janeiro, Brazil. The facility will be deployed in the Sépia field owned by Petrobras. MODEC will engineer, construct, and operate the facility.

Overall, in the last year, more than 10 offshore orders have been placed for the SGT-A35 (GT30) worldwide.

SGT-A35 Development and areas of focus

Adopting a strategy of continuous, incremental improvement of a trusted product base provides Operators with a range of low-risk enhancements in the new unit portfolio, and easily applied as in-service upgrades to existing units.

In the offshore application portfolio, the introduction of the GT30 variant is a key development which is covered in detail in other publications, such as Reference [1].

This paper will focus on describing, in the following sections, other key features recently introduced by Siemens for the SGT-A35. Specifically:

- Enhancements to Free Power Turbines RT61 and RT62;
- Core engine power and efficiency up-rates;
- Additive Manufacturing of select components to improve reliability, functional attributes and availability of spare parts.

RT62 Power Turbine enhancements

All configurations of SGT-A35 gas turbine utilize a two-spool Gas Generator aerodynamically coupled to a Free Power Turbine (FPT). As illustrated in Figure 1 above, the product portfolio comprises of several variants of Free Power Turbine.

The majority of the SGT-A35 fleet currently in operation utilizes the RT62 Free Power Turbine. Approximately 400 units are in service, coupled to -C, -G or -GT variants of the Gas Generator.

An industrial design originally introduced in 1985, the RT62 has gained extensive references across all applications, including onshore and offshore.

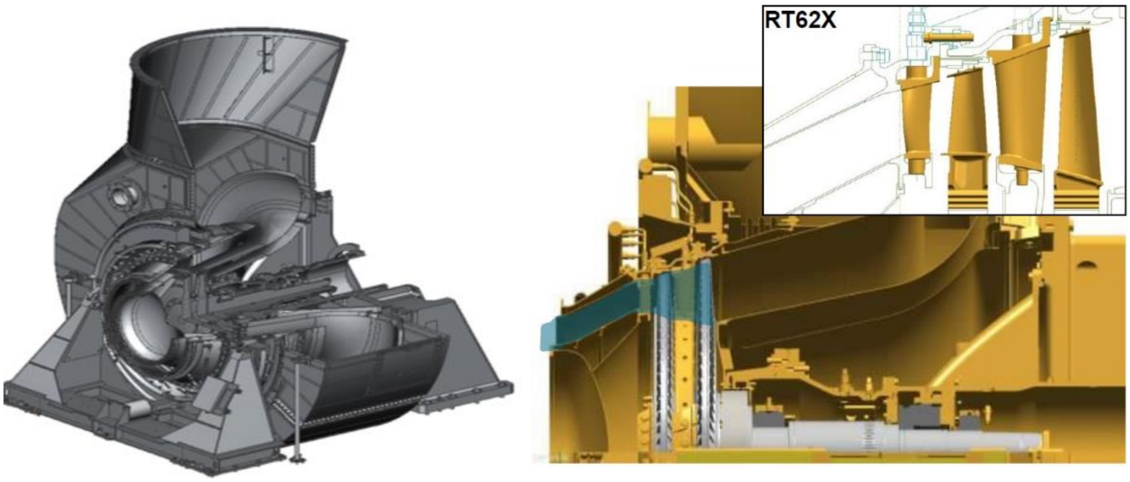


Figure 4: RT62 Power Turbine and RT62X components upgrade.

By applying modern design tools and solutions to select hot gas path components in this proven product, the RT62X upgrade provides significant operational benefits through enhancements in power, fuel efficiency or Time Between Overhauls (TBO).

Furthermore, the upgrade can be tailored selectively in order to maximize each benefit according to the specific operational requirements of each application. This is summarized in the table below for the different variants:

RT62 Current				RT62X Upgrade		
SGT-A35 Variant	**Gas Generator**	**MTBO**	**Power Turbine Entry Temp. (PTET)**	**Power gain (ISO)**	**Heat Rate gain (ISO)**	**MTBO**
C62 *	**– C ***	Case-by-case	750 °C	**2%**	**2.7%**	**Case-by-case**
G62	**– G**	100k hrs	780 °C	**2%**	**2.5%**	**132k hrs**
			785 °C	**6%**	**2.7%**	**100k hrs**
GT62	**– GT**	100k hrs	780 °C	**2%**	**2.4%**	**132k hrs**
		50k hrs	790 °C	**5%**	**2.5%**	**100k hrs**
			800 °C	**8%**	**2.6%**	**50k hrs**

(*) Aftermarket only

The scope of the RT62X upgrade is limited to the following:

- Turbine blades (1st and 2nd stage): Revised 3-D aerodynamic design resulting in decreased blade profile losses;
- Nozzle guide vanes (1st and 2nd stage): Revised 3-D aerodynamics and decreased trailing edge thicknesses for improved efficiency and for life extension;
- Honeycomb tip seals: Improved tip seal design resulting in decreased tip seal leakage and better control on tip clearances.

The upgrade can be implemented as part of the Power Turbine “zero-hour” overhaul typically undertaken at 100,000 hrs interval at a Siemens authorized facility.

RT61 Power Turbine enhancements

The RT61 is a highly efficient, three-stage industrial Power Turbine with an output speed of 4,850 rpm, which finds application in both Mechanical Drive and Power Generation.

Recent enhancements of this product have focused on life cycle attributes, with improvements in Time Between Overhauls and fuel efficiency.

The RT61 Power Turbine is now enhanced through the application of advanced coatings to key components in the RT61 hot gas path, providing significantly improved oxidation and corrosion resistance to enable the doubling of Time Between Overhauls from 50,000 to 100,000 hours. The avoidance of multiple outages creates substantial benefits in life cycle cost and unit availability.

The RT61 100,000 hrs upgrade, which includes the application of new coatings to the Power Turbine first stage vanes and blade tip seals, and the replacement of tie bolts, is now standard on new unit offerings, and available as a “drop in” retrofit to service units in conjunction with scheduled overhaul at a Siemens authorized facility. Further details on this upgrade are available in Reference [2].

Another recent enhancement to the RT61 power turbine focuses on the optimization of fuel efficiency and emissions across the load range, and particularly for pipeline compression applications in cold climates such as Canada.

A key factor to the performance of Gas Turbine configurations that utilize a Free Power Turbine (such as the SGT-A35) is the flow capacity and component optimization of the Power Turbine first stage, and its matching to the Gas Generator exit conditions.

Design conditions in ambient temperature and operating load determine the optimal Power Turbine flow capacity, which is primarily controlled by the geometry and effective area of the Power Turbine's first stage Nozzle Guide Vane (NGV).

This is illustrated in Figure 5 below for fuel efficiency and CO emissions. A reduction in Power Turbine capacity allows maintaining the Gas Turbine's designed firing temperature at lower ambient temperatures, with improvements in fuel efficiency and CO emissions for the colder climates.

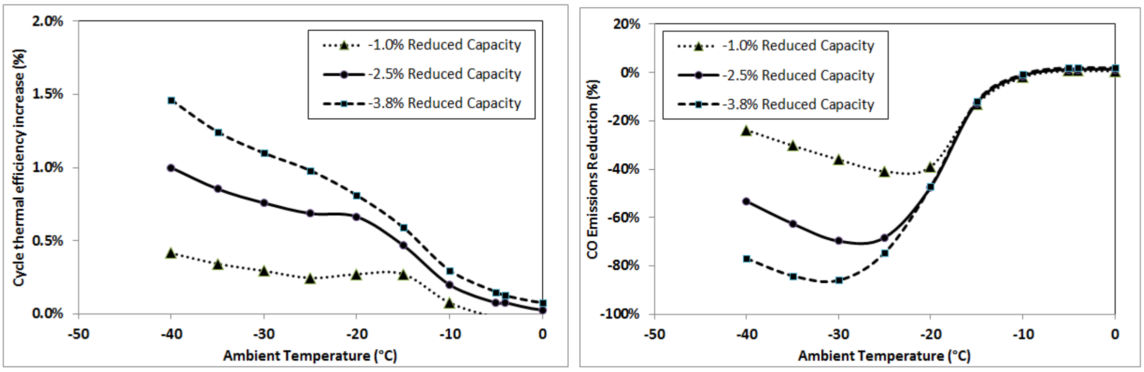


Figure 5: Effect of Power Turbine capacity changes on fuel efficiency (left) and CO emissions (right) across the ambient range.

In order to support TC Energy in the compressor station optimization for a recent pipeline expansion project, Siemens has now introduced a variant to the RT61 Power Turbine with first stage vane optimized for cold climate conditions.

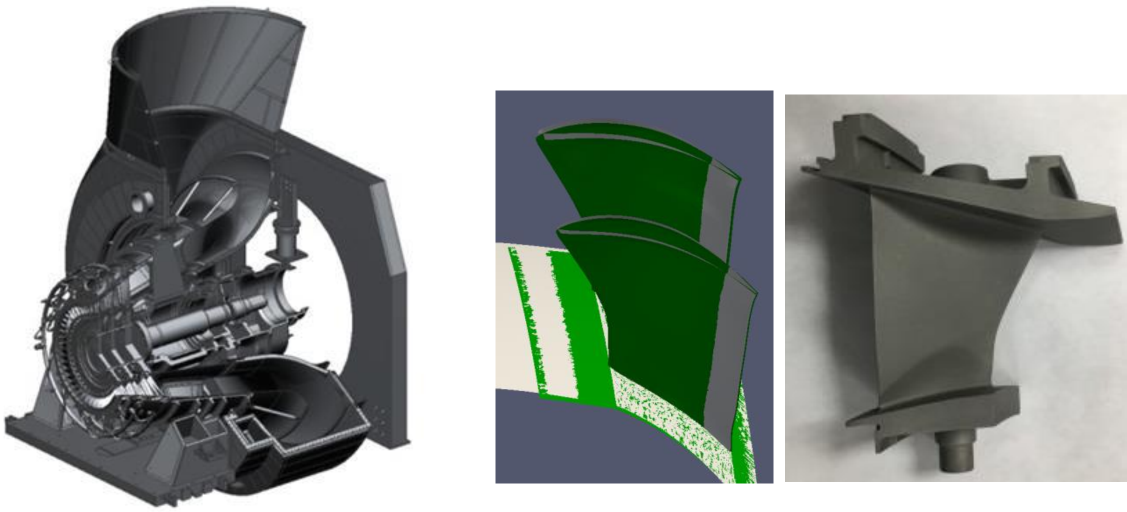


Figure 6: RT61 Power Turbine (left) with optimized first stage NGV (right) for cold climate applications.

This variant provides considerable improvements in fuel burn and environmental attributes. Depending on the ambient conditions, CO emissions can be reduced by up to 40% and fuel burn (and hence CO_2 emissions) by close to 1%.

The SGT-A35 (GT61) optimization for cold climate performance is now available for new unit offerings as well as an aftermarket retrofit to existing units. Further detail on this development and its validation can be found in Reference [3].

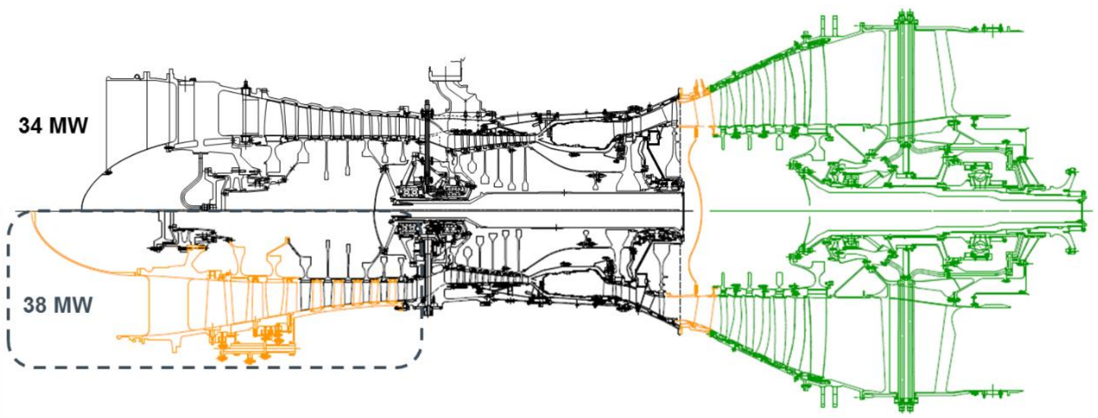
Power & Efficiency up-rates to the SGT-A35 Core Engine

In 2013, the "Gzero" aftermarket upgrade to the SGT-A35 (G62) variants was introduced at the GTEN symposium. The detailed paper is listed as Reference [4].

Introduced as a zero-stage upgrade to the Intermediate Pressure Compressor (IPC) in the -G variant of the SGT-A35 Gas Generator, it is now also available for the higher rated -GT variant of the Gas Generator.

Through this up-rate, the SGT-A35 (GT30) ISO-rating is increased from its original 34 MW to 38 MW. Both variants are available in the SGT-A35 new unit portfolio.

Designed to the latest aerospace standards and seamlessly integrated within the core engine in order to keep its external interfaces unchanged, the addition of the zero-stage provides 10% additional power with only minor changes in the overall engine interfaces to the package, and without any change in the configuration of the turbine hot section or its firing temperature, thus providing a low-risk solution for a significant power and fuel efficiency up-rate.



Nominal ISO rating	34 MW	38 MW
Mechanical Drive (3,429 rpm)		
Shaft power output	33.7 MW	38.1 MW
Shaft thermal efficiency	39.1 %	40.3 %
60 Hz electrical generation		
Power output A/C	33.2 MW	37.4 MW
Simple-Cycle Efficiency	38.5 %	39.7 %

Figure 7: Composite cross-section of the SGT-A35 (GT30) variants, showing the 34 MW (top) and the 38 MW (bottom).

Through proven technology and design practices, this upgrade represents a new evolution introducing new levels of performance to a trusted platform, with ease of retrofit to the existing fleet.

Applications of Additive Manufacturing to the SGT-A35

Siemens has invested in metal Additive Manufacturing (AM) technology since its inception, developing world-class capability for its gas turbine portfolio with commercial applications of Additive Manufactured hot section components starting from as early as 2013, and experience now exceeding 100,000 hrs in commercial operation – see Reference [5].

Additive Manufacturing utilizes a Selective Laser Melting (SLM) process to build parts layer-by-layer from sliced CAD models to form solid objects. This enables highly precise solutions to be formed even for very complex shapes from powdered high-performance materials, without many of the restrictions of conventional processes.

Over the years, Siemens has qualified material properties and data sets for an extensive range of powders for high-temperature alloys, as well as specific tools and optimization procedures covering the integrated cycle of design, analysis, manufacturing and validation of AM components.

The application benefits of this technology are manifold, and include:

- Optimized repair and refurbishment of components, using AM to selectively re-build only the component features which are subject to deterioration in service. This is the case for burner tip repairs, now routinely carried out by Siemens for several of its Gas Turbine products;
- Reverse-engineering and manufacturing of legacy parts, for which a conventional Supply Chain no longer exists or is not economical;
- Simplified supply chain and reduced parts lead time, particularly for spare parts to alleviate the financial burden of inventory by moving towards “spares on demand” models;
- Improved component reliability, through the elimination of failure modes by virtue of having one-piece components rather than brazed or welded assemblies;
- Functional & performance optimization of complex components, by removing many of the geometric constraints imposed by the conventional manufacturing process (e.g. casting or forging);
- Accelerated design iterations, with the ability to “print” and test optimized designs orders of magnitude quicker than the timescales of conventional methods (typically constrained by tooling modifications, etc).

For the SGT-A35, Siemens is utilizing its world-class experience and proven expertise in Additive Manufacturing to introduce yet another level of continuous improvement, by optimizing components in ways which were previously constrained by conventional manufacturing methods.

Combustion components are particularly suitable for harvesting the benefits of AM, by printing as one piece complex shapes with small internal fuel passages that traditionally required multiple brazing operations to join numerous parts. This also intrinsically enhances the reliability and thermo-mechanical fatigue resistance of the part, by eliminating potential crack initiation points at the braze locations.

A recent example is the introduction of the AM burner head for the SGT-A35 non-DLE Dual Fuel injectors. The head has traditionally been a complex assembly requiring 6 different brazed joints to produce the final part that has small passages for air, gas, liquid fuel, and water. The head portion of the burner has now been replaced by a single AM piece that gets welded to the rest of the burner, simplifying both manufacturing and repair process.

Figure 8: SGT-A35 non-DLE fuel injector with AM burner head (to the left of the red line), welded into the assembly.

Extensive validation of the AM component was carried out, including matching of design analysis tool to experimental results on a combustion test rig.

In addition, Thermo-Mechanical Fatigue (TMF) testing was carried out to take both the conventional-made and AM component through thousands of thermal cycles, confirming that the TMF resistance of the AM burner is even higher than its predecessor.

This solution was finally fully validated with engine testing and released into service via a controlled introduction plan, starting commercial operation in early 2019.

The AM component is now the production standard for all SGT-A35 non-DLE units. The process will also be utilized for the repair of fuel injectors in service.

In another example, AM was applied to manufacture the central fuel injector of the SGT-A35 Dual Fuel DLE variant as a single printed part. The opportunity was also taken to optimize some design features in order to enhance functionality, which was prevented in the conventional-made part by manufacturability constraints (e.g. wall thicknesses, casting yield, etc.).

Figure 9: Additive-Manufactured central fuel injector for the SGT-A35 Dual Fuel DLE variant.

Additive Manufacturing provides the opportunity to speed up each design-make iteration by an order of magnitude, dramatically accelerating the development cycle. In this case, it was possible to complete three design-make iterations in the space of only 7 months.

An extensive campaign of combustion testing was carried out on each iteration, to prove the functionality of the design and provide data to optimize the next iteration in this “agile” approach.

Through this rigorous testing campaign, the team was able to validate the required Dual Fuel functionality and operating range, and confirm that the combustion dynamics of this final design are well in line with the proven gas-only variant (over 9 million hrs in service). After full validation, it has now been released as production standard.

Looking ahead, Siemens continues to invest in the application of Additive Manufacturing to the SGT-A35 DLE combustion system, in order to further harvest the benefits described above and enhance the overall product’s functional attributes, such as combustion emissions and fuel efficiency.

Conclusions

The SGT-A35 (Industrial RB211) has become a trusted reference for gas turbine clients, earning a dependable reputation with operators worldwide.

Siemens is continuing to invest in the evolution and improvement of this product line, with a consistent low-risk innovation strategy based on incremental injection of proven technologies. The Siemens aero-derivative portfolio continues to enjoy access to proven aero engine technology, now ideally complemented by a portfolio of technologies developed by Siemens for Gas Turbine applications (e.g. Additive Manufacturing, as expanded below).

This paper has presented some examples of such evolutionary enhancements, which are made available for new offerings as well as in-service upgrades for existing SGT-A35 operators.

Abbreviations

AM	Additive Manufacturing
DLE	Dry Low Emissions
FPSO	Floating Production, Storage and Offloading
FPT	Free Power Turbine
R&D	Research & Development
SLM	Selective Laser Melting
TBO	Time Between Overhauls
TMF	Thermo-Mechanical Fatigue

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