2024 TECHNICAL UPDATE

Record-Breaking Hydrogen Blending for an Advanced-Class Gas Turbine

Constellation Hillabee Power Plant Blend Test

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3002030455

Technical Update, July 2024

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EPRI prepared this report.

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ABSTRACT

Gas turbines (GTs) will need to reduce carbon dioxide emissions and prove their flexibility based on market needs and new proposed rules. Economically, utilizing existing gas turbine assets to meet these requirements will be of great benefit compared to the cost of building new turbines. Determining the lowest-cost, least-intrusive upgrades required is of great interest to power producers. The demonstration described in this report was conducted on one (1) GT unit at the Constellation Hillabee power plant (2x1 Siemens Energy SGT6-6000G configuration), which doubled the mass flow of hydrogen of previous record-breaking dry low NOx demonstrations. This report will serve to provide EPRI's perspectives on knowledge of the capabilities, successes, shortfalls, and other significant items regarding the H_2 blending demonstration project.

The testing was done on an unaltered, existing GT asset, which is of great value for GT operators that already provided power using natural gas. Rules around carbon reduction are being proposed worldwide, including in the United States (where the Environmental Protection Agency (EPA) has recently updated proposed carbon-reduction rules for new gas turbine generation). This demonstration suggests that existing GTs are capable of meeting much more stringent carbon emissions rules than they were initially designed to meet with optionalities such as hydrogen blended fuels. This report documents the evaluation, preparation, execution, and results of this demonstration testing.

The results are provided for the GT community to use as insight into the capability and flexibility of existing assets to meet the future demands of reduced-carbon power generation. While other sites would need to conduct their own assessments—and operation here was limited in scope—these results are provided for the GT community to use as insight into the capability and flexibility of existing assets to meet the future demands of reduced-carbon power generation. Specific information around safety, reliability, and operability that were reviewed are provided for context around existing asset capability. In addition, details about the project and testing execution are included; these provide insight into the updated operations that are required while operating on high-hydrogen blends. Lastly, results from the testing show the impact of hydrogen on the operation, emissions, and performance of the asset.

Keywords

Blending
Combustion
Gas Turbine
Hydrogen
Siemens Energy
SGT6-6000G

EXECUTIVE SUMMARY

Deliverable Number: 3002030455

Product Type: Technical Update

Product Title: Record-Breaking Hydrogen Blending for an Advanced-Class Gas Turbine: Constellation Hillabee Power Plant Blend Test

Primary Audience: Plant managers, long-range planning personnel

Secondary Audience: Plant engineers, general public

KEY RESEARCH QUESTION

What are the challenges and capabilities in preparing for and blending high-volume flows of hydrogen (H_2) gas in a high-efficiency combined cycle (CC) gas turbine with a dry low NOx combustion system?

RESEARCH OVERVIEW

The testing was conducted on hydrogen blending and burning in the combustion system of a high-efficiency CC gas-fired gas turbine.

KEY FINDINGS

- General capability
- Emissions
- Gas turbine and combustion durability and operability
- GT cycle performance/efficiency
- Carbon dioxide (CO_2) emissions
- H_2 operation and control

WHY THIS MATTERS

This report provides EPRI's findings for blending up to ~38% by volume hydrogen in a Siemens Energy SGT6-6000G combustion turbine, including results of testing as well as the preparations and challenges of each. This report will serve to provide EPRI's perspectives on knowledge of the capabilities, successes, shortfalls, and other significant items regarding the H_2 blending demonstration project. This project constitutes the first of a kind in blending large volume flows of H_2 in an advanced high-efficiency gas turbine run in combined cycle operation. The results of this testing program provides information that could be useful to future H_2 blending research studies. future hydrogen blending projects in power generation.

HOW TO APPLY RESULTS

These results can provide information about the results of testing an existing gas turbine with hydrogen fueling.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- This research provides information on hydrogen blending capabilities for planning and projections of future operations with hydrogen in existing gas turbines.

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PROGRAM: Gas Turbine Advanced Components & Technologies, P217

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1 OVERVIEW

Gas turbines will need to reduce carbon dioxide (CO_2) emissions and prove their flexibility based on market needs and rules [2]. Economically, utilizing existing gas turbine assets to meet these requirements will be of great benefit compared to the cost of building new turbines. Determining the lowest-cost, least-intrusive upgrades required is of great interest to power producers. The demonstration described here was conducted on one (1) GT unit at the Constellation Hillabee power plant (Siemens Energy SGT6-6000G 2x1 configuration), which doubled the mass flow of hydrogen of previous record-breaking dry low NOx (DLN) demonstrations.

Key Observation Point

The testing was done on a GT that had only its fuel delivery and control for controlling that fuel, which provides great value for GTs that already provide power using natural gas. The demonstration included H_2 blending up to 38.8%, over testing lasting approximately 12 total hours over four days resulting in approximately 18% reduction in CO_2 emission..

These demonstrations are critical since they show the inherent capability use blended H_2 as a fuel source with limited hardware upgrades. This report documents the evaluation, preparation, execution, and results of this demonstration testing. The results are provided for the gas turbine community to use as insight into the capability and flexibility of existing assets. Specific information concerning safety, reliability, emissions, and operability are discussed to provide context around existing asset capability.

2 INTRODUCTION

2.1 Background

Siemens Energy has been investigating next-generation combustion systems that can extend the capability of hydrogen burning in the gas turbine up to 100%. Similar to other utilities, Constellation is investigating reducing carbon emissions from their power generation portfolio, and hydrogen fueling blending in their gas turbines is one subject of investigation.

2.2 Major Company Team Members

- EPRI – Project management and oversight (including EPRI subcontractor, Kiewit)
- Siemens Energy – Gas turbine original equipment manufacturer (OEM) responsible for project execution and hydrogen (H_2) blending system design
- Constellation – Site customer and owner responsible for overall testing completion (including subcontractor Certarus)

2.3 Objectives/Success Criteria

The project objective was to safely (and without loss to machine reliability) blend hydrogen gas with natural gas in a Constellation Hillabee Siemens Energy SGT6-6000G combustion turbine and collect performance and emissions data.

2.4 Assumptions

No major assumptions are included in the project.

2.5 Scope

The overall project scope for the Hillabee Plant H_2 blending project included hydrogen fuel delivery and control modifications, procedure writing, design/procedure reviews, test execution, demobilization and return to normal plant operations, and issuing test reports.

The EPRI scope included design and procedure reviews, hazard and operability (HAZOP) reviews, test execution, and test report issuance. This report is limited to EPRI's scope of work.

3 PRIMARY TEAM MEMBERS AND RESPONSIBILITIES

The principal team members of the project included:

3.1 Constellation – Power Utility

Constellation is the Utility with oversight and approval authority; they funded the H_2 blending project. Constellation is the site owner and operator of Hillabee Plant. Plant personnel were also actively engaged in executing and enforcing the safety plan, having ownership of the overall plant operation, and ensuring that plant emission compliance was maintained during the testing activities.

3.1.1 Certarus – Constellation Contractor

Certarus is a contractor to Constellation; they were responsible for providing the compressed H_2 gas (via high-pressure tube trailer) and the pressure reduction skid.

3.2 Siemens Energy – OEM and Design Lead

Siemens Energy is the OEM for the gas turbine and was the design and design modification lead of the H_2 test. Siemens Energy supplied flow control system components and upgraded the control system logic, contracted the fuel supplier, led the development of commissioning and operating procedures, and led the execution of the plan.

3.3 EPRI – Contract and Design Review Lead

EPRI was the Contract and Design review lead. EPRI facilitated and participated in numerous project review meetings and oversaw multiple project execution tasks, including design reviews, leak testing, code and procedure reviews, and test execution.

3.3.1 Kiewit – EPRI Contractor

Kiewit is the EPRI contractor that provided the technical review of the proposed design and review of applicable codes and standards.

4 TESTING SUMMARY

This report summarizes the testing of a Siemens Energy SGT-6000G gas turbine with up to 38.8% by volume H_2 blending. This configuration is deemed important to the gas turbine and power generation community by the authors as this turbine, like many gas turbines in operation today, was not built with hydrogen fueling in mind. Similar configuration testing has been conducted, though the testing provides unique insights. This testing is higher by 3x in mass flow and 2x in volume % of the hydrogen tested relative to similar configurations tested.

The hydrogen supply utilized was also a reduced order design (relative to other testing) showing a minimum viable, safe system that can be utilized for H_2 blending testing and potentially for long-term operation. The high flow rates and large change in hydrogen pressures (over time and through the supply) resulted in fuel conditions unique to this testing campaign. Hydrogen and natural gas blend emissions—and NOx emissions specifically—are subjects of current research. NOx emissions with increasing H_2 blends have been shown in other research to be able to be maintained at relatively constant levels to natural gas in DLN combustion systems utilizing varying methods of control and with diffusion systems utilizing diluent for emissions control. Test results in this demonstration exhibit the ability to maintain emissions with this system utilizing combustion temperature reduction and fuel delivery adjustments to the premixed fuel circuits in the combustion system. This testing included two instrumented combustion baskets which confirmed the higher flame speeds and reactivity through combustion hot section metal temperature measurements. In addition, combustion dynamics are known to be affected by H_2 blending. The effects on combustion dynamic amplitudes and frequencies are dependent on the specific frequency range and the system design. Combustion dynamics were measured in this testing.

Beyond system performance, information about test protocols that provide relevant information for future tests and permanent operation was refined and evaluated in this testing.

4.1 Mechanical System

An objective of the H_2 blending addition system design was to blend hydrogen safely and effectively into the natural gas stream without including complex and expensive control and monitoring equipment that may not add specific value to operations.

Figure 1 is a schematic of the high-pressure tube trailer, manifold, and pressure regulation system used. Figure 2 is a schematic of the hydrogen flow control system used. Figure 4 is an image of the hydrogen flow control system.

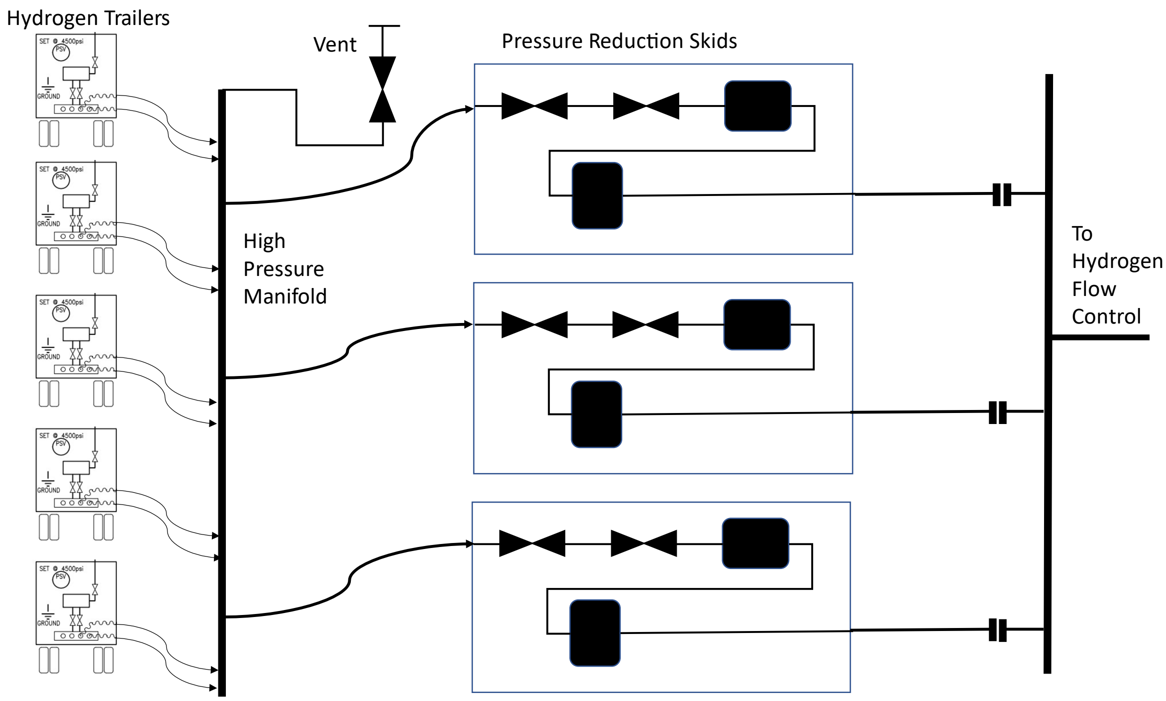

Figure 1. High-pressure hydrogen supply system schematic

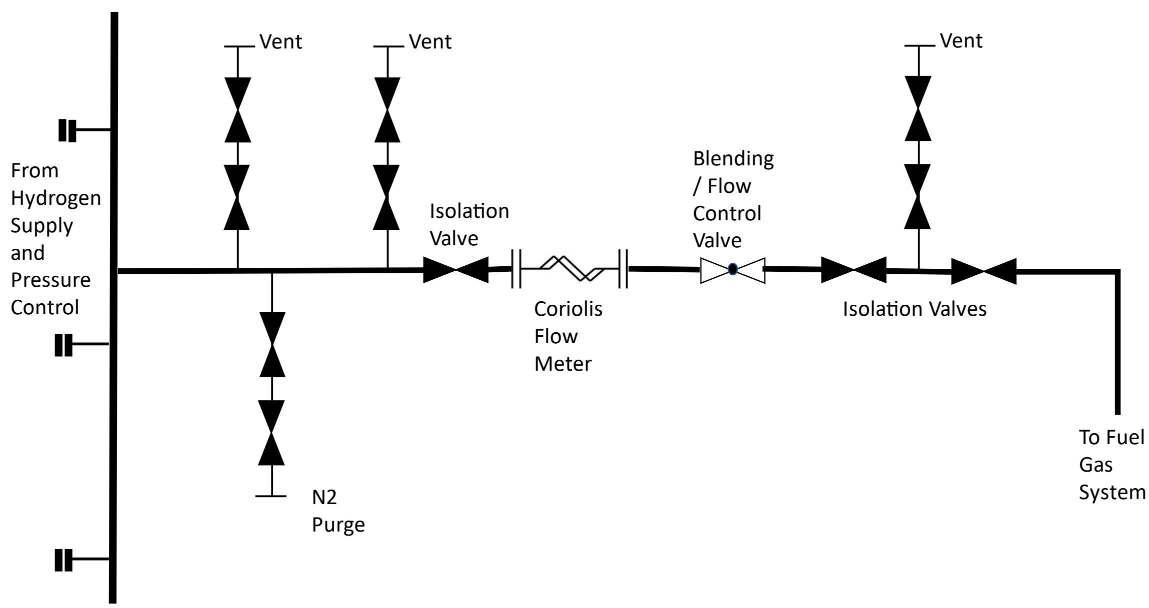

Figure 2. Hydrogen flow control system schematic

4.2 Site Information

Hillabee Generating Station is a combined-cycle natural gas plant in central Alabama that began operating in 2010. Hillabee is a three-unit, 753-megawatt (MW) combined-cycle natural gas-fueled power plant in Tallapoosa County near Alexander City, Alabama. Figure 3 is an image of the site. Figure 4 shows the hydrogen flow control system that was shown in the schematic in Figure 2.

Figure 3 Hillabee Generating Station

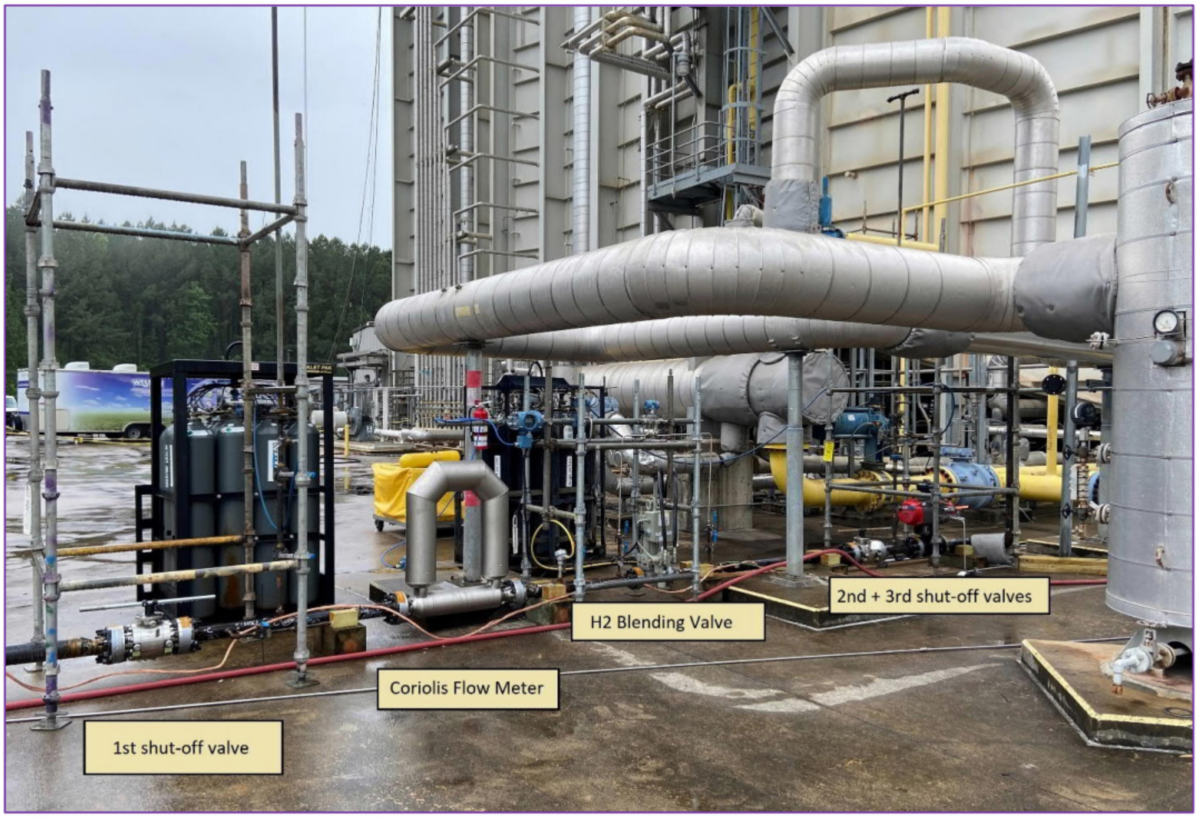

Figure 4. Hydrogen flow control system

4.3 Test Execution

Hydrogen Testing was conducted over a two-week period consisting of five (5) days. There were several criteria critical to test execution success. Communication protocols were developed to ensure that information between parties was controlled and efficient. Testing plans were discussed at a stand-up meeting every day before testing was conducted. The site operations team maintained leadership and control over general GT operations, while Siemens Energy focused on ensuring testing protocols were met. Personnel were located in specific areas on site per communication needs.

The team's focus was ensuring that plant reliability was not impacted negatively due to testing as all testing was conducted in parallel with commercial operation. It was critical to ensure no disruptions to the plan's operations occurred, which was successful based on the protocols followed by the team.

Testing was conducted without significant issues. The machine was able to be adjusted online during testing to complete all test goals. The original goals of lower-by-volume H_2 blending were reached without major issues, allowing the team to stretch to the higher 38.8% H_2 blend, which was achieved.

This limit of the H_2 blend was not due to the combustion system or gas turbine limitations but to the hydrogen supply limitations.

4.4 Emissions

Key Information Point

Emissions data taken during testing exhibits that NOx emissions were able to be kept constant as H_2 blends increased from 0 to over 38% by volume.

Turbine exhaust temperature and fuel delivery changes into the combustion basket (combustion fuel split adjustments) were both independently utilized to maintain NOx emissions levels consistent with natural gas to test multiple methodologies.

4.5 Fuel Temperature

Hydrogen gas temperatures seen during testing varied significantly. As hydrogen was supplied from the high-pressure trailers (and that gas decompressed in the trailers, flowed through metering valves, and exchanged heat with the environment), the gas temperature changed from near ambient temperatures to significantly colder. There are three primary drivers of the hydrogen temperature. The first is the decompression of the hydrogen gas in the storage tanks, which results in a large temperature reduction. Secondly, as the hydrogen gas flows through the metering valves, the Joule-Thompson effect drives a slight temperature increase in the hydrogen gas. This effect is a function of the gas pressure. Finally, there is a temperature increase as the hydrogen gas exchanges heat with the ambient environment. These results can serve as information for others designing hydrogen supply systems and are especially critical for those with a required minimum fuel gas temperature.

4.6 Combustion Dynamics

The results of the acoustic measurements during the H_2 co-firing tests were evaluated with a spectral analysis. The analysis clearly shows that the baseload operation with 30% by volume H_2 co-firing does not increase the overall levels of dynamic amplitudes within this section. For some frequencies, the addition of hydrogen has a damping effect and reduces amplitudes considerably. Observations of combustion dynamics bins (the dynamics spectra data separated into frequency bins and represented by the maximum amplitude in each bin) exhibited that combustion dynamics amplitudes were relatively muted for the H_2 blends tested.

4.7 Combustion Basket Instrumentation

Unique to field testing conducted thus far, Siemens Energy added a full suite of temperature instrumentation to two (2) combustion baskets. This data was used to determine and validate any expected hardware impact of the hydrogen gas.

Test instrumentation with temperature sensors were assembled on two (2) combustor baskets and the corresponding transitions. The measurements of the temperature sensors were used to validate the impact to the metal temperature of the burner and transitions due to the change in flame shape and position with H_2 blending.

Data confirmed the expected behavior of hydrogen combustion, which—due to the higher flame speed—burns with a more compact flame, moving the highest energy density upstream, closer to the burner nozzles. The measured temperature increase was within the capability of the material for the short-term test. The transition piece, which is downstream of the burner, showed no significant change in temperature. Any temperature change in the transition piece was compensated by the cooling system, which is actively regulated and minimizes temperature variations.

5 CONCLUSIONS

Testing conducted on the Siemens Energy SGT-6000G unit at the Constellation Hillabee power plant achieved the major goals of the test planning. Test planning, execution, and results will advance the knowledge base for other similar H_2 blending tests. Results such as the trend of NOx emissions with increasing hydrogen agree well with other tests. Test designs were kept as simple as possible and validated to meet the safety and testing requirements. These results provide additional data to the canon of existing results within the industry and serve as a platform for continued testing.

About EPRI

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Program:

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