Successes

CCADS: Combustion Control and Diagnostics Sensor for Advanced Gas Turbines

Advanced Research

To support coal and power systems development, NETL's Advanced Research Program conducts a range of pre-competitive research focused on breakthroughs in materials and processes, coal utilization science, sensors and controls, computational energy science, and bioprocessing—opening new avenues to gains in power plant efficiency, reliability, and environmental quality. NETL also sponsors cooperative educational initiatives in University Coal Research, Historically Black Colleges and Universities, and Other Minority Institutions.

Accomplishments

- ✓ Process improvement
- ✓ Cost reduction
- ✓ Greater efficiency
- ✓ Lower emissions

Description

The National Energy Technology Laboratory (NETL) has developed and patented an innovative combustion control and diagnostics sensor (CCADS) for gas turbines. The sensor is able to monitor flame properties such as fuel/air ratio and flame stability, enabling close control of instabilities and developing events. CCADS is a breakthrough technology that can provide turbine manufacturers the needed capability to detect and control combustion dynamics and related issues, and lead to higher efficiencies and dramatically lower emissions.

NETL has licensed this technology to an industrial partner, Woodward Industrial Controls. NETL onsite researchers are working with the licensee under a series of cooperative research and development agreements (CRADA) to test the technology at full scale and to make the sensor commercially available. Woodward has served the gas turbine market for over 30 years. For today's market, Woodward provides complete, integrated turbine/fuel control systems. Woodward is fully capable of marketing, manufacturing, and installing advanced fuel injection and control systems incorporating CCADS, and is committed to commercialization of CCADS.

Goals

The goal of this continuing research is to integrate CCADS with necessary fuel quality monitoring and fuel flow control hardware to facilitate close control of combustion. A high degree of control is necessary to ensure stable turbine performance, in order to help achieve ultra-low emission targets for advanced gas turbines operating on natural gas, synthesis gas (syngas) derived from coal gasification, and hydrogen fuel. Gas turbines are relied on throughout the world to generate clean electricity from fuels such as natural gas, and will be a key component of advanced, fuel-efficient technologies such as Integrated Gasification Combined-Cycle (IGCC).

More stringent environmental regulations, and issues such as global climate change, are driving gas turbine manufacturers to continually improve turbine efficiency to reduce operating costs and carbon dioxide emissions, while at the same time reducing emissions of pollutants such as nitrogen oxides (NO_x). Achieving turbine operating conditions that meet both efficiency and emission goals simultaneously usually causes turbine combustors to be unstable, so manufacturers "detune" the combustors to reduce this risk, leading to lower efficiencies and/or higher emissions than would be achievable if instabilities could be controlled.

This work supports the Department of Energy's (DOE) Advanced Power Systems Program goal of zero emissions at competitive operating costs for advanced power plants by 2015 that are fuel flexible, and that are capable of efficiencies of over 60 percent on coal and

Project Duration

Start Date
10/01/06

End Date
09/30/07

Cost

Total Project Value
$200,000

DOE/Non-DOE Share
$200,000 / $0

Industrial Partner

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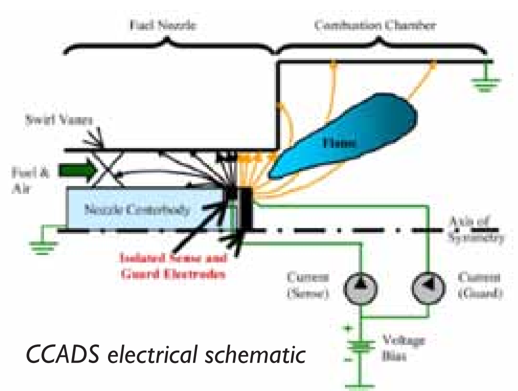
75 percent using natural gas. To achieve these goals, robust sensors and advanced control hardware and techniques must be developed and employed in advanced power technologies such as gasifiers, gas turbines, and fuel cells.

GE 7FB advanced technology gas turbine

Technical Approach and Accomplishments

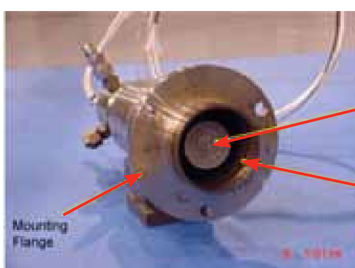
Like natural gas-fired turbines, advanced turbines operating on syngas will require precise fuel delivery to achieve fuel-lean homogenous mixing of the fuel and air in all combustion zones — a prerequisite to operation at the required emission levels. For example, to achieve ultra-low levels of NO_X, gas turbine combustors must operate with a finely controlled fuel-air ratio. The point at which the flame can no longer be sustained also is where the turbine is most susceptible to combustion dynamics, flashback, loss of flame anchor, and lean blowout, further complicated by possible variations in fuel composition.

To address these problems, the multi-sensing capability of CCADS provides a simple, yet robust, in-situ monitoring sensor for diagnosing combustion conditions/activities. As illustrated below, the CCADS flame ionization sensor technique uses two electrically isolated electrodes that are installed on the combustor end of the fuel injector nozzle centerbody. Near that point, the flame is aerodynamically suspended, providing temperature interaction with the electrodes.



CCADS electrical schematic

A commercial prototype of an industrial-scale lean premixed fuel nozzle equipped with integrated CCADS electrodes is shown in the photos below. As shown on the left, after being instrumented with CCADS, the fuel nozzle is bolted to the inlet of the test combustor. As shown on the right, the guard and sense electrodes are integrated into the centerbody of the fuel nozzle.



Centerbody Tip and Guard Electrode

Air and Fuel Passage

Front view looking into the nozzle premixer from downstream, with the guard electrode covering the entire tip of the centerbody

Guard Electrode

Sense Electrode

Top view with the mounting flange removed and the electrodes identified at the end of the exposed centerbody

Integration of the CCADS electrodes into the existing premixed fuel nozzle eliminates the need for extra ports in the combustor wall, a requirement that has limited acceptance of online combustion monitoring by turbine manufacturers due to the added complexity and expense. The CCADS electrodes are manufactured from the same high-temperature alloys as the premix nozzle, so they are resistant to the high temperatures and pressures at the combustor inlet. CCADS provides 360 degree detection of flashback around each fuel nozzle, and responds very quickly, observing flame flickering within milliseconds. Optical sensors and pressure transducers, by contrast, need special cooling or mounting away from the combustor to prevent thermal damage; while thermocouples, applied for flashback detection, provide only a point measurement with a slow response time.

The industrial-style prototype of CCADS, integrated into the fuel premix nozzle, has been tested both under gas turbine combustor operating conditions in the NETL high-pressure combustion test facility, and at commercial facilities of two major turbine manufacturers. Woodward and NETL have documented the testing of the prototype across a wide range of operating conditions in a test rig that duplicated the temperature, pressure, and fuel flows likely to occur in gas turbines. These tests verified the operability of the prototype and its ability to detect the following:

- Flashback in the fuel nozzle;
- Precursor events that correlate with local flame extinction;
- Combustion-driven pressure oscillations; and
- A qualitative measure of local fuel-air ratio in the combustor.

Although these useful CCADS capabilities have been demonstrated, improving CCADS capabilities is necessary to provide quantifiable measurements that establish equivalence ratios for fine-tuned combustion control applications. Flame instabilities and changes in flame location complicate the CCADS measurements. To provide more information related to the flame location, the focus has shifted to investigating time varying voltage techniques. When the flame moves away from the CCADS electrode, the weakly ionized region between the flame and the electrode stores a capacitance charge. This capacitance can be measured using a time varying measurement technique (e.g., sine wave, triangle wave, or square wave). These advanced measurement techniques and the additional information that can be extracted from the flame are expected to improve CCADS performance in advanced power turbine applications.

NETL's in-house development of fundamental laboratory and computational fluid dynamics models has supported CCADS development by providing physical insight into flame ionization and ion transport processes. Computer modeling of combustor design and simulation of combustion processes also are expected to help improve the design of CCADS for use in commercial combustor applications.

Assessing CCADS performance in full-scale testing of natural gas and syngas applications is essential for eventual implementation in commercial turbines. This testing is ongoing through the CRADA partnership with Woodward. Assessing CCADS performance with hydrogen blend fuels also is necessary in connection with syngas turbine applications. Preliminary test results from laboratory burner experiments indicate that CCADS can be used in these applications. Testing under representative turbine combustion conditions in laboratory combustors has demonstrated CCADS flashback detection with 80 percent hydrogen fuel (by volume). Additional evaluations are ongoing to fully assess the sensing potential with hydrogen blends and pure hydrogen.

Benefits

Industry adoption of CCADS will open the door to more efficient, lower emission turbines in advanced energy systems through smarter control of combustion. CCADS technology will enable advanced energy systems to make more efficient use of natural gas, petroleum-based fuels, coal, and biomass, including energy systems that capture and store potential carbon dioxide emissions. For example, combustion dynamics control with CCADS can contribute to improved performance in advanced turbine systems, an enabling technology for advanced low-emissions coal systems. CCADS use with feedback control will increase stability over the entire turbine operating range, resulting in higher performance, durability, and lower emissions. Electric utilities will benefit through reduced costs for maintenance and emissions penalties. Existing gas turbine installations can be retrofitted with CCADS to provide additional operating flexibility.

CCADS has a very low cost relative to the total cost of a gas turbine, while providing substantial benefits both to turbine manufacturers and utilities. The market potential for advanced nozzles incorporating CCADS is conservatively estimated at tens of thousands of units per year in both new installations and retrofit markets. Eliminating unwanted combustion dynamics could result in an estimated $1 billion per year cost savings, and this number could increase in the future with the implementation of IGCC with advanced turbine systems. Together with other advances in energy technologies, these performance improvements and cost reductions will help provide lower cost electricity to consumers in the United States and internationally, while improving the environment and addressing the growing climate change issue.

"Industry adoption of CCADS will open the door to a new generation of more efficient, ultra-low emission turbines in advanced energy systems"

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