THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

SOUTHERN RESEARCH INSTITUTE

NYSERDA

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Natural Gas-Fired Microturbine Combined With Heat Recovery System
APPLICATION:	Distributed Electrical Power and Heat Generation
TECHNOLOGY NAME:	IR Power Works™ 70 kW Microturbine System
COMPANY:	Ingersoll-Rand Energy Systems
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the purchase, design, distribution, financing, permitting, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups that consist of buyers, vendor organizations, and permitters, and with the full participation of individual technology developers. The program evaluates the performance of technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Greenhouse Gas Technology Center (GHG Center), one of six verification organizations under the ETV program, is operated by Southern Research Institute in cooperation with EPA's National Risk Management Research Laboratory. The GHG Center has collaborated with the New York State Energy and Development Authority (NYSERDA) to evaluate the performance of the IR PowerWorks™ 70 kW Microturbine System offered by Ingersoll-Rand Energy Systems. This verification statement provides a summary of the test results for the IR PowerWorks System.

TECHNOLOGY DESCRIPTION

Large- and medium-scale gas-fired turbines have been used to generate electricity since the 1950s. Technical and manufacturing developments during the last decade have enabled the introduction of microturbines with generation capacities ranging from 30 to 200 kW. The IR PowerWorks System is one of the first cogeneration installations that integrates microturbine technology with a heat recovery system.

The following description of the IR PowerWorks System was provided by the vendor and does not represent verified information.

Electric power is generated with an integrated Ingersoll-Rand microturbine with a nominal power output of 70 kW (59 °F, sea level). The system incorporates a gas generator compressor, recuperator, combustor, power turbine, and electric generator. Air enters the unit and is compressed to about 35 psig in the gas generator compressor and then heated to around 1,000 °F in the recuperator. A screw compressor type fuel booster is used to compress the natural gas fuel, the compressed air is mixed with the fuel, and this compressed fuel/air mixture is burned in the combustor under constant pressure conditions. The resulting hot gas is allowed to expand through the power turbine section to perform work, rotating the turbine blades to turn a generator that produces electricity. The rotating components are of a two-shaft design with the power turbine connected to a gearbox and supported by oil lubricated bearings. The generator is cooled by air flow into the gas turbine. The exhaust gas exits the turbine and enters the recuperator, which captures some of the thermal energy and uses it to pre-heat the air entering the combustor, improving the efficiency of the system. The exhaust gas then exits the recuperator through a muffler and into the integrated IR heat recovery unit.

The integral heat recovery system consists of a fin-and-tube heat exchanger, which circulates a mixture of approximately 16 percent propylene glycol (PG) in water through the heat exchanger at approximately 20 gallons per minute (gpm). The heating loop is driven by an internal circulation pump and no additional pumping is required. The thermal control system is programmable for individual site requirements. Minimum settings may vary, but the maximum fluid temperature entering the PowerWorks may never exceed 200 °F.

The IR PowerWorks system includes an induction generator that produces high-frequency alternating current (AC) at 480 volts. The unit supplies an electrical frequency of 60 hertz (Hz) and is supplied with a control system which allows for automatic and unattended operation. An active filter in the turbine is reported by the turbine manufacturer to provide clean power, free of spikes and unwanted harmonics. The power unit operates at 44,000 revolutions per minute (rpm), and the generator operates at 3,260 rpm regardless of load.

VERIFICATION DESCRIPTION

Verification of the IR PowerWorks was conducted at the Crouse Community Center in Morrisville, New York. The facility is a 60,000-square foot skilled nursing facility providing care for approximately 120 residents. The IR PowerWorks system was installed to provide electricity to the facility and to provide heat for domestic hot water (DHW) and space heating. During normal occupancy and facility operations, electrical demand exceeds the IR PowerWorks generating capacity, and additional power is purchased from the grid. On rare occasions, when facility electrical demand is below 70 kW (demand can drop as low as 50 kW in some instances), the excess power is exported to the grid. In the event of a power grid failure, the system is designed to automatically shut down to isolate system from grid faults. When grid power is restored, the IR PowerWorks system can be restarted manually.

Prior to installation of the IR PowerWorks, the facility used two gas-fired boilers to generate hot water for space heating and DHW throughout the complex. The two boilers are Weil-McLain Model Number BG-688 units, installed in 1996. Each boiler has a rated heat input of 1,700 thousand British thermal units per hour (MBtu/hr), gross output capacity of 1,358 MBtu/hr, and a net hot water production rate of 1,181 MBtu/hr. The IR PowerWorks is configured in-line with the boiler supply and return fluid (PG) lines (working fluid is a mixture of 16-percent propylene glycol in water).

Testing commenced on August 14, 2002, and was completed on August 21, 2002. It consisted of a series of short periods of "controlled tests" in which the unit was operated at full load (the IR PowerWorks unit tested did not have the capability of intentionally modulating power output). Three test replicates were conducted during normal site operations regarding heat recovery and use. During these tests, the facility boilers were thermostatically controlled to maintain desired supply PG temperature. A second set of three tests was conducted at full power with the boilers turned off to demonstrate the unit's ability to produce more heat. These controlled test periods were followed by six days of extended monitoring to verify electric power production, heat recovery, power quality performance, and efficiency during an extended period of normal site operations. During this period, the IR PowerWorks System operated 24 hours per day at full electrical power output and normal heat recovery rate.

The classes of verification parameters evaluated are:

Heat and Power Production Performance
Emissions Performance (NO_X, CO, THC, CO_2, and CH_4)
Power Quality Performance

Evaluation of heat and power production performance includes verification of power output, heat recovery rate, electrical efficiency, thermal efficiency, and total system efficiency. Electrical efficiency was determined according to the ASME Performance Test Code for Gas Turbines (ASME PTC-22) and tests consisted of direct measurements of fuel flow rate, fuel heating value, and power output. Heat recovery rate and thermal efficiency were determined according to ANSI/ASHRAE test methods and tests consisted of direct measurements of heat transfer fluid flow rate, differential temperatures, and specific heat of the heat transfer fluid. Ambient temperature, barometric pressure, and relative humidity measurements were also collected to characterize the condition of the combustion air used by the turbine.

The evaluation of emissions performance occurred simultaneously with efficiency determination at both normal site conditions and with site conditions altered to enhance heat recovery. Pollutant concentration and emission rate measurements for nitrogen oxides (NO_X), carbon monoxide (CO), total hydrocarbons (THC), carbon dioxide (CO_2), and methane (CH_4) were conducted in the turbine exhaust stack. All test procedures used in the verification were U.S. EPA Federal Reference Methods. Pollutant concentrations in the exhaust gas are reported in two sets of units-parts per million volume, dry (ppmvd) corrected to 15 percent oxygen (O_2), and mass per unit time (lb/hr). The mass emission rates are also normalized to turbine power output and reported as pounds per kilowatt hour (lb/kWh).

Annual NO_X and CO_2 emissions reductions for the IR PowerWorks System at the test site are estimated by comparing measured lb/kWh emission rates with corresponding emission rates for the baseline power and heat production systems (i.e., systems that would be used if the IR PowerWorks System were not present). At this site the baseline systems include electricity supplied from the local utility grid and heat from the facility's standard natural gas boilers. Baseline emissions for the electrical power were determined following Ozone Transport Commission guidelines. Baseline emissions from heat production are based on EPA emission factors for commercial-scale gas-fired boilers.

Electrical power quality parameters, such as electrical frequency and voltage output, were also measured during the six-day extended test. Other performance parameters, including current and voltage total harmonic distortions (THD) and power factor, were monitored to characterize the quality of electricity supplied to the end user. The guidelines listed in the Institute of Electrical and Electronics Engineers' Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems were used to perform power quality testing.

Quality Assurance (QA) oversight of verification testing was provided by Southern Research Institute (SRI). Following specifications of the ETV Quality Management Plan (QMP), SRI staff conducted three performance evaluation audits and an audit of data quality on at least 10 percent of the data generated during this verification.

VERIFICATION OF PERFORMANCE

Heat and Power Production Performance

- All controlled tests occurred at similar operating conditions (ambient temperatures defined on S-2: 76 to 86 ^{o}F; barometric pressure: 14.01 to 14.07 psia; relative humidity: 45 to 68 percent).

- During the controlled test period, 50.62±0.84 kW of electric power was generated at full load. Heat recovery rate during normal facility operations was 143.5±1.82 MBtu/hr. Corresponding efficiencies were 25.3±0.46 percent for electrical generation, 21.0 ± 0.31 percent for heat production, and 46.3±0.55 percent for total combined heat and power (CHP) efficiency.

- During controlled test periods with the boilers turned off, enhanced heat recovery rate was 173.2±1.82 MBtu/hr. Corresponding heat production efficiency was 24.9±0.35 percent during these tests. These results demonstrate that heat recovery performance of the IR PowerWorks can be improved by reducing the heating loop temperature. These results represent the highest heat recovery rate achievable at this facility under current heating loop design and operation, but do not represent the maximum heat recovery potential of the IR PowerWorks where lower loop temperatures are evident.

HEAT AND POWER PRODUCTION					
Test Condition	Electrical Power Generation		Heat Recovery Performance		Total IR PowerWorks System Efficiency (%)
	Power Delivered (kW_e)	Electrical Efficiency (%)	Heat Recovery Rate (MBtu/hr)	Thermal Efficiency (%)	
Full Power, Normal Site Operations	50.62	25.3	143.5	21.0	46.3
Full Power, Heat Recovery Potential Enhanced	52.34	25.7	173.2	24.9	50.6

- Heat input at full load was 684.1 MBtu/hr, or 12.5 standard cubic feet per minute (scfm) natural gas. Heat rate at full load was 13,487 Btu/kWh_e.

Emissions Performance

- **During normal site operations, average NO_X concentration was 0.86 ppmvd @ 15 percent O_2. This equates to a mass emission rate of 0.0024 lb/hr and a power normalized emission rate of 4.67×10^{-5} lb/kWh$_e$. Mass emissions of CO_2 averaged 82.9 lb/hr (1.60 lb/kWh$_e$).**

- CO concentrations averaged 0.62 ppmvd @ 15 percent O_2 during normal site operations. This equates to a mass emission rate of 0.0011 lb/hr and a power normalized emission rate of 2.09×10^{-5} lb/kWh$_e$.

- Emissions of THC were near the sensitivity of the sampling system, averaging 2.38 ppmvd @ 15-percent O_2 during normal site operations. Methane concentrations were not detected during any of the test periods (< 1 ppmvd).

- At full load, NO_X emissions per unit electrical power output were 4.67E-05 lb/kWh, well below the average levels reported for the regional grid (0.0024 lb/kWh). The average CO_2 emissions for the regional grid are estimated at 1.53 lb/kWh which is slightly lower than the emission rate for the IR PowerWorks (1.60 lb/kWh). These values, along with emission reductions attributed to the IR PowerWorks heat recovery performance yield an average annual emission reduction of 1,333 lbs (34 percent) for NO_X, and 211,744 lbs (7 percent) for CO_2. Calculated emission reductions include 7.8 percent line losses across the regional grid.

CRITERIA POLLUTANT AND GHG EMISSIONS									
Test Condition	**(ppmvd @ 15% O_2)**				**(lb/kWh$_e$)**				
	NO_X	CO	THC	CH_4	NO_X	CO	THC	CH_4	CO_2
Full Power, Normal Site Operations	0.86	0.62	2.38	< 1.0	4.67×10^{-5}	2.09×10^{-5}	4.48×10^{-5}	$< 4.93 \times 10^{-5}$	1.60
Full Power, Heat Recovery Potential Enhanced	1.07	0.65	0.54	< 1.0	5.84×10^{-5}	2.14×10^{-5}	1.04×10^{-6}	$< 4.87 \times 10^{-5}$	1.78

Power Quality Performance

- Throughout the six-day test period, the IR PowerWorks System maintained continuous synchronization with the utility grid. Average electrical frequency was 60.001 Hz and average voltage output was 494.75 volts.
- The power factor remained relatively constant for all monitoring days with an average of 67.5 percent and a range of 62.7 to 73.9 percent.
- The average current THD was 4.76 percent and the average voltage THD was 2.05 percent, both lower than the ±5 percent threshold specified in IEEE 519.

Details on the verification test design, measurement test procedures, and Quality Assurance/Quality Control (QA/QC) procedures can be found in the Test Plan titled *Test and Quality Assurance Plan for the Ingersoll-Rand Energy Systems, IR PowerWorks*™ *70 kW Microturbine System* (SRI 2002). Detailed results of the verification are presented in the Final Report titled Environmental Technology Verification Report *for the Ingersoll-Rand Energy Systems, IR PowerWorks*™ *70 kW Microturbine System* (SRI 2003). Both can be downloaded from the GHG Center's Web site (www.sri-rtp.com) or the ETV Program web site (www.epa.gov/etv).

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