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Laboratory R&D on integrated energy systems (IES)

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Abstract

Integrated energy systems (IES) offer the potential for a significant increase in the nation's fuel use efficiency by generating electricity onsite near the load and recycling the exhaust gas for heating, drying, cooling, or dehumidifying. A key challenge for IES is the efficient and cost-effective integration of distributed generation (DG) equipment with thermally-activated (TA) technologies. The US Department of Energy (DOE) launched the IES program in 2001 to focus on laboratory and field research to address these critical issues, advance the technology and accelerate application of combined Cooling, Heating and Power (CHP). An example of IES is the combination of an onsite microturbine with heat recovery, HVAC, desiccant and absorption chiller units. IES, in conjunction with other new energy efficient building technologies, will maximize the efficiency of energy use, reduce harmful emissions to the environment, improve power quality and reliability and provide flexibility for meeting electric power peak load demands as compared with large central power plants. The R&D performed at the Oak Ridge National Laboratory's (ORNL) IES Laboratory focuses on assessing the operational and emissions performance of current DG and TA technologies operated individually and in combination as an IES; developing and verifying mathematical models of the individual devices and IES; and supporting the development of test protocols and standards for assessing IES technologies.

The IES Test Laboratory is a flexible test-bed for the configuration of DG (presently a 30-kW natural gas-fired microturbine-generator) with various heat recovery units (an air-to-water heat recovery unit or HRU, direct- and indirect-fired desiccant dehumidification systems, and an indirect-fired single-effect absorption chiller). The exhaust gas from the microturbine-generator (MTG) is used to drive the HRU and/or used directly in the direct-fired desiccant dehumidification unit. The hot air and hot water flows from the HRU can be controlled and directed via automated damper controls in order to test various IES configurations and operating modes. The hot air can be conditioned with an air-mixing chamber.

The IES testing results produced so far show that the operating parameters and efficiencies of the overall system and individual devices depend on loading (electric and thermal), as well as on ambient weather conditions (temperature and humidity levels). Outdoor temperature is a major factor since the MTG is located outside and its power and heat output are functions of the outside temperature and humidity and no attempt is currently being made to adjust its inlet air temperature, i.e., air cooling from the TA units. Under certain operating conditions and combinations of IES, the efficiency (including all parasitics) of the overall system can be as high as 55% (based on higher heating value of the natural gas).
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1. Introduction

The centralized generation model that has been used by the electric power industry for several decades is confronting a number of economic, technical and environmental problems including long lead times, high

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Nomenclature

Abbreviations

AC	absorption chiller
CHP	cooling, heating and power
COP	coefficient of performance
CT	cooling tower
DG	distributed generation
DOE	Department of Energy
E	efficiency
EGFDD	exhaust-fired desiccant dehumidification unit
HHV	higher heating value (i.e., of natural gas)
HRU	heat recovery unit
IES	integrated energy system
LC	latent capacity
LCOP	latent coefficient of performance
MTG	microturbine generator or microturbogenerator or microturbine for short
ORNL	Oak Ridge National Laboratory
TA	thermally-activated

Variables

C_P	heat capacity, kJ/kg °C or Btu/lb °F
G	volumetric flowrate, m^3/min or scfm
h	enthalpy, kJ/kg or Btu/lb
Q	heat input, thermal input, cooling capacity, heating capacity, latent capacity, kW or Btu/h
t	temperature, °C or °F
W	electric power, kW or Btu/h
ρ	density, kg/m^3 or lb/ft^3

Subscripts

chw	chilled water
in	input, inlet
out	output, outlet

capital cost and the need for modernization of the transmission and distribution (T&D) systems, electric generation's recent price pressure on natural gas and significant environmental impact. All of these issues are reasons to pursue other forms of electric generation such as distributed generation that is located near the end-use load. Further, distributed generation technology is becoming more reliable, efficient, prevalent and reduces losses on T&D lines by placing the generation next to the load. In a recent report prepared in 2001 by the National Energy Policy Development Group, the concept of combined cooling, heating and power (CHP), also known as integrated energy systems (IES), is identified as a strategy for addressing increased energy demands and peak power issues [1]. Recent developments in distributed generation (DG) technologies have opened new opportunities for relatively small-scale IES that can be used in buildings. DG in combination with thermally-activated (TA) technologies, which use waste heat for heating purposes or thermally-driven desiccant dehumidification and absorption cooling, provide important opportunities for IES to be a viable technology for buildings [2,3].

Microturbine generator (MTG) technology, as a prime mover, currently represents 250 kW or smaller sized units that have efficiencies of 25%[1] or lower (including parasitic losses). The efficiency of the current technology is limited by the components' high temperature corrosion limits of the MTG. In order to increase the overall efficiency of current MTGs above 50%, the MTG must be combined with waste heat recovery technology like TA desiccant systems and absorption technology [2].

A DOE Laboratory for testing IES was commissioned in 2001 at ORNL. The scope of the facility is to test DG in combination with TA technologies for optimum waste heat recovery and overall energy efficiency. The objectives of the laboratory include [4]

- collection of performance data on current DG and TA technologies both individually and operated as an integral part of an IES,
- development of models of the individual devices and verification of an IES model based on integrated operation and
- support the development of testing protocols and standards for assessing IES technologies.

The goal of the IES program is to increase the overall energy efficiency of DG systems by integrating them with waste heat recovery and TA technologies. The TA systems use the DG's hot exhaust gas (by-product of power generation) to produce heating, cooling and/or drying the desiccant material used by dehumidification systems.

The IES Laboratory has a flexible test-bed configuration for testing various heat recovery systems (Fig. 1) in conjunction with the DG. The exhaust gas from the DG can either be used directly and/or routed to an air-to-water heat exchanger (also referred to as a heat recovery unit or HRU). The exhaust gas and water flows from the HRU can be varied and directed via automated damper controls to test various IES configurations and operating modes. The exhaust gas can be conditioned with outside air in an air-mixing unit. The IES Laboratory

[1] Hereinafter, all the efficiencies and coefficients of performance given in this paper are calculated at higher heating value (HHV) of natural gas.