Design, Construction, and Commissioning of a 60-kW Microturbine Demonstration Facility

Glenn Wrate, Michael Swedish, Frederik Betz, Justin Reese, Chad Weis, and Lee Greguske

Milwaukee School of Engineering / Focus on Energy

Abstract

A joint project between the Wisconsin's Focus on Energy program, the Milwaukee School of Engineering (MSOE), City of Milwaukee, and We Energies to develop a 60-kW microturbine demonstration facility is described. All the salient mechanical and electrical data (speed, torque, voltage, current, etc.) from the microturbine and its associated equipment is made available to the students at the Milwaukee School of Engineering, and, in the future, other educational institutions. A subset of the data, in particular the energy costs, break-even points, and reliability statistics, are made available to the general public. Since the site is several kilometers from the MSOE campus, all of the data is made available remotely via the Internet. The facility has provisions for student tours of the site and a secure entrance and student work area for graduate students or senior projects. A multidisciplinary team of students and faculty (ME and EE) specified the desired parameters, assisted in development of the data acquisition system, and oversaw the development of the web-based delivery system. One of the more challenging aspects of this project was the number of entities involved. All told, ten different organizations played a role in the project. One of the major tasks for the students was to coordinate between and among these various organizations. A driving force for the students was to provide a useful tool for the students that came after them. This paper includes a description of the facility and microturbine technology, information on the data acquisition system, descriptions of the web-based instructional materials, and experiences with student recruitment and interactions.

Introduction

Genesis of the Wisconsin's Focus on Energy Program

Focus on Energy is a Wisconsin-based partnership consisting of both private and public organizations that focuses on saving energy and money for the people and corporations in Wisconsin. Focus on Energy provides businesses and residents with education and technical services. Their aim is to help people save money and improve their economic well being, increase energy reliability and efficiency, and reduce the need for fossil fuels; improving Wisconsin's environmental future. The services that are offered to the clients of Focus on Energy are provided by a group of firms, contracted by the Wisconsin Department of Administration's Division of Energy[1]. As part of this work, Focus on Energy does the testing of energy saving devices. This paper discusses the first phase of the testing of one such device, a microturbine with waste heat recovery, and the aspect of the project that affect teaching and students. Subsequent papers will focus on the technical aspects of the project will detail the implementation and classroom use of the online systems.

Pedagogical Goals

Electrical Engineering Goals

One of the goals of the electrical engineering portion of this facility is to aid instruction in the area of building electrical power system design. MSOE offers a design specialty in this area through its Architectural Engineering and Building Construction Department[2]. The building associated with the microturbine facility has an extensive load shedding scheme. Educators and students will have access to the view the programming and real-time data from the load management system through the web portion of the facility. Another area of interest in the building electrical design specialty is backup generation. Facilities of this type are intended, eventually, to replace tradition internal-combustion backup generators. This facility is only intended to handle a portion of the emergency load – the exit lighting system, but not the fire pumps. Since the entire design of the facility will be published, it also will be used as a case study for feeder circuit design, among other topics.

For traditional Electrical Engineering courses, this facility will supplement textbooks and computer simulations in the area of power system design and analysis. Recently, one of the most important topics in the power system area is distributed generation. This facility will allow educators and students a detailed view of the workings of one of the most promising forms of distributed generation: a microturbine with a waste heat recover system. It will be a great introduction to the topic of distributed generation. Continuing on the web site, classes can then find out how distributed generation reduces the need for base-load generation, and the subsequent transmission problems and losses. They will also be able to investigate possible problems with distributed generation such as protective relaying and power quality. Two areas of particular importance are synchronization and stand-alone mode.

This system will synchronize power with the building load and the utility grid by means of a dual mode controller. The dual mode controller provides feedback to the microturbine's power electronics, and therefore the microturbine can produce power that is synchronized to frequency, phase, and load of the building. Synchronizing information will be available to all users of the system via the web.

The microturbine system is also equipped to operate in stand-alone mode. Stand-alone mode allows power generation when no power is available for the electric utility. In other words, the system will be capable of generating power in the case of a power outage. A large on-board battery pack is used to power connected loads and start the microturbine. Once the microturbine reaches full speed, the large battery pack is utilized as an electric buffer. In addition to start-up, the battery provides extra power in the case of a sudden load increase, and therefore allows the microturbine time to increase speed to meet the load demand. This battery will also sink power in the case of a sudden load decrease.

The stand-alone mode feature of the microturbine should not be confused with an uninterruptible power supply (UPS). The system will only be capable of running small and important building loads, such as lighting. Unlike a UPS, in the case of a power outage, the system will require startup time before it is capable of providing power.

Another area that will gain from this facility is power electronics. Two of the basic topics in power electronic courses are bridge and inverter design.[3] This facility will allow students at MSOE, and other institutions in the future, to view waveforms from the bridge and inverter sections of the microturbine during startup, and while running at different loads. On-line systems in the past[4] have focused on systems of less than one kW. With this facility, a 60-kW system is demonstrated.

Mechanical Engineering Goals

Interest in small cogeneration systems has been growing in recent years for a number of reasons. They can serve as backup power generators, and they can mitigate transmission and distribution constraints. From a resource utilization standpoint, the potential for use of both electrical and thermal outputs in cogeneration systems makes them an attractive option for reducing total energy use, and hence energy costs. The thermodynamic analysis of these systems involves application of both the 1st and 2nd Laws.

A major goal of this demonstration project is to allow students access to information that will facilitate real-time 1st and 2nd Law analysis of the microturbine/heat recovery system. Energy inputs and outputs, exergy flows and exergy losses will be accessible to the students. With real time cost information (for electricity and natural gas), these results can be translated into actual cost savings when compared to separate generation of electricity and thermal energy or best case potential for electrical and thermal utilization. Remote access to the data means that the analysis can be carried out in the classroom, resulting in a high degree of flexibility for the course instructor.

Because this is an actual commercial installation, the students will be able to make assessments about the effectiveness of the installation and recommend changes to future installations that will enhance the effectiveness (in terms of resource and cost savings) of future microturbine installations.

Government/Industry Goals

Demonstration of Energy-Saving Technology

This review and demonstration project will identify the practicality of combining distributed generation and combined heat/power technologies by analyzing performance data, generated savings (both energy, peak power, and cost), operating reliability and reduced maintenance requirements of this pilot microturbine system.

The project will also demonstrate load shedding strategies based on incorporation of a continuously self-upgraded facility load curve, real time operating cost/savings data, and peak kW segment slice analysis. Development would include a "smart system" controller that would automatically start and stop the microturbine system based on a set point for quantitative cost savings. Compared parameters would include the present given electrical power rate (kWh & kW cost), time of day (on-peak/off-peak), spot fuel cost, fuel rate, power produced (kW) and amount of heat reclamation

Maximizing heat reclaim potentials for building heating and domestic hot water heating would also be developed through analyzing and exploring various system flow rates, multiple differential temperature settings, and varying percents of throughput versus bypass operation.

The project is also intended to be an educational, training, and showplace type of demonstration for microturbine technology. Tours and technical presentations would be conducted for such groups such as ASHRAE, NSPE, ASME, IEEE, etc., as well as other interested parties. At the conclusion of the project, a technical paper will be published on the results and findings of the research effort. During the life of the project, MSOE faculty and students will be able to log onto the microturbine site to view operating data real-time, as well as all previously generated (historical) data.

Pilot Test for Future City of Milwaukee Projects

Probably the single largest contribution of the microturbine review and demonstration project is that it could become the cornerstone for emergency power systems for the City of Milwaukee in its many buildings. A major consideration is the planned installation of 750 to 1,000 kW of generation set for the Milwaukee City Hall Complex in 2003-2004. With four or five microturbines (200 kW each), the city could have the necessary standby power it needs, plus significantly more flexibility and an available tool to reduce operating and energy costs.

With a successful demonstration, and the movement of the City of Milwaukee to embrace this technology, it will become a model for other cities and municipalities as an alternative to existing diesel or gas reciprocating emergency power systems, which are neither environmentally friendly nor cost effective in providing supplemental heat, power, and security to their respective building and government systems.

Energy Savings

The energy savings are calculated to be:

- 60kW power
- 20,800 therms / year
- The value of 60kW is calculated at $400 kW /year, or $24,000/year
- The value of 20,800 therms/year at $.563 / therm, or $11,710/year
- Project life is considered by Focus on Energy as seven years

The net present value of this investment is calculated, using 6% interest and seven year project life, to be approximately $163,000.

Operating at a projected 79% overall efficiency, the microturbine will achieve a net 34% therm savings over power plant and boiler system requirements, in addition to providing a 60 kW demand reduction. This amounts to a unit savings of 4.33 terms per hour, or 20,800 therms per year over the projected building heating period. Based on $0.563/therm, the yearly therm savings amounts to $11,710 per year, and at $400/kW the demand savings is worth $24,000 per year, resulting in a net project savings of $35,710 per year.

Public Goals

Informing the public on how electricity is produced is another goal of this facility. A December 2002 article in the ASEE Prism states that only 53% of the respondents could explain to a friend "how energy is transferred into electric power" while 70% could explain "how a home heating system works" and 90% could explain "how a flashlight works." The project began achieving this goal with an article in the local paper[5]

First Technical Tasks

Electrical Instrumentation

For the high-speed generator voltage and current and the dc bus voltage and current measurements we choose a Yokogawa WT 1600 Digital Power Meter[6]. Since the high-speed generator output frequency is 1600 Hz, a device that could handle frequencies from dc to over 80 kHz was necessary. This device also makes on-line presentation of the data much simpler. The device has an integral ftp server, which will be polled by a Unix-based server at the City of Milwaukee. Initial, the data will be available only to MSOE students. As part of the on-going project, students will be developing web pages to make the data available to other institutions.

A Rockwell Automation Bulletin 1403 Powermonitor II will monitor the ac power output of the microturbine[7]. Data from this device will be made available to all users of the facility via Engage Networks. In addition to standard rms voltage, current, and power measurements, the device also provides voltage and current waveforms, TIF, Crest Factor, and IEEE 519 voltage and current.

Mechanical Instrumentation

The instrumentation required to completely analyze this cogeneration plant is extensive. The students working on this project have specified a variety of thermocouples, pressure transducers, flow meters, vibration sensors, and decibel meters. Utilizing these sensors, along with the provided information from Capstone, will allow the students to complete a first and second law analysis of the cogeneration plant.

At the time of this writing, the instrumentation for measuring the data points necessary for analyzing the micro-turbine from both a thermodynamic first and second law approach have been specified and ordered. Many of the sensors have arrived and have been installed. Furthermore, a couple of necessary and critical data points which are internal to the micro-turbine are not capable of being measured at this time, due to proprietary information. As a result, attempts are being made to obtain this information from the supplier, Capstone; until then, minor assumptions will be made. If the information is not made available, these assumptions will be used until the critical points can be measured.

Student Interactions

The efforts of the students working on this project have been impressive. With very little guidance, they have been working directly with the responsible engineers at the City of Milwaukee and all the contractors associated with this project. They see this project as a major benefit to themselves, and to future students. One student commented on the project as follows:

> "The Capstone microturbine project has been a terrific experience in applying classroom theory to real world applications. Also, the networking with various corporations and working in a team with people from a variety of backgrounds towards a common goal has been very educational."

Conclusions

While it is too early to tell if this initiative will be successful, one thing is certain, the City of Milwaukee, the State of Wisconsin, and local industry are attempting to deal proactively with the current energy concerns. This demonstration project is proof of that. In addition, the ability to display all pertinent mechanical and electrical data on the operating microturbine is a significant contribution to the academic endeavors in this area.

Acknowledgment

The authors offer their sincere thanks to Hugo Heyns, Wisconsin's Focus on Energy Business Program Director; Venu Gupta, Director of Building and Fleet Services, Joseph Jacobsen, Management Facilities Engineer, Andrew Hilgendorf, Electrical Services Supervisor, Timothy Ringle and Jim Morden of the City of Milwaukee Department of Public Works; Dave Broihahn and Jan Scott at Unison Solutions, LLC; and Ken Brickner, National Sales Director, Jon Kuhl, Application Engineer, and Alan Gilgenbach, Director of Internet Applicance Technology at Engage Networks, Inc. and Mr. Richard Westmore, Principle of Enertech for their ongoing work on this project.

Bibliography

[1] Glenn Wrate, "Focus on Energy – Wisconsin's Initiative to Reduce Industrial Energy Consumption", *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*, Session 2333

[2] Glenn T. Wrate, "Development of a Building Electrical Power Systems Design Specialty," *Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition*, Session 1433

[3] Herbert L. Hess, “Power Electronics Instruction: Topics, Curricula, and Trends,” *Proceedings of the 1997 American Society for Engineering Education Annual Conference & Exposition*, Session 3233

[4] Shy-Shenq P. Liou, Hans Soelaeman, Peter Leung, James Kang, “A Distance Learning Power Electronics Laboratory,” *Proceedings of the 1998 American Society for Engineering Education Annual Conference & Exposition*, Sessions 1526 and 2526

[5] “Water tower getting new life with offices, microturbines” *Milwaukee Journal Sentinel*, December 22, 2002 http://www.jsonline.com/news/metro/dec02/105196.asp

[6] URL: http://www.yokogawa.com/tm/Bu/WT1600, WT1600 Digital Power Meter

[7] URL: http://www.ab.com/PEMS/products.html, power, power quality, power monitoring, energy management, power meter, utility management - PEMS

Biographies

GLENN WRATE of the Milwaukee School of Engineering is a Co-Principle Investigator for this project. Dr. Wrate is an Associate Professor and the Director of the Master of Science in Engineering Program. He graduated with a Doctorate of Philosophy in Electrical Engineering from the Michigan Technological University in 1996. He is a license Professional Engineer in the State of California.

MICHAEL SWEDISH of the Milwaukee School of Engineering is a Co-Principle Investigator for this project. Professor Swedish is an Associate Professor and Chair of the Energy Committee in the Mechanical Engineering Department. He graduated in 1979 with a Masters Degree in Mechanical Engineering from Marquette University. He is a licensed Professional Engineer in the State of Wisconsin.

FREDERIK BETZ, a mechanical engineering student at the Milwaukee School of Engineering is involved in the programming of the data transmission software supplied by Engage Networks, and the calculations for determining the efficiency and thermal values governing the cogeneration system.

JUSTIN REESE, a mechanical engineering student at the Milwaukee School of Engineering is involved in specifying of mechanical instrumentation and the calculations for determining the efficiency and thermal values governing the cogeneration system.

CHAD WEIS, an electrical engineering student at the Milwaukee School of Engineering, is involved in instrumentation and monitoring of the electric power signal at different stages.

LEE GREGUSKE, Manager of Technology for Focus on Energy. He is the contract administrator for the project. Lee gave us all the money!!!