ENERGY-SAVINGS SYSTEMS FOR COMMERCIAL BUILDING CHP AND INDUSTRIAL WASTE HEAT APPLICATIONS

Timothy C. Wagner
United Technologies Research Center

EDITOR'S NOTE
The following article includes more content of a commercial nature than the editor would normally prefer. However, as editor, I decided the technical content may still be of interest to the readers.

ABSTRACT

Electricity in the United States is typically obtained from "the grid," a collection of central power plants and transmission and distribution networks. Because of inefficiencies in generation and distribution, only 1/3 of the energy input to U.S. power plants reaches the end customer. Systems employing thermally activated technologies (TATs) can provide significantly higher efficiencies by integrating TAT equipment with either on-site power generation or available waste heat sources. In this article, two alternatives to central power plant generation will be described and operational experience with the systems will be presented.

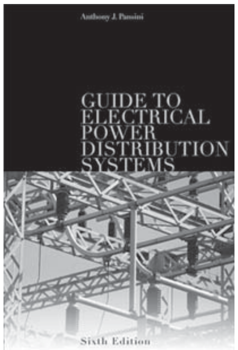
INTRODUCTION

On-site electrical power generation, termed distributed generation or DG, has been receiving much attention as a result of several factors, including reliability issues with grid-supplied electricity, power outages caused by severe weather, poor power quality, and the economic impact

Covers the impact of distributed generation on power distribution systems…

GUIDE TO ELECTRICAL POWER DISTRIBUTION SYSTEMS

BRAND NEW EDITION



SIXTH EDITION
By Anthony J. Pansini

Written by a highly regarded power industry expert, this comprehensive manual covers in full detail all aspects of electric power distribution systems, both as they exist today and as they are evolving toward the future. A new chapter examines the impact of the emergence of cogeneration and distributed generation on the power distribution network. Topics include an overview of the process of electricity transmission and distribution, a thorough discussion of each component of the system – conductor supports, insulators and conductors, line equipment, substations, distribution circuits and more – as well as both overhead and underground construction considerations. Improvements in both materials and methods of power distribution are also explored, including the trend toward gradual replacement of heavier porcelain insulators with lighter polymer ones. The complex aspects of electric power distribution are explained in easy-to-understand, non-technical language.

ISBN: 0-88173-505-1

ORDER CODE: 0542

6 x 9, 265 pp., Illus.
Hardcover, $92.00

CONTENTS

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Guide to Electrical Power Distribution Systems, Sixth Edition	**0542**	**$92.00**	

② Indicate shipping address: **CODE: Journal 2004**

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order)

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

Applicable Discount	
Georgia Residents add 6% Sales Tax	
Shipping Fees	**9.00**
TOTAL	

MEMBER DISCOUNTS
A 15% discount is allowed to AEE members.
☐ AEE Member (Member No.______________________)

③ Select method of payment:
☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

CARD NO.

Expiration date *Signature*

Make check payable in U.S. funds to:
AEE ENERGY BOOKS

√

Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

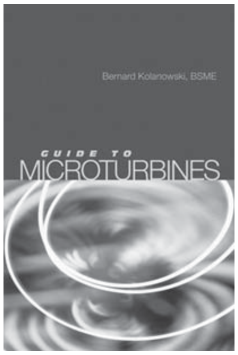
INTERNET ORDERING
www.aeecenter.org

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

Get the facts on important new developments in microturbine technologies…



GUIDE TO MICROTURBINES

NEW

By Bernard F. Kolanowski

This book will bring you up to speed on all aspects of microturbines, covering the full scope of technologies now available, as well as where and how they are being applied, and how their increased use will impact the electric power industry in the years ahead. The first section examines how microturbines work, their use for power production, fuel variations, environmental advantages, and how they are connected with utility systems. The second section focuses on applications and case histories, examining use of microturbines for distributed generation, cogeneration, waste fuels, peak saving, and cooling applications. Also covered are permitting, project financing, and available government resources, and what the future holds.

ISBN: 0-88173-418-7

ORDER CODE: 0518

6 x 9, 236 pp., Illus.
Hardcover, $98.00

CONTENTS

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Guide to Microturbines	**0518**	**$98.00**	

② Indicate shipping address:

CODE: Journal 2004

Applicable Discount	
Georgia Residents add 6% Sales Tax	
Shipping Fees	**9.00**
TOTAL	

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order)

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

MEMBER DISCOUNTS
A 15% discount is allowed to AEE members.
☐ AEE Member (Member No.______________________)

③ Select method of payment:
☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

CARD NO.

Expiration date *Signature*

Make check payable in U.S. funds to:
AEE ENERGY BOOKS

√ Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

of rising energy costs. The key to achieve economical application of distributed generation is to either (a) use the thermal exhaust energy created by the prime mover, or (b) recycle available waste heat to drive a thermally activated technology (TAT) device that delivers a second energy stream valued by the customer. In addition to economic benefits, these systems have the potential to achieve higher fuel utilization than central power plants, thereby reducing fossil fuel use and air pollution. These approaches have been identified as an important part of the U.S. energy strategy for accomplishing critical energy and environmental goals [1]. U.S. building sector market potential for cogeneration or combined heat and power (CHP) has been estimated to be at least 17 GW in 2010 and 35 GW by 2020 [2, 3].

In this article, two recently developed energy-saving products will be described and operational experience with the systems will be presented. The first product is a family of cooling, heating and power systems that is the first to integrate microturbines and a double effect absorption chiller in a pre-engineered solution. The second is a bottoming cycle designed to utilize waste heat to produce electricity. The novel feature of this Rankine cycle device is that the components are derived from commercially available refrigeration equipment. Both systems provide energy-efficient, on-site power for commercial and industrial applications.

CHP SYSTEM

The integrated CHP systems of interest in this article consist of four, five or six natural-gas-fired microturbines, a double effect absorption chiller/heater, a diverter valve and two or three fuel gas boosters. The systems, known as the PureComfort™ 240M, 300M and 360M, are pictured in Figures 1-3. These modular, pre-engineered products provide energy-saving, reliable solutions for building cooling, heating and power needs. Because the microturbine exhaust is collected in a manifold and used to directly drive the double effect absorption chiller, the system fuel utilization exceeds 70%.

The PureComfort™ systems are designed to operate in three modes: Power Only mode, Power/Cooling mode and Power/Heating mode. In Power Only mode the microturbines generate electricity, the exhaust is vented to atmosphere, and the chiller/heater is not used. In

Figure 1. PureComfort™ 240M

Figure 2. PureComfort™ 300M

Figure 3. PureComfort™ 360M

the Power/Cooling mode, the microturbines produce electricity and the exhaust is used to power the chiller, which provides chilled water that can be used for air conditioning. In Power/Heating mode the microturbines generate electricity and the waste heat driven chiller provides hot water for space heating. The performance specifications of these three systems are summarized in Table 1.

Table 1. PureComfort™ Performance

System	240M	300M	360M
Gross/Net Electric Power [kW$_e$]	**59°F:**	**59°F:**	**59°F:**
	240/229	300/287	360/345
	96°F:	**96°F:**	**96°F:**
	213/202	265/252	316/301
	32°F:	**32°F:**	**32°F:**
	240/229	300/287	360/345
Cooling Power [kW$_c$/RT]	**95°F:**	**96°F:**	**95°F:**
	420/120	490/140	543/155
	59°F:	**69°F:**	**59°F:**
	585/167	676/193	753/215
Heating Power [kW$_t$/MBH]	**32°F:**	**32°F:**	**32°F:**
	295/1005	358/1222	420/1432
	69°F:	**59°F:**	**59°F:**
	339/1155	412/1405	483/1647

Each microturbine in the PureComfort™ systems generates 60 kW of electric power. The microturbine includes a turbine engine, solid-state power electronics, a fuel system, and an indoor/outdoor-rated enclosure. The engine, shown in Figure 4, is a single shaft design with a radial compressor and a radial turbine. The engine utilizes a recuperator to preheat the combustion air for improved electrical efficiency. The engine drives a permanent magnet generator at speeds up to 96,000 rpm at full load. The high-frequency alternating current output from the generator is converted to three-phase alternating current by insulated gate bipolar transistors (IGBTs) in a solid-state power electronics module located inside the microturbine enclosure.

The chiller/heater, pictured in Figure 5, was derived with minor modification from a commercially available direct fired, double effect

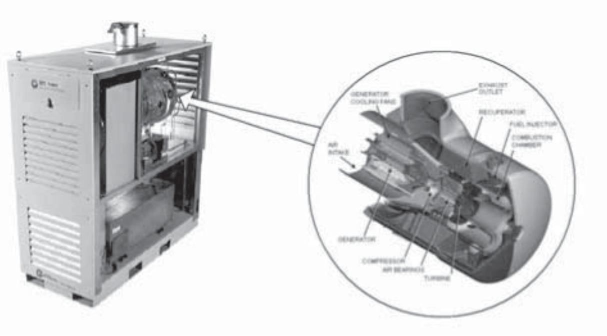


Figure 4. 60 kW Microturbine.

Figure 5. Waste heat driven absorption chiller.

lithium bromide-water absorption machine. The chiller/heater includes an evaporator, absorber, condenser, high-temperature and low-temperature generators, solution heat exchangers, refrigerant and solution pumps, purge system, controls and auxiliaries. The exhaust flow to the chiller is regulated by a diverter valve located in the ducting between the microturbine exhaust manifold and the chiller. The position of the control valve is commanded by the chiller controller to maintain the chilled water temperature set point. Any exhaust not required to drive the chiller is vented through a bypass. When the chiller is not being used, an air seal blower located in the diverter valve provides a pressurized air seal to prevent hot exhaust gas from entering the chiller.

The chiller/heater operates on a typical lithium bromide-water double effect absorption cycle, in which water at low absolute pressure (vacuum) is the refrigerant. The chilling effect is created by boiling the water at approximately 5.7°C (42.3°F). To make the process continuous, the refrigerant (water) must be removed as it vaporizes in the evaporator. This is accomplished by using a lithium bromide solution (which has a high affinity for water) to absorb the water vapor. As this process continues, the lithium bromide becomes diluted, reducing its absorption capability. A solution pump then transfers the weak (diluted) solution to the generators where it is re-concentrated in two stages (double effect) to boil off the previously absorbed water. A variable frequency drive on the solution pump automatically maintains optimum solution flow to the generators at all operating conditions for maximum efficiency. The diluted solution is pumped to the high-temperature generator where it is heated and re-concentrated to a medium concentration solution by the heat from the microturbine exhaust.

The chiller/heater can also be used to provide hot water for space heating to reduce or eliminate dependency on existing or supplemental boilers. When operated as a heater, hot water temperatures of 60°C (140°F) are standard. In this mode the cycle follows a different vapor flow path than that undertaken for cooling and does not use the absorption process. All heat rejection from the machine is designed to take place through the evaporator (now the heating bundle) in a classic two-pipe system that utilizes only the evaporator nozzles. Changeover from cooling to heating requires switching the positions of two hand valves, draining the absorber-condenser water circuit and selecting the heating mode at the control panel. The chiller/heater also has an option to deliver hot water at 79.4°C (175°F). In this case, a factory-installed auxiliary heat exchanger is added to the chiller allowing 4-pipe operation at higher water temperatures than can be provided through the evaporator circuit. The PureComfort™ 240M, 300M and 360M are modular, pre-engineered solutions. The advanced digital electronics of the microturbines provide clean power that is in compliance with IEEE-519. Mechanical reliability is inherent in the system based on the low number of moving parts: the microturbine is a single shaft design that utilizes air bearings, and the chiller utilizes two hermetic refrigerant pumps. The PureComfort™ family of integrated CHP systems is environmentally friendly, with ultra-low NO_x at full power. The chiller/heater utilizes water as the refrigerant, thus avoiding the use of substances that lead to global warming or depletion of the ozone layer. Furthermore, with an overall fuel utilization in excess of 70%, the system produces significantly lower emissions than traditional systems utilizing the grid and electric chillers. The system is designed for low noise and vibration, making possible application to commercial buildings without requiring costly sound attenuation or vibration considerations. The ability of the system to provide electricity and utilize the waste heat for cooling and heating provides the opportunity to reduce energy consumption, which has the potential for significant savings in energy costs in many markets. Finally, the system is designed to be remotely monitored.

The PureComfort™ systems are well-suited for commercial building applications. Typical vertical segments include:

- Hospitals
- Hotels
- Large office buildings
- Supermarkets
- Educational/institutional buildings

The PureComfort™ 240M integrated system has been tested in all 3 modes of operation [4]. The product was introduced in December 2003, and to date several units have been ordered and are being shipped to customer sites for installation. In July 2004 the chiller/heater performance of the PureComfort™ 240M was enhanced and the PureComfort™ 300M and 360M were introduced.

RANKINE CYCLE WASTE HEAT RECOVERY

The second energy-saving system of interest is based on the Rankine cycle. The system, shown in Figure 6, is known as the PureCycle™ 200, a product which recycles waste heat into electricity. This product generates 200 kW of net electric power under ISO conditions (59°F, sea level) provided sufficient waste heat is available. The waste heat can be from any number of different sources including various industrial processes, reciprocating engines, industrial gas turbines and landfill flares. The system has four major components: a pump, an evaporator/boiler, a turbine/generator, and a condenser. The PureCycle™ 200 is unique in that the components were derived from existing refrigeration equipment.

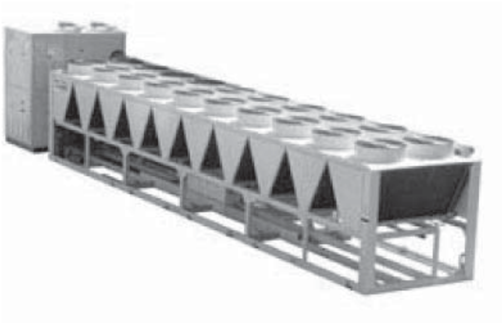


Figure 6. PureCycle™ 200

This derivation is possible because the vapor compression cycle used by refrigeration equipment is similar to the Rankine cycle operating in reverse.

A comparison of the Rankine and vapor compression cycles is presented in Figure 7. In the Rankine cycle, waste heat enters the evaporator and heats the working fluid until it is vaporized. Hot vapor then drives a turbine to create electrical power. The expanded vapor goes into the condenser where it condenses back into a liquid as it cools. The cooled liquid is pumped back into the evaporator to repeat this process. This closed-cycle process is called the Rankine cycle. In the vapor compression cycle, energy in the form of heat is absorbed in the evaporator. The compressor does work on the fluid to raise the pressure so that energy can be rejected in the condenser. The pressure of the working fluid is dropped as the fluid flows through an expansion valve and the cycle is repeated. The vapor compression system can be transformed into a Rankine cycle by replacing the expansion valve with a pump and by running the compressor backwards as a turbine. This similarity permits use of well-known refrigeration technology as the basis for PureCycle™ 200 component design.

One key feature of the Rankine cycle device described in this article is that the turbine is derived from an existing production centrifugal refrigeration compressor. A centrifugal compressor used in typical HVAC chillers is shown in Figure 8. Refrigerant vapor enters the compressor through a set of inlet guide vanes used for capacity control. The compression work is done in the impeller, causing an increase in both the static pressure and absolute velocity. A pipe diffuser is used at the exit of the impeller to recover additional static pressure from the kinetic energy of the high velocity vapor leaving the impeller. The flow leaving the

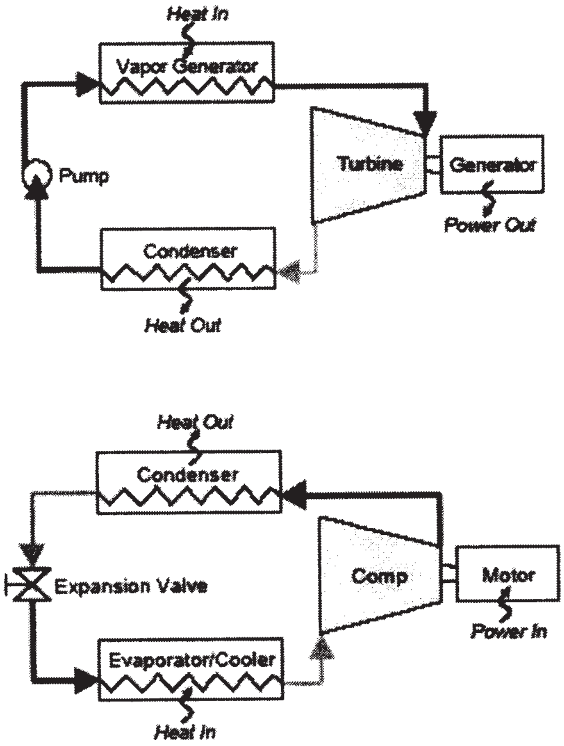


Figure 7. Comparison of Rankine cycle and vapor compression cycle.

diffuser enters the discharge collector before exiting the compressor. This compressor has state-of-the-art aerodynamic efficiency using a discrete passage diffuser (pipe diffuser) with variable geometry features, an impeller with controlled internal diffusion blading, and a large exit plenum. The high-speed impeller is connected through a step-up gear to a hermetic, refrigerant cooled two pole induction motor. An oil pump provides lubrication for the bearings and gears. These features allow the compressor to operate in reverse as a turbine.

In addition to the turbine, the PureCycle™ 200 condenser and evaporator designs are also based on mass-produced HVAC equipment. The condenser design is based on a typical air-cooled condenser with minor modifications to the header design and the internal circuiting. The design of the evaporator (boiler) is based on the generator design used in direct-fired absorption chillers. Additional information on the application of refrigeration hardware to power cycles may be found in Reference 5.

Because the PureCycle™ 200 power system uses waste heat as free fuel to generate electricity, there are no costs associated with running the

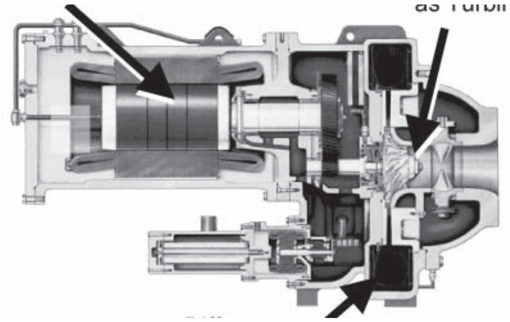


Figure 8. Compressor/turbine cutaway.

system other than for extremely low maintenance requirements. No fuel is burned and no emissions are produced. The U.S. DOE estimates that 4.3 quadrillion Btu's of waste heat energy are lost annually from industrial processes and equipment [1], including:

- Industrial processes and stacks
- Reciprocating engines
- Industrial gas turbines
- Thermal oxidizers
- Flares
- Incinerators

In addition to extensive prototype testing, full scale test and validation of the PureCycle™ 200 has been accomplished with three field trial units. One unit, shown in Figure 9, was powered by the exhaust of three reciprocating engines. A second field trial unit, shown in Figure 10, recovered waste heat from a landfill flare. A third field trial unit, shown in Figure 11, was driven by a burner. Several thousand hours of field trial operation have been completed. The PureCycle™ 200 product is scheduled for commercial launch in third quarter 2004.

CONCLUSIONS

Two energy-efficient systems for on-site power generation have been developed and commercialized. One system is the first integration of four microturbines and a double effect absorption chiller. The system

Figure 9. PureCycle™ field trial with landfill flare.

Figure 10. PureCycle™ field trial with reciprocating engines.

was shown to achieve an overall fuel utilization that is double what is achieved by the "grid." The second system presented was a Rankine cycle system, the components of which were derived from existing refrigeration components. These systems offer energy-saving alternatives to central power plant generation for commercial and industrial applications.

References

1. Thermally Activated Technology Roadmap, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, May 2003

2. Integrated Energy Systems (IES) for Buildings: A Market Assessment; Final Report; Resource Dynamics Corporation for Oak Ridge National Laboratory, Oak Ridge, TN, August 2002.

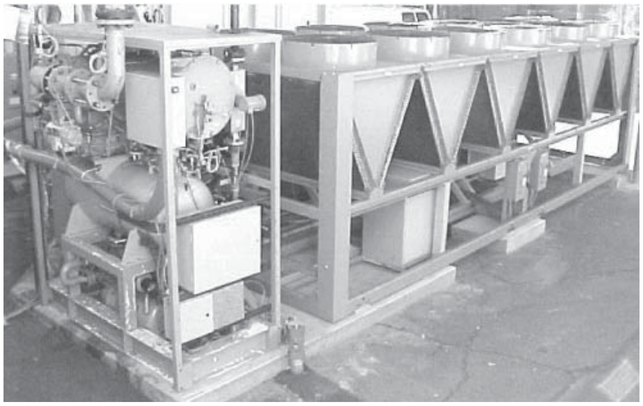


Figure 11. PureCycle™ field trial unit.

3. The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector, Report prepared by ONSITE SYCOM Energy Corporation for U.S. Department of Energy, January 2000.

4. Wagner, T.C., Marler, M.M., and Jung, S., Performance Characteristics of a Microturbine-Double Effect Absorption Chiller CHP System, submitted for publication at ASME 2004 IMECE.

5. Brasz, J.J. and Biederman, B.P., Low Temperature Waste Heat Power Recovery Using Refrigeration Equipment, ICR0587, presented at the 21st IIR International Congress of Refrigeration, August, 2003.

ABOUT THE AUTHOR

Dr. Tim Wagner is a project leader in the CHP Program Office at United Technologies Research Center (UTRC). Dr. Wagner is currently leading the development of integrated cooling, heating and power systems that couple microturbines and thermally activated technologies (TAT). During his 17 years at UTRC, Dr. Wagner has led or contributed to numerous projects in the fields of thermodynamics and heat transfer. He holds several issued or pending patents. In addition to his position at UTRC, Dr. Wagner is an adjunct associate professor of mechanical engineering at Rensselaer at Hartford, where he has been an advisor for over 30 master's seminar projects. Dr. Wagner holds a B.S., M.S. and Ph.D. in mechanical engineering from Virginia Tech. During his doctoral program he was a NASA Fellow at NASA Langley Research Center in Hampton, Virginia. Dr. Wagner is an Associate Fellow of AIAA and a member of ASHRAE and ASME. He may be contacted at wagnertc@utrc.utc.com