Microturbines

Technology and End-Use PQ Application Issues

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ABSTRACT

Distributed Generation (DG) is predicted to play an increasing role in the electric power system of the near future. One of the recent developments in DG technologies has been the advent of microturbines. Microturbines are small (typically 15–300 kW), high-speed generator power plants that can operate on a variety of fuels including natural gas, diesel, gasoline, propane, kerosene, or other similar high-energy fossil fuels. Microturbines are also well suited to operate on lower grade (lower energy) fuels such as methane-based gas produced from biomass or landfill refuse.

The objective of this technology review document is to assess microturbine vendor and technology profiles and to characterize the end-use power quality issues related to microturbine applications. Toward this objective, specific end-use power quality issues were reviewed to include dynamic load response, motor-starting capability, and impact of increased source impedance in a stand-alone mode of operation. The application of microturbines for power quality improvement will require technology advancement from the current generation. This will require the power electronics to withstand the inrush current requirement for motor-start applications and increasing the dynamic response capability of these machines using localized energy storage.

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1
MICROTURBINE TECHNOLOGY

Microturbines currently are being developed into what may become a favorable power generation alternative for distributed, remote, and co-generation as well as end-use facility applications. For these applications, traditional utility-type gas-turbine generators are too large. Microturbines are small (typically 15–300 kW), high-speed generator power plants that can operate on a variety of fuels including natural gas, diesel, gasoline, propane, kerosene, or other similar high-energy fossil fuels. Microturbines are also well suited to operate on lower grade (lower energy) fuels such as methane-based gas produced from biomass or landfill refuse.

Though microturbines and utility gas-turbine generators work on the same thermodynamic principles, the size difference causes them to differ markedly in their designs, their operating characteristics (particularly rotational speed and ability to react to system disturbances), and the types of electric generators they use.[1] Figure 1-1 highlights the internal components of a sample microturbine including the compressor, combustion chamber, turbine, air bearings, and the generator.[2] Power to spin the turbine and to rotate the dc electric generator is produced by the combustion of the fuel at high pressure. The generator rotation speed varies depending on the power requirements. The energy created is converted to grid quality 50/60 Hz by power electronics and controllers that also provide the controls, protection, and communications for the microturbine engine. The generator also operates as a starter motor using battery power to bring the turbine up to speed to begin operation thus eliminating the need for a separate starter and simplifying the design.[1] The recuperator uses the heat from the turbine exhaust to pre-heat the intake air to keep the internal temperature high thus increasing the efficiency of operation.

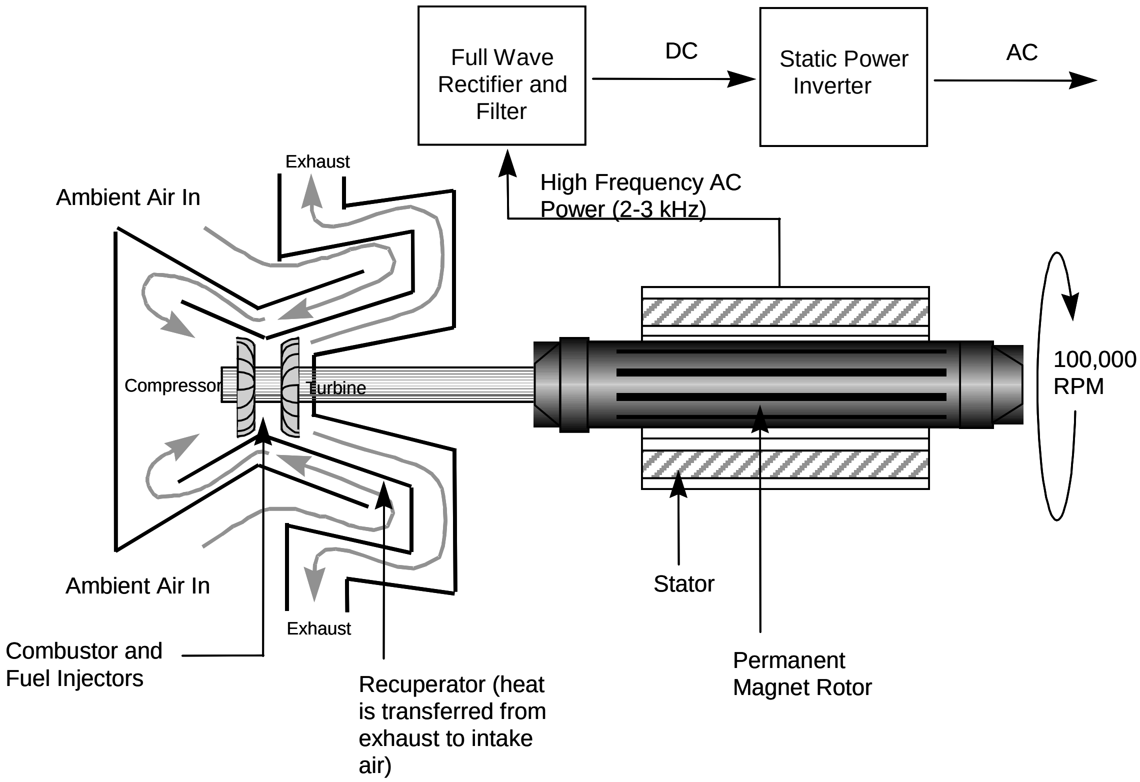

Figure 1-1
Microturbine showing permanent-magnet, single-shaft rotor design[2]

Since the air compressor, turbine, and generator are mounted on a single shaft and spin at the same rate, there is no gearbox and only one moving part. With air bearings, there is no need for lubricating oil and virtually no wear on the major components of the system. While the single-shaft design used in microturbines may not be the most efficient design possible, it is simple, robust, and easy to maintain.[1]

Application Areas

Table 1-1 presents potential application areas. Originally, the turbines used in these units were designed mostly for commercial applications such as to power aircraft generators, small helicopters, buses, trucks, etc.[1] Currently, most microturbine generators are aimed at distributed generation and end-use, customer-site applications as opposed to units made for utility system installation. Most current experience is with grid-parallel connected units.

Table 1-1
Microturbine Application Areas

Application Areas
Distributed Generation Additional capacity Peak shaving Power quality and reliability (if it can support the local load in stand-alone mode)
Facility End-Use Additional capacity Standby with an energy storage system (back-up UPS) Power quality and reliability Primary power--Industrial, Commercial, Residential
Co-Generation (combining need for electricity and thermal energy) Heating Cooling Process drying and baking Supplementing boiler combustion air
Remote Generation Off-grid locations Construction sites Marine applications Developing countries
Transportation Small helicopters Buses and trucks Hybrid electric vehicles
Resource Recovery Utilization of bio-gas from landfills Utilization of unprocessed oil/gas that is otherwise flared

Table 1-2 shows a comparison of the average performance of microturbines with other small distributed generation systems including fuel cells, photovoltaic, and wind turbines. This table was constructed based on manufacturer's data and projections, technical journals, laboratory research, and on-site inspection and measurement of prototype and production-distributed generation units.[1] In this table, "Initial Cost ($/kW)" refers to complete installed cost. "Efficiency (%)" represents the net fuel-to-AC power efficiency that will be achieved in typical types of service. "Availability (%)" depicts the percent of time the unit can be expected to be available to produce power. "Lifetime (years)" projects the overall service lifetime of the equipment. "Cost (¢/kWh)" gives the projected overall cost for base load.

Table 1-2
Comparison of Small Distributed Generation Systems for 2002 Installations

Generation System	Typical Size (KW)	Initial Cost ($/kW)	Efficiency (%)	Availability (%)	Life (Years)	Cost (¢/kWh)
Microturbine	110	500	36	98	18	7.9
Fuel Cell	100	900	37	96	10	8.2
Photovoltaic Tracking	50	2,200	16	97	12	12.0
Wind	500	1,750	20	96	20	10.5

Much of the current interest in microturbines stems from the potential that improved designs may provide electrical services at costs comparable to the higher end of common electric utility prices. The advantages are seen to be:[1]

- Durability and low maintenance. Many are rated at 25,000 hours (nearly 3 years) between failures or maintenance intervals with some design goals of 98% availability. This matches the "fix-it-and-forget-it" desires for small business and residential markets.
- Simple design with a high potential for inexpensive, high-volume manufacturing.
- Compact, vibration-free, easy to install and repair.
- Low emissions. NO_x emissions from microturbines are approximately 0.2 lb/MWh without catalytic processing. In contrast, U.S. fossil fuel generation of power averages 5.8 lb/MWh, more than 10 times that of microturbines.
- Fuel flexibility. Microturbines can run on a variety of fuels including natural gas, diesel, gasoline, propane, kerosene, or other similar high-energy fossil fuels. Microturbines are also well suited to operate on lower grade (lower energy) fuels thus can cleanly burn "waste" gases that would otherwise be vented or flared at oil fields, landfills, and sewage treatment plants.

The disadvantages are seen to be:

- Not the quietest of the distributed generation options. Microturbines require considerable muffling that reduces output and fuel efficiency.
- Fuel efficiency is rather low compared to other distributed generation types.
- Most units are still in a developmental stage.

- Energy production from available equipment is still quite small and requires several units operating in parallel.
- True dynamic performance is being evaluated.
- Operation is more suited to providing base load because the power electronic output stage does not provide any surge rating.

End-Use Power Quality Application Issues

A common belief is that DG technologies, including microturbines, will improve the local power quality. This potential for better quality is cited as one of the valuable attributes of installing distributed generators. This stems from the belief that DG technologies can support the local load thereby preventing power quality anomalies that may affect the load from the distribution grid. However, the reality is somewhat different.

One critical item that is not taken into account when assessing the potential power quality benefits of distributed generation is the difference in source impedance of DG technologies compared to the grid when operating in a stand-alone mode. This difference in the source impedance, as well as the slow response during dynamic load change, has the potential to impact end-use power quality negatively. Following are some issues regarding end-use power quality that need to be assessed carefully for microturbine application:

- **Transient Response:** Microturbines have a noticeable transient response to rapid changes in demand, that is, a delay as they accelerate and decelerate the output to “catch up” to instantaneous shifts in demand.[1] The power electronic units currently in use do not have the energy storage or the filtering capability needed to deal with large instantaneous shifts in demand.[1] For example, one particular small microturbine generator requires about a second to react when the demand shifts from 3kW to 8kW. This is a fairly good response for very small units. Such a 5kW shift occurs many times a day in many end-use applications, e.g., when an electric water heater switches from “off” to “on.” The result for this microturbine generator is a momentary drop in voltage lasting about a second with each demand shift as the microturbine adjusts to the higher load level. That transient can drop the bus voltage to a point outside the CBEMA curve where many computer-type loads will cease operation and need to be reset. A similar voltage surge will occur when major loads switch off. Because many large appliances in end-use facilities switch on and off several times a day, this level of transient voltage variation could prove unacceptable in many applications.
- **Motor Start:** When the microturbine is disconnected from the grid and is supporting local load within a customer facility, the ability to handle motor-start inrush current is reduced significantly. The largest size motor that can be started by a microturbine in stand-alone mode will be limited to approximately 15-20% of the rated capacity of the microturbine. While operating in a grid-connected mode, this is not an issue since the grid provides the necessary source stiffness to handle the inrush current of motor loads.
- **Voltage Distortion:** When operating from the grid supply, voltage distortion within a customer facility depends on the background voltage distortion, nonlinear load current within the facility, and the source impedance. Since the source impedance of a microturbine can be an order of magnitude higher than the utility supply, the voltage distortion during stand-alone

mode can be much higher, especially if there are significant nonlinear loads within the customer facility.

PQ Issues Related to Utility Interconnection[2]

In most applications, the microturbine will be connected to the grid and will operate in parallel with the utility source. Extensive research has been conducted to assess the potential issues related to utility interconnection of distributed generation. An in-depth analysis of these issues is beyond the scope of this document. Reference 2 provides a summary of utility interconnection issues and the impact of DG in general on distribution systems. These issues can be summarized as follow:

Impact of Microturbines on Voltage Regulation

Voltage regulation practice in distribution systems is based on radial power flows from the substation to the loads. DG introduces "meshed" power flows into the distribution system that may interfere with the upstream voltage regulators or line drop compensators (LDCs). In essentially all cases, the impact on the feeder primary will be negligible for any individual microturbine DG unit. However, when the aggregate capacity of the deployment of many small units reaches a critical threshold, or when the capacity of a single unit is large enough, voltage regulation studies are desirable to insure that the feeder voltage will be maintained within appropriate limits.

Impact of Microturbines on Short-Circuit Levels and Coordination

The fault current contribution from a single, small microturbine unit is not large. However, the aggregate contributions of many small units or a few large units can alter the short-circuit levels enough to cause a lack of coordination between the fuse and the breaker. For inverters, the fault contributions will depend on the maximum current level and the duration at which the inverter's current limiter is set to respond. On some inverters, fault contributions may last for less than a cycle; in other cases, it can be much longer.

When a single generator is added to the system, a manual calculation of the peak fault currents (based on manufacturer's data) can be performed to screen for a serious impact on the existing short-circuit levels. For multiple generation devices scattered throughout the system, or for large generators, the only accurate approach is to perform a software-based short-circuit analysis that correctly models the short-circuit behavior of the generators. In many cases, the DG units will not pose a threat to existing coordination; only a relatively few cases may require changes in protection settings.

Grounding and Transformer Interface

The microturbine must be applied with a transformer configuration and grounding arrangement compatible with the utility system to which it is to be connected. Otherwise, voltage swells and overvoltages that damage utility or customer equipment may be imposed on the utility system.

Proper review of the facility grounding characteristics and the utility system design prior to installation of the microturbine unit can ensure that grounding compatibility problems are dealt with appropriately. Grounding compatibility is crucial to ensure that power quality and reliability are not degraded by the addition of the microturbine units. Table 1-3 shows some transformer arrangements for DG sites and the issues related to these transformer arrangements.

Table 1-3
Some transformer arrangements used for DG sites

Transformer Configuration (high side/low side)	Comments
Delta/Wye-grounded or Delta/Delta	Neither of these will provide effective grounding unless a suitably sized primary-side grounding bank is installed adjacent to the step-up transformer.
Wye-grounded/Wye-grounded	If the generator neutral connection does not meet effective grounding requirements or is not grounded at all, then the transformer bank does not create an effectively grounded source with respect to the DG unit even though the neutral connections to the transformer are grounded on both sides.
Wye-grounded/Delta	Typically provides effective grounding regardless of generator grounding arrangement.

Islanding

Islanding occurs when the microturbine (or a group of microturbines) continues to energize a portion of the utility system that has been separated from the main utility system (see Figure 1-2). This separation could be due to operation of an upstream breaker, fuse, or automatic sectionalizing switch. Manual switching or “open” upstream conductors could also lead to islanding. Islanding can occur only if the generator(s) can self excite and sustain the load in the islanded section.

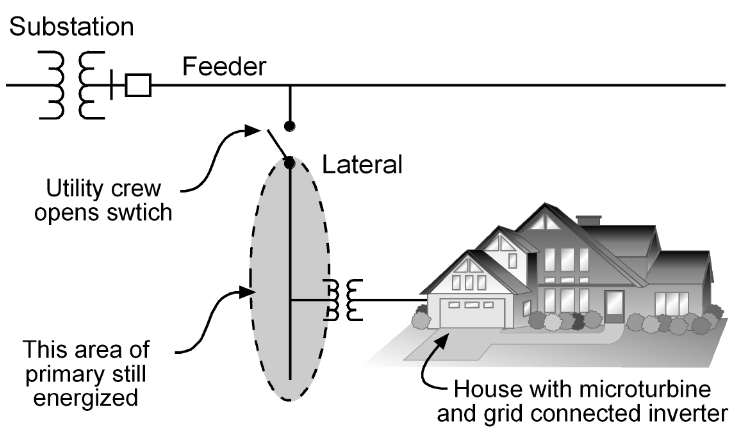

Figure 1-2
Possible Scenario for Islanding

Islanding can happen in a variety of circumstances. Proper protection must be provided to avoid islanding in all typical applications of DG. Most utilities have standards specifying the relays required to help prevent island development.

To prevent islanding, a microturbine unit operating in parallel with the utility system should quickly sense a significant voltage sag or disruption of service on the utility side and disconnect from the system. Many utilities have standards requiring that this time be about 10 cycles or less for serious feeder disturbances (deep voltage sags or interruptions).

Since islanding can cause severe voltage quality and reliability problems, the proper use and setting of anti-islanding controls is one of the more important issues for microturbine installations. For small photovoltaic inverters, IEEE standards that describe the settings and types of controls required are already available.[4] For other types of inverters and larger installations, the settings and controls required are still being defined. IEEE has a new standard under development (IEEE P1547) that will address all DG sizes and technologies. Most utilities and many state energy commissions also have standards that address the islanding issues.

Application of Stiffness Ratio for Screening Microturbine Application Issues

Because of the small size of microturbines, impact on the distribution system will be negligible for low penetration rates. This is the most likely scenario in the near future. Also, if reverse-power flow is not allowed as part of the interconnection agreement and the microturbine is used only to support the local load, the impact on the distribution system will be negligible. When assessing the impact of microturbines on the distribution system, one of the key criteria is to calculate the relative size of the microturbine with respect to the utility source strength. The term "Stiffness Ratio" is used often as a criteria to quantify the impact of distributed generation on the distribution system. Stiffness ratio is defined as:

Stiffness Ratio

$$S_{tf} = \frac{SCkVA(AreaEPS) + SCkVA(DG)}{SCkVA(DG)}$$

Where: S_{tf} = Stiffness ratio

[Note: The stiffness ratio is calculated at the Point of Common Coupling (PCC) except when there is a transformer(s) dedicated to one customer in which case the stiffness ratio is calculated on the high-voltage side of the dedicated transformer(s).]

SC kVA (Area EPS) = the short circuit contribution in kVA of the area Electric Power System (EPS), and

SC kVA (DG) = the short circuit contribution in kVA of the DG.

The short circuit (SC) contribution of microturbine will depend on the inverter characteristics and the control set points. Typically, inverter contribution to fault current can range from 100% to 400% of rated inverter current. In some cases, the inverter contribution to fault current may be even less than 100% of rated current. Figure 1-3 shows the possible ranges of inverter fault current. In all practical purposes, the stiffness ratio for microturbine applications will be greater than 100 unless the utility source is very weak. For example, on a typical 12 kV line, fault currents ranges from 12,500 amps near the source substation to 1,250 amps at the end of the line. If a 75 kW microturbine is installed at the end of the line, the fault level from the utility source will be 25,980 kVA_{sc}. The fault contribution from the microturbine will be in the range of 75

kVA_{sc} to 300 kVA_{sc} (assuming a fault current contribution ranging from 100% to 400% of rated current). This results in a stiffness ratio in the range of 87 to 346. Application of microturbines with a stiffness ratio in this range and without reverse-power flow capability will have very little impact on the distribution grid.

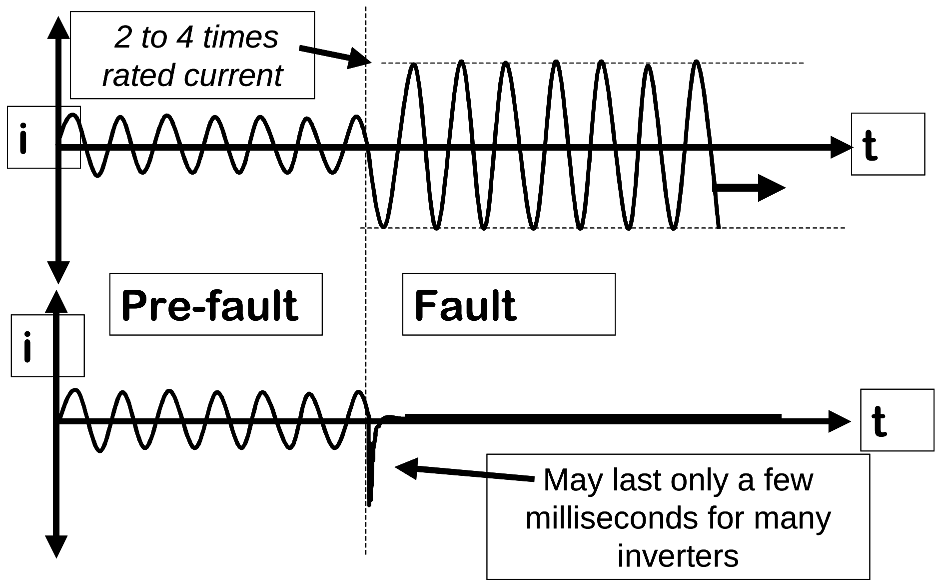

Figure 1-3
Characteristics of Inverter Fault Current

However, if the penetration rate of the microturbines increases or if they are connected to a weak utility source on the distribution system, the fault current contribution for these DG sources can interfere with utility protection systems.

Energy Storage

When utility interconnection is not a viable alternative because there are no utility facilities nearby, or the utility's interconnection tariffs are too costly to justify the interconnection, or the microturbines are being used as standby systems, energy storage techniques can be applied. The microturbine can be connected to a battery or flywheel system that meets the instantaneous dynamic load demands causing the energy storage devices to be charged by the microturbine during low load. For standby systems, the transfer from the parallel grid connection to the sole reliance on the microturbines can go smoother with energy storage included in the system.

Microturbine Manufacturers and Available Products

Several commercial microturbine products are available.

Table 1-4 provides a list of manufacturers, their products, and Web site information.

Table 1-4
Manufacturer Information

Manufacturer	Location Web Site: www.	Product	Ratings
Allied Signal (now merged with Honeywell)	Albuquerque, NM **parallon75.com**	Parallon 75® turbogenerator	75 kW
Capstone Turbine Corporation	Tarzana, CA **capstoneturbine.com**	Micro-Turbine™	30 kW; can be combined up to 300 kW
Caterpillar Solar Turbines	San Diego, CA **cat.com**	Saturn®	1 MW
Northern Research and Engineering Corp. (NREC) (Ingersoll-Rand [IR])	Woburn, MA **nrec.com or ingersollrand.com/ energysystems**	PowerWorks™	30, 70, 250 kW
Rolls-Royce Corporation (was Allison/GM)	*Indianapolis, IN* **www.rolls-royce.com**	MicroTurbine™	20 – 270$^+$ kW

Allied Signal (now merged with Honeywell)

Honeywell Power Systems, Inc., is the developer and manufacturer of the Parallon 75® turbogenerator. The Parallon 75® is a compact, self-contained unit that uses a microturbine to convert natural gas or other fuels, including alternative fuels like flare gas and landfill gas, into electricity for on-site power generation. The Parallon 75® is automatic and operates unattended. All operations, including start-up, synchronization with the grid, dispatch, and shutdown, are automatic. The system is designed with "plug-and-play" technology. To install the Parallon 75®, a gas line is connected to the unit and the unit is connected to the main circuit breaker in the building. The specifications for one of the units are given in Table 1-5.

Example installations of the Parallon 75® turbogenerator include McDonald's restaurant in Bensenville, Illinois; Heinemann's Bakery in Chicago, Illinois; and Stevens Institute of Technology in Hoboken, New Jersey. In addition, it has been demonstrated successfully in parallel to the ESKOM utility grid (the first microturbine to connect with the utility grid in South Africa).

Table 1-5
Parallon 75® Turbogenerator Specifications

Maximum Power at ISO Conditions *(59° Fand sea level)*	75 kW continuous rating
Thermal to Electrical Efficiency (including auxiliaries, less gas pump)	30% target, 28.5% target, 27% guaranteed minimum at maximum power, ISO conditions at minimum heat content of 19,500 BTU/LBM/LHV
Voltage Output	Options for 120/208, 120/240, 230/400, 240/415, 277/480, 360/600 all 3-phase or 4-wire (with optional transformer), 50 to 60 Hz. Single-phase operation must be balanced within 10%.
Availability/Uptime	>95%.
Dimensions	Approximately 92" (2334 mm) L x 85" (2163 mm) H x 48" (1219 mm) W
Weight	Approximately 2850 lb (1295 kg), not including optional gas compressor, transformer, and battery
Fuel Consumption	1000cfh or 9.5 Therms per hour
Fuel Pressure	75-85 psig [optional integral gas compressor for low pressure (>7 inches) available]
Start Up	Normal start, 2.5 minutes
NO_x Emissions at 15% O_2	50 ppm standard day
Noise	65 dBa at 10 meters, low frequency
Design Life	Following the recommended maintenance program, the unit is designed to operate a minimum of 40,000 hours. The useful life of the machine under normal operating conditions is expected to be 10 years.
Warranty Service	One year from date of installation, not to exceed 18 months from purchase. Honeywell, Inc., is the authorized warranty service provider in North America.

Capstone Turbine Corporation

Capstone offers the Model 330 MicroTurbine™ (Figure 1-4), 150-480 V_{rms}, 46 A_{rms}, 30 kW, for three-phase, four-wire applications. This product can be combined in the MultiPac option up to 300 kW. Table 1-6 and Table 1-7 provide preliminary specifications and example areas of application. Of the smaller turbines, the Capstone Model 330 is the first to be truly commercial. There are now more than 100 operating in the field. The system is equipped with lead-acid battery-pack energy storage to provide cold-start capability and transient handling. The battery pack can source or sink up to 30 kW. A remote monitoring system is also available.

Figure 1-4
Capstone Model 330 MicroTurbines™ (Courtesy of Capstone Turbine Corporation)

Table 1-6
Capstone Model 330 MicroTurbine™ Preliminary Specifications

Feature	Value	Note
Output Voltage, (rms, L-L)	150 – 480 V_{rms}	87 – 277 (L-N)
Output Frequency	10 – 60 Hz	User selectable
Voltage Regulation	± 5%	Steady-state
Max Transient Current	76 A_{peak}	10 seconds
Max Continuous Current	46 A_{rms}	rms current
Max Transient Power	45 kW	480 V
Max Continuous Power	30 kW	480 V
Cold Start Time	120 Seconds	Turbine start time
Max Instantaneous Load	30 kW	After turbine start

Table 1-7
Example Capstone MicroTurbine™ Applications

Company	Location	Business	How MT Applied
Williams Company	Tulsa, OK	Large industrial energy company	In conjunction with power cell load-leveling batteries.
Sierra Pacific	Roseville, CA	Sierra Plaza shopping center	Grid connected providing base load and peak shaving.
Walgreen's	Merrillville, IN	Shopping store	Micro co-generation (developed. by Energy USA) provides power and exhaust energy, powers building air conditioning.
PanCanadian	Alberta, Canada	Oilfield operator	Provides reliable power to oilfield equipment; the otherwise flared natural gas fuels the turbines.

Capstone also offers a MultiPac option that provides for multiple microturbine systems (up to 10) to behave as a single generating source. Communication and control for all systems are accomplished through a single source.

For connection to the grid, each microturbine independently synchronizes to the grid, but the MultiPac has a single interface point for OFF, ON, and power demand control.

For stand-alone operation, the MultiPac synchronizes the voltage source outputs of the individual microturbines such that they share power and current on both a dynamic and steady-state basis. The "master" broadcasts synchronization information to the "slaves" over a dedicated, digital communications bus that is proprietary to Capstone. All units, master and slaves, share the load(s) equally.

A MultiPac system in stand-alone mode will line-start motors up to approximately n x 6.75 hp where n is the number of model 330 MicroTurbine™ in the MultiPac. Using the RampStart feature (whereby voltage and frequency may be variably ramped to nominal during initial start), a MultiPac will start motors up to approximately n x 36 hp.

Caterpillar Solar Turbines

Solar gas turbines are designed for robustness, efficiency, durability, high reliability, and availability. The design also allows for extended intervals between major inspections in demanding industrial and marine applications. The solar gas turbines operate with low levels of vibration, can be easily sound attenuated, and require minimal maintenance compared to other types of combustion engines.

Currently, the smallest gas turbine offered by Caterpillar Solar Turbines is the Saturn®. The Saturn® is rugged and compact and has over 4,800 installations. It was introduced in 1960 at which time it was among the first small industrial gas turbines in the world. The Saturn® gas turbine family has logged more than 620 million operating hours and is available in a single-shaft, constant-speed configuration for driving generators and in a two-shaft, variable-speed version for applications such as gas compression and driving pumps.

Table 1-8 and Table 1-9 give the Saturn® performance in gas compression and mechanical drive applications and in power generation applications, respectively, both at ISO conditions.

Table 1-8
Performance in Gas Compression and Mechanical Drive Applications at ISO Conditions

Name/Model	ISO Output, kW (hp) Continuous	Heat Rate, kJ/ kW-hr (Btu/ hp-hr)	Exhaust Flow, kg/ hr (lb/ hr)	Exhaust Temp, deg C (deg F)
Saturn® 20*	1185 (1590)	14 670 (10,370)	23 410 (51,615)	520 (970)

Table 1-9
Performance in Power Generation Applications at ISO Conditions

Name/ Model	ISO Output, kWe Continuous	Heat Rate, kJ/ kW-hr (Btu/ kW-hr)	Exhaust Flow, kg/ hr (lb/ hr)	Exhaust Temp, deg C (deg F)
Saturn® 20**	1210	14 795 (14,625)	23 540 (51,900)	505 (940)

* designates two-shaft, variable-speed engine
** designates single-shaft, constant-speed engine

Northern Research and Engineering Corp. (NREC), (Ingersoll-Rand [IR])

Ingersoll-Rand produces the PowerWorks™ family of small gas-turbine products (Figure 1-5). These high-efficiency, rugged, and reliable microturbines are being developed for power generation, cogeneration, and other applications.

Figure 1-5
Ingersoll-Rand PowerWorks™ Microturbine. (Courtesy of Ingersoll-Rand)

Each member of the PowerWorks™ family uses a small, long-life, low-emission, gas-turbine engine as the prime mover and offers various options for heat recovery. The simple "ruggedized" turbocharger-based engine offers reduced maintenance and lower operating costs when compared to reciprocating engine-driven systems. IR employs "off-the-shelf" industrial and vehicle components like turbochargers. This allows IR to offer cost-effective packages that are adapted to the rigors of industrial applications. IR prefers the two-shaft PowerWorks™ configuration because they believe the single-shaft design presents a compromise between the requirements of the gas turbine engine itself and the needs of a particular load. The turbine in the two-shaft design provides flexibility in matching to mechanical drive load-following while reducing stress and prolonging engine life.

PowerWorks™ systems currently are being developed for a variety of industrial and commercial applications. For example, in electricity/waste heat cogeneration systems, the low-NOx, recuperated gas-turbine engine directly drives a low-speed induction generator. Sizes range from 30 to 250 kW of delivered AC electrical power while producing dry, low emissions (less than 9 ppm NOx) with no post-combustion treatment. Electrical efficiency for the systems is 33% while overall cogeneration efficiencies can exceed 80%. In the past decade, natural gas-fueled systems such as these have become less expensive to operate than electric motor-driven chillers due in part to rising electricity costs and comparatively low gas prices in the summer.

Rolls-Royce Corporation (www.rolls-royce.com)

The Rolls-Royce Corporation, which purchased the microturbine division of Allison/GM in about 1995, offers their MicroTurbine^{TM} products in the 20 to 270^{+} kW range. These are mobile, high-temperature, ceramic regenerator units that are small and very space/weight efficient. The Rolls-Royce MicroTurbine^{TM} family of products had its beginnings in the automotive area (e.g., hybrid electric vehicles) and is currently focused on military applications.

Conclusions

It is possible that microturbines may play an increasingly important role in the future supply of energy worldwide if their potential to enhance distributed generation systems by providing reliable and durable fuel-efficient units is realized. However, to provide power quality benefit to the connected load, microturbines should be able to accommodate step-load changes and provide the reactive power required for motor-starting applications in the stand-alone mode. With the proliferation of nonlinear loads in customer facilities, the issues related to the source impedance of microturbines and voltage distortion also need to be evaluated carefully.

For grid connection operation, there remain significant issues related to distribution system interaction that are similar to other DG technology applications. If microturbine or other smaller DG technologies proliferate and become a significant portion of the feeder load, it is unlikely that the existing distribution systems (which have been designed with the idea of one-way power flow) will be able to accommodate the higher penetration rate. In such cases, microturbine application will be limited to one-way power flow for supporting the local load only.

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