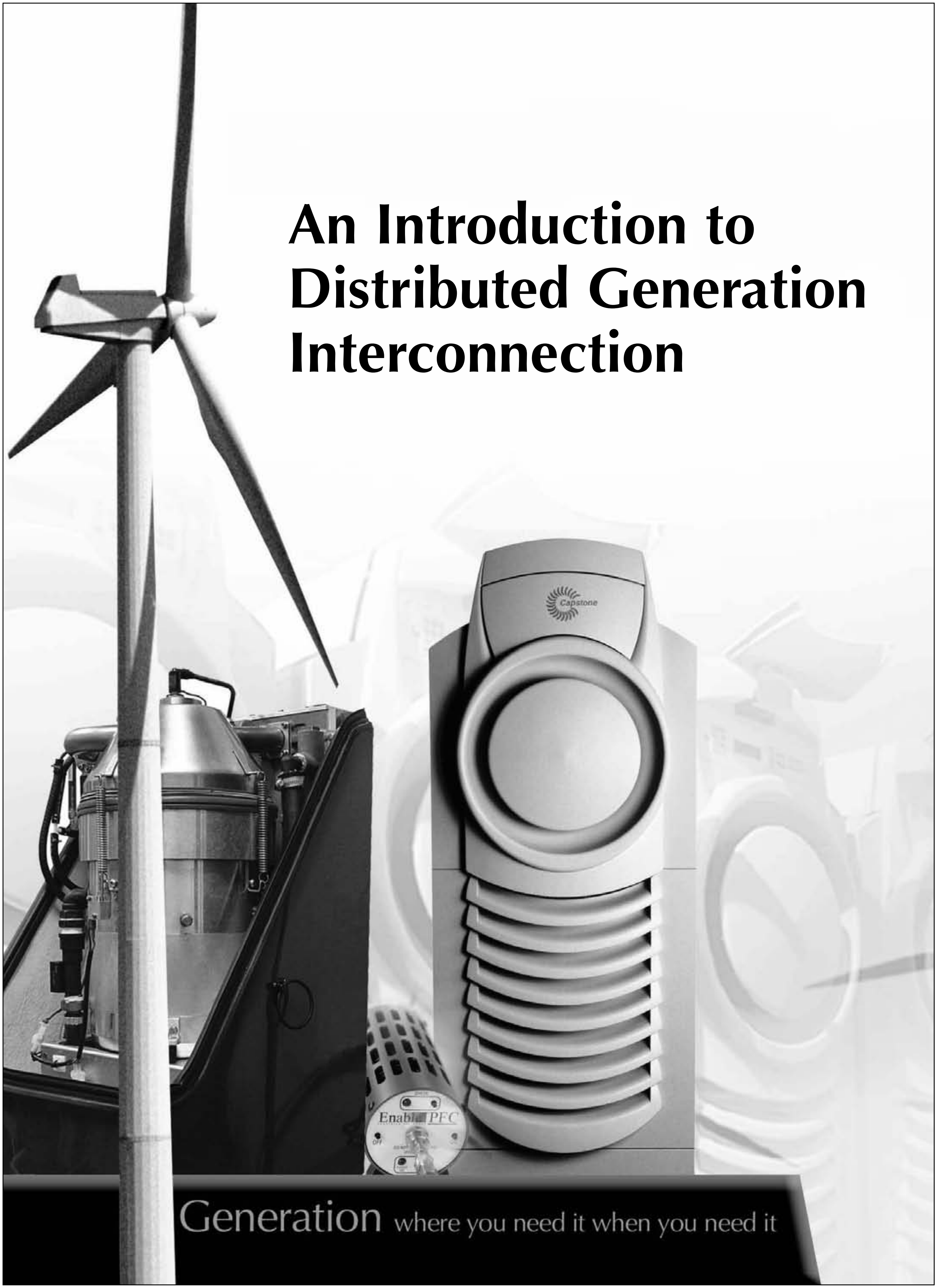
An Introduction to Distributed Generation Interconnection



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An Introduction to Distributed Generation Interconnection

How to use this manual

In conjunction with the accompanying video presentation, the purpose of this manual is to provide an overview of the technologies and issues involved in the design, utilization and interconnection of Distributed Generation (DG) to the utility grid.

The U.S. Department of Energy (DOE) commissioned the development of this manual and the accompanying video due to the growing market for DG, the relative newness of some of the generation technology, and the importance of correct interconnection with the electric grid. Its purpose is to provide an overview to those who are considering using the technology, or to those who may be in a position to inspect or to approve the installation of such technology.

The manual and video are results of a collaborative effort from the U.S. DOE, the State of Wisconsin Division of Energy, Alliant Energy, and Unison Solutions. Neither this manual nor the video are meant to be a comprehensive study of Distributed Generation, but rather an overview with which to create familiarity with the subject matter and the relevant issues.

As always, consult local authorities to receive the information appropriate to each project. Ordinances, permitting policies and regulations may vary by installation, technology, locality, utility and state. (See the References section for sources of information.) Actual project requirements may differ from what is offered in this manual.

Introduction

In general terms, Distributed Generation (DG) is any type of electrical generator or static inverter producing alternating current that (a) has the capability of parallel operation with the utility distribution system, or (b) is designed to operate separately from the utility system and can feed a load that can also be fed by the utility electrical system. A distributed generator is sometimes referred to simply as “generator”.

Distributed generators include induction and synchronous electrical generators as well as any type of electrical inverter capable of producing A/C power. An Emergency or Standby Generation System is designed so as to never electrically interconnect or operate in parallel with the utility system. An Interconnected Generation System is any generator or generation system that can parallel (or has the potential to be paralleled via design or normal operator control), either momentarily or on a continuous basis, with the utility system.

The term Distributed Generation is sometimes used interchangeably with the term Distributed Resources (DR). But DR is intended to encompass non generating technologies such as power storage devices like batteries and flywheels in addition to generators, while DG is limited to small scale (less than 20 MW) electrical generation located close to point of use. Unlike central power plant generation, DG often utilizes the waste heat from the generation process as an additional form of energy for space or process heating, dehumidification, or for cooling through absorption refrigeration.

Forms of Distributed Generation

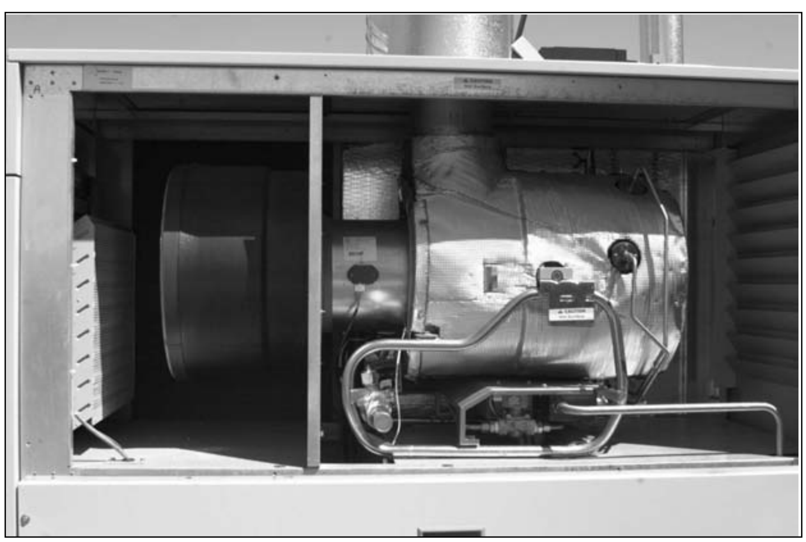
Distributed Generation technologies that require a Supplied Fuel

1. Microturbines:

Microturbines are scaled down turbine engines with integrated generators and power electronics. They are generally characterized by having only one rapidly moving part (moving at 100,000 rpm) supported either by air- or liquid-lubricated bearings. The microturbine generates high-frequency AC power that is rectified by a power electronics package into utility grid-quality, three-phase 400-480v AC power. Microturbines can operate on a wide variety of gaseous and liquid fuels, and have extremely low emissions of nitrogen oxides. Electrical efficiency of microturbines is in the 25-30 percent range. Although the latest combined cycle gas turbines can achieve maximum output efficiencies nearing 60 percent, the US Environmental Protection Agency and the Department of Energy notes that average power plant efficiency in the country is 34 percent. Since 5-10 percent of that is lost in transmission and distribution, the national average may actually be about the same as that of on-site microturbines without heat recovery.

Ancillary heat from microturbines can be used on-site for water and space heating, process drying, food processing and absorption chilling. Doing so delivers a total system efficiency of at least 70 percent, and use of the exhaust stream for process drying, greenhouse heating/CO_2 supplementation and similar tasks yields efficiencies exceeding 90 percent.

Capstone MicroTurbine, 30kW



Capstone MicroTurbine, 60kW

2. Fuel Cells:
A fuel cell is an electromechanical engine. It harnesses the energy released when hydrogen and oxygen combine. This reaction produces electricity, heat and water. Fuel cells produce almost no pollutants and have no moving parts.

In principle, a fuel cell operates like a battery. However, a fuel cell does not run down or require recharging. It will produce energy in the form of electricity and heat as long as fuel is supplied.

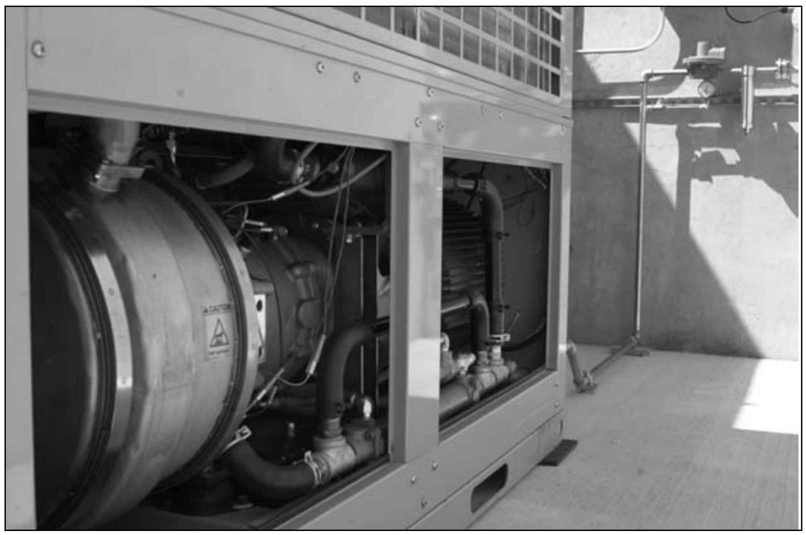
The hydrogen needed for reaction in a fuel cell is typically produced from hydrogen rich fuels such as natural gas, propane, or methane from biogas recovery. These hydrogen rich fuels are run through a fuel "reformer" that converts the fuel from its original composition to hydrogen and to carbon dioxide.

Proton Exchange Membrane (PEM) Fuel Cell

3. Stirling Engines:
Robert Stirling originally patented “A New Type of Air Engine with Economizer” in 1816. The Stirling engine is also known as an "external combustion engine.” Combustion in the form of a steady flame takes place outside of the sealed chamber or cylinder. The Stirling engine runs cleaner and more efficiently than an internal combustion engine.

The Stirling engine derives its power from heating and cooling a gas inside a sealed chamber with a piston. When the gas is heated, it will expand and build pressure within the sealed chamber; thus pushing a piston out. When the gas cools, it will contract and pull the piston in. The economizer, now known as a regenerator, stores heat between the hot and cold cycles.

STM Stirling Engine/Generator (Beta version), 25 kW External View



STM Stirling Engine/Generator (Beta version), 25 kW Case Open

4. Internal Combustion Reciprocating Engines:
The most common internal-combustion engine is the piston-type. The confined space in which combustion occurs is called a cylinder. In each cylinder a piston slides up and down. One end of a connecting rod is attached to the bottom of the piston by a joint; the other end of the rod clamps around a bearing on one of the throws of a crankshaft; the reciprocating (up-and-down) motions of the piston rotate the crankshaft, which is connected by suitable gearing or directly to a generator.

Reciprocating Engine/Generator

Distributed Generation technologies that do not require a Supplied Fuel

1. Solar or Photovoltaic:
A solar or photovoltaic (PV) cell is made of special materials called semiconductors, an example of which is silicon crystal. The photovoltaic cell is designed to convert light energy into electric current. It is a specially constructed diode, which is an electronic component with positively and negatively charged fields that force the movement of electric current in only one direction. The border between the negative and positive fields is called the diode junction.

When light strikes the cell's exposed active surface, a portion of the light energy is absorbed by the semiconductor material. The energy knocks electrons loose from their positive and negative sites in the silicon crystal, allowing them to flow freely. Some of the electrons have sufficient energy to cross the diode junction and cannot return to positions on the other side of the junction without passing through an external circuit. This flow of electrons is called current, and by placing metal contacts on the top and bottom of the photovoltaic cell, current can be drawn off for external use. Since the current obtained from these devices is small and the voltage is low, they must be connected in large series-parallel arrays (solar panels) if useful amounts of energy are to be converted. Practical devices of this kind are about 10 percent to 15 percent efficient.

Typical Solar-Photovoltaic Installation

2. Wind:
Modern wind energy systems consist of three basic components: a tower on which the wind turbine is mounted; a rotor (with blades) that is turned by the wind; and the nacelle. The nacelle is the capsule-shaped component which houses the equipment, including the generator that converts the mechanical energy in the spinning rotor into electricity. Rotor blades need to be light and strong in order to be aerodynamically efficient and to withstand prolonged use in high winds.

The rotor, which spins when driven by the wind, supports blades that are designed to capture kinetic energy from the wind. Nearly all-modern wind turbines have rotors that spin about an axis parallel to the ground. The spinning rotor turns a shaft, which converts the wind's energy into mechanical power. In turn, the shaft drives the generator, which converts mechanical energy into electricity.

Typical Wind Generation Installation

Inverter vs. Non-Inverter Technologies

Most microturbines, wind generators, and photovoltaic systems use inverters. An inverter converts DC voltage and current into AC voltage and current, via power electronics and microprocessors. The inverter system also provides most of the protective relay functions and automatically synchronizes with the voltage and frequency from the electric grid, eliminating the need for discrete relays for voltage and frequency protection. The power electronics can be used for power factor correction and provide greater flexibility than non-inverter systems.

Most reciprocating engine-powered generators are non-inverter. As such, they require a defined engine speed to drive a synchronous or induction generator to deliver 60 Hz AC power. In contrast to inverter systems, protective relay functions must be external.

Capstone MicroTurbine Inverter Assembly

Air Permitting a Distributed Resource

The hourly emission rates for all criteria air pollutants must be analyzed and the construction permit threshold levels calculated for each DR project. These calculations are made using the manufacturer's data and U.S. Environmental Protection Agency emission factors. In addition, the annual emission rate for these pollutants must be included in the permitting process to the state or federal agency that has jurisdiction. The emissions from many distributed generation systems are low enough that there are currently no air pollution control permitting requirements. However, it is recommended that an environmental engineering firm be engaged to manage the permitting process on larger distributed generation installations.

Electrical Interconnection of Distributed Generation

General Design Requirements:

The interconnection and equipment requirements listed in the following sections are typical and applicable to most distributed resources interconnected for parallel operation with the distribution system.

Distributed Generation Equipment Protection:

Protection and safety devices are intended to provide protection for the distribution system, electric provider workers, other electric provider customers, and the general public. Protection devices will ensure that the fault current supplied by the distributed generator is interrupted if a fault on the distribution system occurs. When a fault occurs and a distribution breaker trips, it will be necessary to disconnect a distributed generator. Automatic reclosing is utilized on distribution systems to clear temporary faults. The installer must ensure that the distributed generator is disconnected from the distribution system before automatic reclosing. Protection devices will also prevent reclosing an out-of-synch distributed generator with the distribution system.
The installer is responsible for protecting its distributed generation equipment in such a manner that distribution system faults such as outages, short circuits, automatic reclosing of distribution circuits or other disturbances do not damage the distributed generation equipment. The equipment protection also prevents the distributed generation from adversely affecting the distribution system's capability of providing reliable service to other customers.

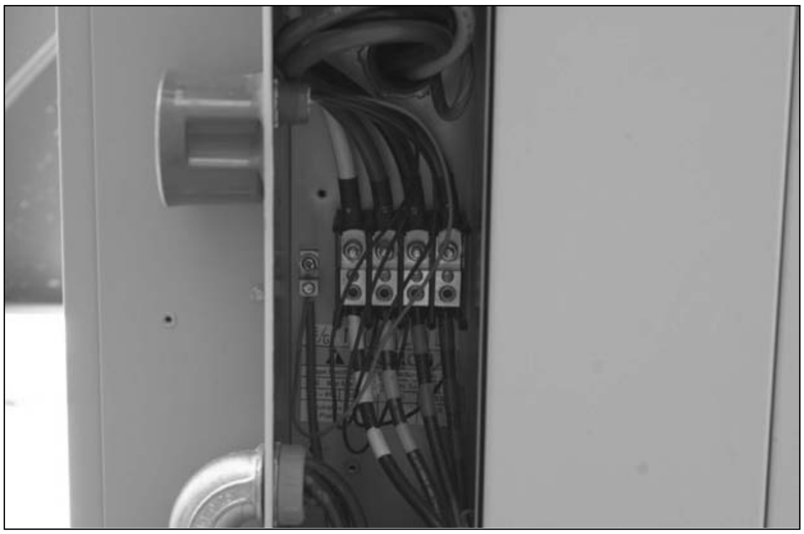
Equipment Circuit Breakers:

Equipment circuit breakers on the generator side of the point of interconnection must be capable of interrupting maximum available fault current.

Compliance with Codes:
The distributed generator and interconnection installation must meet all applicable national, state, local (including construction), and safety codes.

For example, working space or clearances for electrical equipment operating at 480 volts, requiring examination, service or maintenance while energized, need:

- 3 feet minimum clearance from exposed live parts or the enclosure opening to no live or grounded parts on the other side.
- 3.5 feet minimum clearance from exposed live parts or the enclosure opening to a grounded surface on the other side. Concrete, brick or tile walls are considered grounded.
- 4 feet minimum clearance for exposed live parts on both sides of the work space,
- The width of the working space in front of the electrical equipment shall be the width of the equipment or 30 inches, whichever is greater.
- The height of the working space shall be clear and extend from grade to at least 6.5 feet.



480 v Interconnection point requiring proper clearance

Manual Disconnect:
The system shall include a manual disconnect switch that opens, with a visual (air) break, all ungrounded poles of the interconnection circuit. The manual disconnect switch must be rated for the voltage and fault current requirements of the generation facility, and must meet all applicable UL, ANSI and IEEE standards. The switch must meet the requirements of the National Electric Code (NEC), and be properly grounded. The manual disconnect switch must be capable of being locked in the open position.

Typical 480 v manual disconnect with a visible open

Metering Requirements:
The installation normally includes a meter to monitor the electricity produced.

Typical utility metering installation

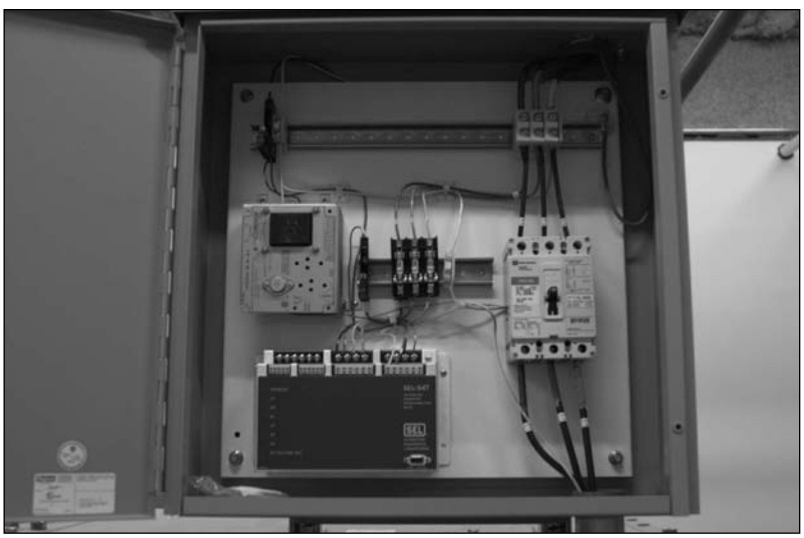
Grounding:
Proper grounding is required between the distributed generation and the distribution system to provide an adequate fault current path. Grounding practices shall be in conformance with IEEE Std.142-1991.

Islanding:
Islanding occurs when distributed generation becomes separated from the main generation source on a distribution system, yet continues to independently serve a portion of the distribution system. Distributed generation must be equipped with protective hardware and/or software designed to prevent the generator from being connected to a de-energized distribution system. Islanding is not allowed under most guidelines.

Power Quality:
Power quality defines the limits of DC injection, voltage flicker, harmonics, immunity protection, and surge capability. The distributed generation should not create system voltage disturbances.

Synchronizing Distributed Generation:
The installed equipment must be synchronized with the distribution system.

Automatic Interrupting Device:
Distributed generation must include an automatic interrupting device that is listed with a nationally recognized testing laboratory, and is rated to interrupt available fault (short circuit) current. The interrupting device shall be tripped by any of the required protective functions.



Typical Interrupting Device that is tripped by a protective relays

Protection Functions:
Protective system requirements for distributed generation are influenced by many factors including:

- Type and size of the power source
- Voltage level of the interconnection
- Location of the distributed generation on the circuit
- Distribution transformer
- Expansion plans of the site

- Distribution system configuration
- Available fault current
- Load that can remain connected to the distributed generation under isolated conditions
- Amount of existing distributed generation on the local distribution system.

Protective system requirements can vary. As a result, it is impossible to standardize protection requirements strictly according to any single criteria, such as generator size. The specific protection for each parallel interconnection must be individually determined for each installation.

It is therefore important that the local electric provider must be involved at the earliest possible date, prior to the purchase of protection equipment, to determine any specific protection requirements.

Power Factor:
The power factor of the distributed generation interface, as measured at the point of common coupling, shall be greater than 0.9 (leading or lagging).

Dedicated Transformer:
Larger distributed generation (typically over 20 kW) may be required to be isolated from other customers supplied by the same transformer. This would be accomplished by use of a dedicated power transformer connecting to the distribution system. The primary purpose of the dedicated transformer is to ensure that (a) the generator cannot become isolated at the secondary voltage level with a small amount of other customer's load, and (b) the generator does not contribute any significant fault current to other customer's electrical systems. It also helps to block any voltage fluctuation or harmonics produced by the distributed generator

Anti-islanding Test:
The anti-islanding test requires that the unit shut down upon sensing the loss of power on the distribution system. The test is to be conducted with the generation as close to its full output as possible.

Synchronism Check:
This function blocks out-of-phase closing and also prevents closing and energizing a dead low voltage bus by the generator.

Under-voltage:
This function must be adjustable from 70-90 percent nominal service voltage and have time delay to override system transients and clearing of external faults. All phase voltages shall be monitored with an under-voltage relay to provide maximum tripping reliability for three phase generators.

Negative Sequence Current:
This function should have a long setting time and low voltage pickup setting to detect transformer overloads due to unbalanced feeder loads.

Over-current:
This function serves as the main over current protection and is set to coordinate with the distributed generation protection and any protection on the local load.

Over-voltage:
This function must be adjustable from 105-120 percent nominal service voltage and have a definite time delay to override system transients. Phase voltages must be monitored with an over-voltage function to provide maximum tripping reliability for three phase generators.

Under-frequency:
An under frequency function with single set point of 59.3 Hz and 10 cycles definite time delay is typical.

Over-frequency:
An over-frequency function with a single set point of 60.5 Hz and 10 cycles definite time is typical.

Commissioning and Utility Acceptance Testing of Distributed Generation
Before parallel operation with the utility system, the installation typically must be witnessed and inspected by the utility. This could include:

- The acceptance testing of all relays according to the utilities minimum requirements.
- The placement of in-service relay taps according to settings.
- The operability of the protective equipment including relays, circuit breakers and communication channels.
- The phasing and synchronizing checks of all related equipment.
- The anti-islanding test requires that the unit shutdown upon sensing the loss of power on the distribution system. Either removing the customer meter or opening a disconnection switch, while the generator is operating, can simulate this.

Type Testing:
Type test results must be certified by a nationally recognized test organization. Distributed generation paralleling equipment that is certified to have met the applicable type testing requirements of UL1741 (IEEE 929-2000) shall be acceptable for connection to the distribution system.

Note that interconnection protection is defined at the point of interconnection. Therefore, voltage, frequency and current values used for interconnection protection must be monitored at the point of interconnection. In some cases, a generator may be located an appreciable distance from the point of common coupling.

The use of pre-certified (type tested) paralleling equipment does not automatically qualify the distributed resource for interconnection to the distribution system at any selected point of interconnection. An interconnection review must be performed to determine the compatibility of the distributed resource with the distribution system capabilities at the selected point of interconnection.

Distributed Generation using Bio-fuels and the impact of Siloxanes

Distributed generation can utilize a variety of fuels such as natural gas, diesel, propane and bio-fuels. Bio-fuels offer the challenge of dealing with siloxanes. Siloxanes are relatively volatile organic/silicon compounds that are used extensively in consumer products such as deodorant, lipstick and makeup.

As biogas that contains siloxanes is combusted, the silicon reacts with oxygen to form silicon dioxide (SiO_2), a solid white powder commonly known as silica. Sand (quartz) is nearly pure silica. Silica particles are abrasive and have a very high melting temperature.

When siloxanes are present in the fuel to a microturbine, tiny particles of silica form in the combustion section. The silica particles travel with the exhaust gases at very high speeds through the nozzle vanes into the turbine wheel, and then exit through the recuperator and heat exchanger (if installed). Over time, the abrasive particles can cause erosion of some of the metal surfaces they contact, as well as fouling and plugging heat exchanger surfaces.

Troublesome silica deposits and erosion have also been found in other power generating equipment used for landfill gas and digester gas, such as internal combustion engines and gas turbines. These deposits are often found on the cylinder heads and rings of internal combustion engines, and on the heat recovery stream generator tubes of gas turbines. Maintenance and rebuild requirements tend to be very high, as evidenced by unit availability data. It is not common for internal combustion engines at wastewater treatment plans to have top-end rebuilds twice a year,

Typical biogas siloxane removal system

For these reasons, as technology is driven towards higher performance levels and lower emissions, siloxane removal is expected to become a more common process step in all biogas power generation systems.

Distributed Resources operating as CHP or Trigeneration

Combined heat and power, or CHP, is not uncommon for distributed generation. It can be applied large scale, e.g. several hundred MW power plants for district heating, or small scale, e.g. a few kW Stirling engines for residential use. The fundamentals remain the same: instead of one separate unit for the power generation and a separate burner for the heat generation, the exhaust heat from the power generating unit is used as a prime source of heat. As a result, the system efficiency can be 70-90 percent.

There are three main categories of CHP:

- Direct heat
- Hot water and steam
- Cooling

Applications involving both heating and cooling are sometimes referred to as Tri-generation (Trigen) or CCHP (combined cooling, heating and power).

Direct heat applications use the exhaust heat for drying processes, e.g. drying of bricks, chemical compounds or food processing.

Hot water and/or steam are the most common CHP applications. The exhaust stream is led through a heat exchanger to heat water. The hot water is then used to provide space heating or process heat.

Absorption chillers or desiccant dehumidification systems achieve cooling. There are two types of system configurations. "Indirect fired" systems are systems using hot water from a heat exchanger. "Direct fired" systems are systems using the exhaust heat from the generation system.

Typical CHP Installation

Exhaust heat being recovered from Capstone MicroTurbines

Exhaust heat from MicroTurbines being transferred to hot water in a heat exchanger

Conclusion

Distributed generation is becoming an increasing important part of the power infrastructure. The advantages of increased power reliability, higher energy efficiency when waste heat is utilized, and the elimination of electric grid transmission and distribution losses, are all driving the installation of DG. As the number of installations grows, it is important that safety through the compliance to all local and national codes remains the key focus of the installation.

Glossary of Distributed Resource Terms

Aerobic: In the presence of oxygen.

Aerobic Digester: A system used to break down biological wastes by microorganisms in the presence of oxygen. This method of waste treatment usually has a high-energy input.

AGA: American Gas Association

Anaerobic: In the absence of oxygen

Anaerobic Digester: A container that holds biological wastes, such as manure, in an environment without oxygen. Microorganisms growing in this environment produce methane and other products.

Baseload: The amount of electric power delivered or required continuously.

Biogas: Gas formed from the breakdown of organic material.

Btu: British Thermal Unit. Heating value typically expressed as the amount contained in one cubic foot of a gaseous fuel.

Co-firing: The use of a fuel, other than the principal fuel, to augment of generation of power at the facility.

Cogeneration: The optimizing of fuel efficiency by generating and utilizing both electrical and thermal energy.

Combustion turbine: See gas turbine.

Digester Gas: A gas containing methane produced from anaerobic digestion of animal or other organic wastes.

Distributed Resources (DR): Energy resources that provide either generation, energy storage or demand side management.

Distributed Generation (DG): Small-scale generation that provides electric power at a site closer to a customer than a central generation facility. A unit can be connected directly to a customer's facility or directly to a utility's transmission or distribution system.

Fuel Cell: Energy conversion devices that react hydrogen (H_2) or high-quality (hydrogen-rich) fuels like methane and oxygen into electric current (and heat) without combustion.

Gas Turbine: A rotary engine similar to a jet engine usually fired with natural gas.

Grid: The electric power industry infrastructure of interconnected electrical systems and services that provide power to all users.

IEEE: Institute of Electrical and Electronic Engineers

IEEE 1547: National interconnection standard approved in 2003

Interconnection: The connection between the distribution line and the customer. Disconnection and overcurrent protection are required.

Kilowatt (kW): A unit of power equal to 1000 watts or about 1.34 horsepower.

Kilowatt-hour (kWh): A unit of work or energy equal to that expended by one kilowatt in one hour.

Methane: The combustible gas produced by anaerobic digesters. The gas produced by a digester will normally have between 55 percent and 85 percent of the heating value of natural gas.

Megawatt (MW): One million watts.

Megawatthour (MWh): A unit of work or energy equal to that expanded by one Megawatt in one hour.

Microturbine: A small turbine, similar to a jet engine, capable of operating on a variety of gaseous and liquid fuels, which is connected to an electric generator.

NEC: United States National Electric Code

NEMA: National Electrical Manufacturers Association

NFPA: National Fire Protection Association

Net Metering: An arrangement where customers can offset their consumption and sell and extra energy generated at the same rate they pay. The energy quantity is determined by bi-directional metering that registers electrical flow in both directions.

Photovoltaic Cell (PV): Converts sunlight directly into electricity with a semiconductor junction such as a diode.

Power Quality (PQ): PQ is the concept of powering and grounding sensitive electronic equipment in a manner that is suitable to the operation of that equipment. For retail service, the service voltage shall not vary by more than five percent above or below the standard voltage.

Reciprocating Engine: Another name for an internal combustion engine. The engine can be spark of combustion ignition and may use a variety of petroleum or bio based fuels.

Sour-gas: A general term that refers to digester or landfill gases and may also be used for some types of petroleum gas. Generally means that the gas contains high levels of hydrogen sulfide.

Stirling Engine: An external combustion engine that converts heat from a variety of sources into mechanical energy that can be used to generate electricity.

Substation: A transformer location where the power from transmission lines is stepped down in voltage to the distribution lines.

Transfer Switch: Allows power to flow from only one source, utility or generator, to a load. Eliminates the possibility of a dangerous interconnection.

UPS: Uninterruptible Power Supply. A device that typically uses stored energy to maintain continuous delivery of power to a load during a failure of a primary source.

Watt: A unit of power of the rate of doing work (1/746 horsepower).

Wind Turbines: A wind generation system that converts wind power into mechanical power that is used to generate electric power.

Wind Farm: A group of wind turbines in close proximity.

References

NFPA (National Fire Protection Association)
Contact Information: www.nfpa.org
PH: 617-770-3000

NEC (United States National Electric Code)
Contact Information: www.nfpa.org
PH: 617-770-3000

NEMA (National Electrical Manufacturers Association)
Contact Information: www.nema.org
PH: 703-841-3200

IEEE (Institute of Electrical and Electronic Engineers)
Contact Information: www.ieee.org
PH: 212-419-7900

AGA (American Gas Association)
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