Distributed Energy Resources and Combined Heat and Power : A Taxonomy of Terms

Richard M. Scheer, Energetics
Anna Monis Shipley, American Council for an Energy-Efficient Economy
R. Neal Elliott, American Council for an Energy-Efficient Economy

ABSTRACT

It has become clear from several recent meetings of analysts (Energetics 1999a and 1999b), that the distributed energy resources (DER) and combined heat and power (CHP) communities are in need of a common set of definitions to describe segments of the marketplace. Two parameters appear to require inclusion in the taxonomy: system size and system design and operation. This is not an academic issue – it has significance for the enumeration of current systems and the estimation of market potential, since it will allow analysts to explicitly declare what is included in, and excluded from their estimates and projections.

We are presenting the terms in this study to bring clarification to the growing and complicated areas of distributed energy resources and combined heat and power. The next step in this process is for the industry to adopt this set of terms and to begin to establish a consistency in the language used. Such consistency is necessary for accurate data collection: a global terminology will make possible the development of metrics to track DER and CHP installations and the integration of these systems into the nation's energy portfolio.

Introduction

In recent years, there has been increased interest on the part of electric customers to install generating facilities at or near their site. Today's businesses rely highly on electronic equipment, and the need for reliable, high quality electric power is constantly increasing. However, while dependence on electrical power is increasing, the power delivered by the electrical grid is becoming more and more unreliable. The importance of reliable electrical power cannot be over-emphasized for the nearly 90% of small businesses in the United States who reported experiencing at least one power outage during 1998. According to a survey sponsored by Allied Signal Power Systems Inc., 500 small business owners reported an average of three power outages last year, costing each business an approximate average of $7,500 per day (Allied Signal Power Systems, 1999). As a result of these and other findings, businesses are looking to increase the reliability of their electrical systems to as much as 99.9% through the installation of distributed energy resources.

As interest in this area grows, and more studies address these various technologies, it becomes apparent that there are many different terms that are currently being used to describe similar systems and technologies. This brings about a great deal of confusion to both customers and suppliers. In this study, we attempt to bring clarity to the most common terms that are being used in the area of extra-grid electricity generation: Distributed Generation (DG), Distributed Power (DP), and Distributed Energy Resources (DER).

A special subset of distributed energy resources is Combined Heat and Power (CHP). Because many businesses are finding that CHP technology can provide highly efficient solutions to their electrical quality and reliability issues, CHP terminology is in need of clarification as well. Combined heat and power technologies can fall under the category of Distributed Generation. However, CHP is not only a distributed energy resource. It has also been used by utilities as a central power generating technology. Since CHP can be tailored to small and large applications and creates two forms of usable energy, it becomes quite difficult to classify the different types of systems.

Distributed Energy Resources Taxonomy

Analysts, scientists, and law makers have been using a wide array of terms for what can be described very generally as electric power generation at, or near the point of use. It includes a wide range of technologies that utilize both fossil and renewable fuels to produce energy outside of the conventional utility system. The aims of distributed energy resources are to increase the quality and reliability of the power supply to a customer at a competitive price and to reduce overall environmental emissions.

The current predominant electric system structure in the United States is the central generation system with distributed consumption. Under this configuration, a large utility-owned generating station produces electricity, transmits it to an electric substation, and sends it through a distribution transformer. The voltage of the electricity is reduced at the distribution transformer to a level that is appropriate for the customer. Figure 1 provides a simplified illustration of the electric power grid.

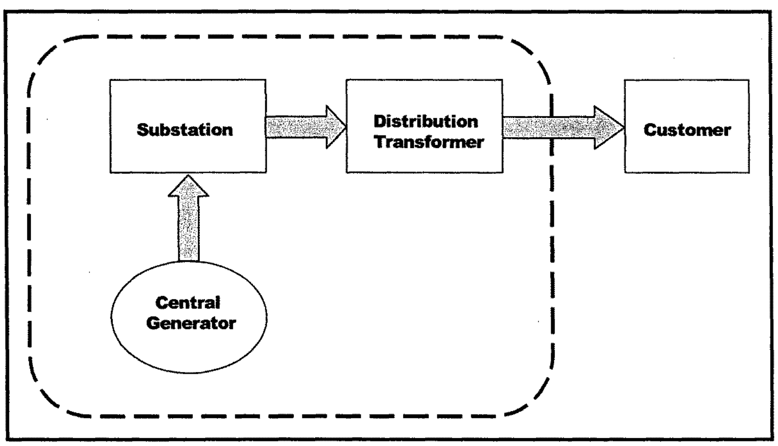

Figure 1. The Electric Power Grid

Because of increased demands and incidences of widespread power outages during peak times in the past few years, many utility customers have sought to generate their own power (Allied Signal Power Systems, 1999). As stated in the introduction, businesses are becoming much more dependent on the reliability of their electrical systems. Many of these systems also require increasingly high quality power. The implementation of distributed energy resources can be beneficial for both the customer and the utility, but it should be noted once again that the aim of local systems should be to increase the quality and reliability of service. A customer that completely removes itself from the electrical grid faces the possibility of outages and decreased reliability. Implementing distributed energy resources along with grid power can offer reliability 99.9% of the time (Johnson, 1999).

The energy produced through distributed energy resources can be utilized by the local user, or can be sold back to the grid. The terms that have been used by the electric industry include Distributed Generation, Distributed Power, and Distributed Energy Resources. We will attempt to clarify and define these terms in a manner that will appeal to the majority of the power generating community and create the groundwork for a unified industry terminology. For the purposes of this study, the term Distributed Energy Resources (DER) will refer to the broadest range of technologies that can provide power to the user outside of the grid, while also including demand-side measures.

DER Definitions and Terminology

The classification of Distributed Energy Resources must take into account the size, system design, and operation of power generating sources. For the purposes of this taxonomic study, we will attempt to segment the market into the following three subheadings: Distributed Energy Resources, Distributed Generation, and Distributed Power. Table 1 displays the definitions of each of these terms.

Table 1. Definitions of Distributed Energy Resources

Distributed Generation	Any technology that produces power outside of the utility grid
Distributed Power	Any technology that produces power or stores energy
Distributed Energy Resources	Any technology that is included in DG and DP as well as demand side measures

Our definitions will begin from the most specific, and expand to the most general. Distributed Generation (DG) is defined as anything outside of the conventional utility grid that produces electricity. DG technologies include internal combustion engines, fuel cells, gas turbines and micro-turbines, hydro and micro-hydro applications, photovoltaics, wind energy, solar energy, and waste/biomass fuel sources. DG also includes non-utility combined heat and power plants. Table 2 displays the properties of various DG technologies.

Table 2. Properties of Various Distributed Generation Technologies

Technology	Size	Installed Cost ($/kW)	O&M Costs (cents/kW)	Fuel Type	Typical On-Site Duty Cycles
Internal Combustion Engines	50 kW - 5 MW	$800 - $1,500	0.7 - 1.5	Diesel, propane, NG, oil, and biogas	Baseload
Small Turbines	1 MW - 50 MW	$700 - $900	0.2 - 0.8	Diesel, propane, NG, oil, and biogas	Baseload , intermediate peaking
Micro-Turbines	25 kW - 500 kW	$500 - $1,300	0.2 - 1.0	Diesel, propane, NG, oil, and biogas	Baseload, intermediate peaking
Fuel Cells	1 kW - 200 kW	~ $3,000	0.3 - 1.5	Hydrogen, biogas, and propane	Baseload
Photovoltaic	0.30 kW - 2 MW	$6,000 - $10,000	Minimal	Solar	Peaking
Wind Power	600 Watts - 1.5 MW	$900 - $1,100	1.0	Wind	Varies

[California Energy Commission, 1999]

Distributed Power (DP) encompasses all of the technologies included in DG as well as electrical storage technologies. DP includes batteries, flywheels, modular pumped hydro-electric power, regenerative fuel cells, superconducting magnetic energy storage, and ultracapacitors.

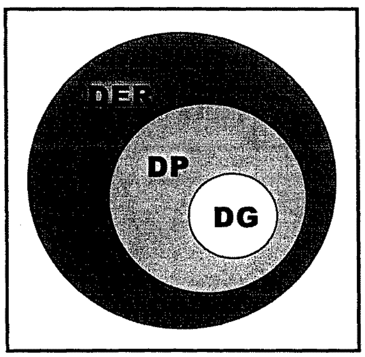

Figure 2. The DER Sphere

Distributed Energy Resources (DER) includes all the technologies categorized as DP and DG, and adds demand-side measures. Demand-side measures focus on altering the level and timing of electricity use at a given site. Such steps can improve energy efficiency, which reduces the total energy consumption, and load management, which reduces energy use during specific periods of high cost. Under this configuration, power may be sold back to the grid. The complete scope of DER is represented graphically in Figure 2.

DER may be utilized by a facility to provide mechanical power, such as compressed air—for a particular application, thereby displacing grid power. In this way, mechanical power might be considered a DSM measure. However, mechanical drive applications are not included in the definitions of DER, DP, and DG, due to the general consensus within in the industry that these terms almost universally refer to electrical power only. It is worth noting however, that engine-driven air compressors and chillers can offer many benefits of on-site electricity generation while avoiding the barriers associated with interconnection to the electricity grid, capital costs, and electrical generation and reconversion to mechanical power. However, since none of the existing databases track this part of the market, we have chosen not to include this application in our definitions.

Combined Heat and Power Taxonomy

Many experts and analysts agree (Energetics 1999a and 1999b) that the combined heat and power (CHP) community is in need of a common set of definitions for establishing segments of the CHP marketplace. Two parameters appear to require inclusion in the taxonomy: system size, and system design and operation. While this may appear a mundane and academic issue, it has significant importance to the enumeration of current CHP systems and the estimation of market potential, since it will allow analysts to explicitly declare what is included in and excluded from their estimates and projections.

Concerning CHP classification, these technologies represent a special area within the realm of DG. CHP systems that are installed at or near the point of use for off-grid applications are considered to be distributed generation systems (see Figure 3). However, large utility-owned or Independent Power Producer (IPP) CHP units are not included in DG. The size of this type of unit is typically between 40 – 400 MW. This non-DG CHP encompasses about 40% of all CHP-produced power (Elliott and Spurr, 1999).

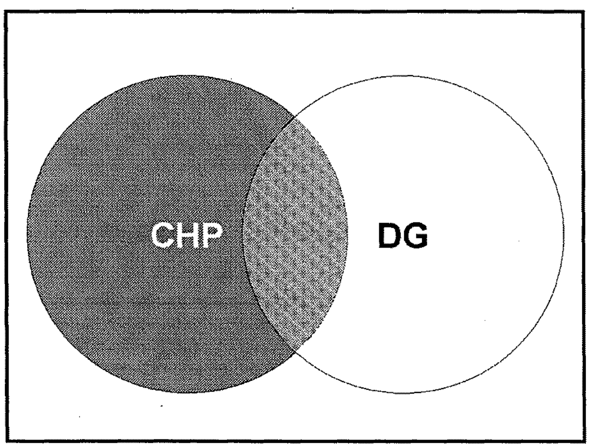

Figure 3. Overlap Between CHP and DG.

System Size

Determining the size of a CHP system is complicated by the fact that the system, by definition, produces at least two usable forms of energy. The output is generally grouped into thermal energy (heating or cooling), and power. Among the thermal outputs are direct process heating, steam, hot water, cooling, and chilled water. Among the power outputs are electricity, shaft-horsepower, and compressed air. In conventional, separate heat and power systems, these same outputs are produced by distinct systems, as shown in the example in Figure 4 (Elliott and Spurr 1999).

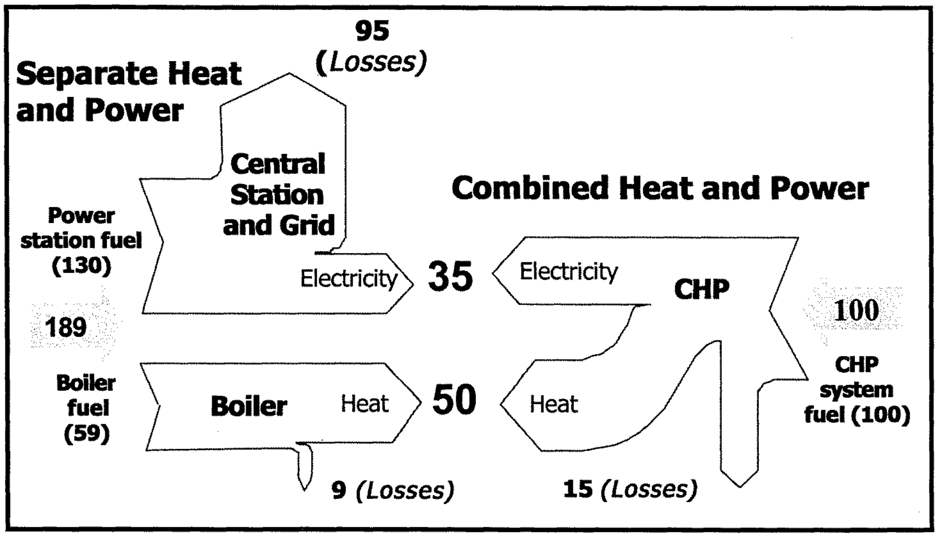

Figure 4. Comparison of Energy Flows in a Typical CHP System to Separate Production of Heat and Power
Source: Kaarsberg and Elliott (1998)

The industry has adopted a convention of sizing systems based on power output. In a system where more than one form of usable power is produced, the outputs should be aggregated to define the size of the system. For example, compressed air can be produced through a combustion turbine, by bleeding the primary compressor stage, while the turbine produces electricity. The total power output for the system would be the created electricity plus the energy value of the compressed air produced.

The thermal output of a CHP system is captured as the ratio of the power manufactured to the usable thermal energy. This parameter, the power-to-heat ratio (α), is the ratio of electrical and mechanical energy to thermal energy, and it varies with equipment selection and system design. This ratio is expressed as:

$$\alpha = \frac{e_{electric} + e_{mechanical}}{e_{thermal}}$$

So, for the example in Figure 1:

$$\alpha = \frac{35}{50} = 0.7$$

Since CHP produces multiple forms of usable energy, conventional approaches to defining efficiency are problematic. A discussion of efficiency in a CHP context appears in Elliott and Spurr (1999).

CHP system design capacities are normally expressed in kilowatts (kW) or megawatts (MW). The use of power output reflects the legacy of reporting requirements by the Energy Information Administration (EIA) and the Federal Energy Regulatory Commission (FERC), who require the reporting of electric generating capacity of all plants that connect to the electricity grid. No similar, consistent reporting of thermal output is in place. In addition, reporting of systems with power capacity below 1 MW or that do not generate electricity does not exist. A number of different categories are used by different analysts. Table 3 proposes a set of definitions that attempt to harmonize different analysts' terms.

Table 3. Size Categories of CHP Systems

Category	System Power Size Range
Micro	less than 500 kW
Mini	500 to 2 MW
Small	2 MW to 15 MW
Medium	15 to 40 MW
Large	Greater than 40 MW

System Design and Operation

CHP systems are further characterized by their design and operation. Through analysis of the current CHP literature it has become apparent that the systems fall into the following six categories: traditional, regulatory-driven, market-driven, district energy systems, self-powered buildings, and direct drive systems. A summary of the six market segments as well as the characteristics of each segment are displayed in Table 4.

Table 4. CHP Market Segments

Market Segment	Typical Size (MW)	Dominant Ownership	Typical Power-to-Heat Ratio	Design Strategy	Power Utilization
Traditional	3-40 (small - medium)	Owner Operated	0.2 – 1.5	Match existing process thermal base-load	On-Site
Regulatory-Driven	50-1,000 (large)	3rd Party	> 2 (CTCC) > 0.5 (Steam)	Maximize power generation	Merchant
Market-Driven	1-20 (small - medium)	3rd Party	0.5 – 2	Balance power and thermal loads	On-Site/ Merchant
District Energy	1-40 (small - medium)	3rd Party	0.2 – 2	Match existing thermal load	On-Site/ Merchant

Market Segment	Typical Size (MW)	Dominant Ownership	Typical Power-to-Heat Ratio	Design Strategy	Power Utilization
Building CHP	0.1-10 (micro - small)	3rd Party	0.4 – 2	Match building space conditioning load	On-Site
Direct Drive	0.1- 4 (micro-small)	3rd Party and owner operated	05 – 1.5	Size to driven load with heat recovery	On-Site

Many analysts divide the CHP market into two categories: traditional and regulatory-based. The division of the CHP market into these two categories resulted from the Public Utilities Regulatory Policy Act of 1978 (PURPA), which created the category of the independent power producer for those facilities that used cogeneration (see Elliott and Spurr 1999 for a more detailed discussion of PURPA). Prior to PURPA, cogenerators were discouraged from producing excess power, since there were no ready markets.

Traditional CHP is characterized by Energy and Environment Analysis (EEA)(1998) as systems where the host facility's steam demand drives the system design, matching the electricity capacity to existing steam demand. In most cases, all the power produced is used internally. In regulatory-based CHP, a third party satisfies the steam requirements of the "thermal host" customer, while maximizing the electric power production. The siting of non-traditional CHP systems is driven by available markets for the electricity.

The nature of the thermal host can vary. Elliott and Spurr (1999) break the market into three classes: industry, district energy systems, and small-scale buildings. Industrial CHP has dominated in large part due to the characteristics and size of the steam loads. New technology, which has made smaller systems economical, has expanded markets in all three areas.

Traditional CHP Systems. Most traditional CHP systems used back-pressure steam turbines to generate electricity, which was used to displace a relatively small portion of the electricity purchased to meet on-site electricity demand. These facilities are predominately industrial (Elliott and Spurr 1999). The average traditional system is about 20 MW (EEA 1999). Generation is usually sized to meet the base steam load during high operating hours. As a result, the generated electricity displaces a portion of the electric base-load demand. More recently, combustion turbines have entered into this market, increasing the power-to-heat ratio that can be achieved. The power-to-heat ratio for these systems are usually modest: EEA uses a range from 0.2 for steam-turbine-based systems to 1.5 for combustion turbine combined cycle(CTCC)-based CHP systems. The majority of these systems have in the past been owned by the plant.

Regulatory-Driven CHP Systems. Typical non-traditional CHP facilities are greater than 100MW, and are designed to maximize electricity production. To qualify under PURPA, they are required to produce at least 5% of their usable energy in the form of steam or hot water. CTCC has become the preferred technology at these facilities and are almost exclusively third-party owned. Under the PURPA model, the steam is sold to a host customer, usually a large manufacturing facility. The electricity is sold to the local power company under a "buy-back" contract.

These non-traditional facilities have a high power-to-heat ratio. EEA uses a lower bound of 0.5 for boiler/steam turbine systems, and 2.0 for CTCC systems. Some PURPA-qualifying facilities (QFs) were little more than conventional power plants that made use of a small portion of their waste heat in order to comply with the requirements.

With the passage of the Energy Policy Act of 1992, the new category of independent power producer was created, the exempt wholesale generator. These "merchant" plants sold their power on the wholesale market rather than under contract to the local utility. The terms merchant, independent power producer, and exempt wholesale generator are frequently used interchangeably. Though the majority of the new merchant plants are conventional power generators without heat recovery, some plants have been built as CHP facilities. With the restructuring of electricity markets and the introduction of new technologies, such as aero-derivative combustion turbines, the line between these two categories has become blurred. Many of the new CHP "traditional" facilities are third-party owned due to the outsourcing trend in industry where a firm's capital is focused on its core operation.

New technologies have allowed for higher power-to-heat ratios than could be achieved with a steam-turbine-based system. A higher fraction of a facility's electric power demand can be met by these systems, and excess power may be available for sale in some cases. Because of reduced equipment unit-cost, designs that provide some degree of load following, both thermal and power, are now economically feasible. These technology developments also allow for the implementation of smaller merchant power plants.

Market-Based CHP Systems. These market and technology developments have created a new category of hybrid systems. These hybrid systems are for the most part third-party owned, and serve a single customer facility. They fall within the small and medium size categories, and have a higher power-to-heat ratio than is associated with traditional systems. However, their primary focus is on meeting on-site energy requirements. Many of these systems are modular, and may have the potential for either thermal or power demand load following (i.e., the power production varies with the on-site thermal demand).

District Energy Systems. District Energy Systems (DES) provide steam, hot water, and/or chilled water from a central plant to individual buildings or industrial process areas through a system of pipes. A DES facility's aggregated thermal energy makes it attractive to add CHP at existing facilities (Spurr 1999): this is partly why these systems have boasted such rapid growth in recent years. The size of a DES can fall anywhere between the small to large size categories. The CHP facility could be placed into any of these categories. The aggregation of thermal demand from a number of customers distinguishes it from the industrial CHP facilities.

Self-Powered Buildings. More technologically advanced, high-efficiency reciprocating engines and cost-effective micro-combustion turbines are allowing CHP to become a viable option for smaller commercial buildings. These two CHP systems supply part of the electrical requirements for a building while providing heating and/or cooling. Most of the CHP focus has been on the industrial and institutional sectors, since they have relatively large and constant thermal loads. This creates the high load factors needed to make traditional CHP operating regimes economically attractive. With the emergence of modern, smaller-scaled technologies, a new market for "self-powered" buildings is emerging (Kaarsberg, et al. 1998). These are typically at the micro- or mini-scale, such as the reciprocating engines from Waukesha and Caterpillar which have a capacity beginning at 25 kW (Elliot and Spurr 1999). For large buildings, however, the systems may extend into the small size range. While most of the thermal loads for industrial CHP will supply the process of heating, it is anticipated that building CHP will focus on space conditioning loads. Space conditioning is cooling-dominated and the systems will focus on cooling technologies such as direct-drive, absorption, and desiccant cooling.

Direct-Drive. The CHP market models discussed so far in this section have focused exclusively on electric power generation. Some people see direct-drive equipment as an emerging CHP market. Engine-driven air compressors and chillers can offer many benefits of on-site electricity generation, while avoiding the barriers associated with interconnection to the electricity grid. None of the existing databases track this part of the market (Energetics 1999a).

Conclusions

The definition of terms used in the Distributed Energy Resources and Combined Heat and Power communities were established based on system size and design and operation. This has appeared to be the most logical and descriptive way to present the terms. The disadvantage with this approach is that the non-electric energy production in CHP systems is not directly reflected.

DER and CHP can contribute to the transformation of the energy future of the United States. CHP offers significant, economy-wide energy efficiency improvement and emissions reduction potential. Our existing system of centralized electricity generation charts an unsustainable energy path, one that includes increasing fuel consumption and carbon emissions. A recent study found that instead of building new power plants to meet electrical demands, the installation of DER could reduce CO_2 and NO_x emissions by 50% or more (Kaarsburg, Gorte, Munson, 1999). Besides saving energy and reducing emissions, distributed generation also addresses emerging congestion problems within the electricity transmission and distribution grid.

The terms that have been presented in this study aim to bring clarification to the growing and complicated areas of Distributed Energy Resources and Combined Heat and Power. The next step in this process is for the industry to consider this set of terms to begin using greater consistency in terms and definitions. Such consistency is necessary for accurate data collection: a global terminology will make possible the development of metrics to track DER and CHP installations and the integration of these systems into the nation's energy portfolio.

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