Microgrid Power Systems

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Introduction

Evolutionary changes in the regulatory and operational climate of the electric utility industry and the emergence of smaller generating systems such as microturbines have opened new opportunities for on-site power generation by electricity users. *Distributed energy resources* (DER) - small power generators located at users' sites where the energy they generate is used - have emerged as a promising option to meet growing customer needs for electric power with an emphasis on reliability and power quality. When aggregated, distributed energy resources such as photovoltaics, wind generators, fuel cells, microturbines, and other small generation sources can form into virtual power plants. And when coupled with intelligent control systems and directly fed loads, they become microgrids. There is significant potential to organize these resources into microgrids to meet both the customer and utility needs.

The microgrid represents an entirely new approach to integrating DER. Traditional approaches for integrating DER focus on the impacts on grid performance of one, two, or a relatively small number of small sources. Traditionally utilities have required interconnected generators to shut down automatically if problems arise on the grid. By contrast, the microgrid is designed to seamlessly separate or *island* from the grid and reconnect to the grid once the grid is re-stabilized.

At present, the electric grid in the United States is composed of three very large grids. Microgrids become a "grid within the grid" and create an entirely new approach to how the US electric system is configured. The advantage of microgrids includes increased reliability and power quality and increased autonomy with respect to the main grid, offering greater resilience in extreme weather conditions. Microgrids are growing in popularity due to both extreme weather events and the availability of newer equipment, enabling the implementation of intelligent generation, storage, and loads managed by the microgrid controller.

The generally accepted definition of a microgrid is:

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and that connects and disconnects from such grid to enable it to operate in both grid-connected or "island" mode.

Important concepts in this definition are:

- A microgrid fixed physical boundaries
- Has distributed energy resources (DERs) and load
- Can disconnect from and parallel with the area electric power system
- Can be intentionally islanded

Following on the definition, not only is a microgrid delimited geographically, it is connected to the electric power system at one point, known as the *point of common coupling* (PCC), and is interconnected with only one utility substation. The microgrid can automatically transition to/from and operate islanded, operates in a synchronized mode when utility-interconnected, and is compatible with the electric power system protection devices and coordination. The microgrid generation may include renewables, fossil-fueled generators, battery storage, fuel cells, and combined heat and power (CHP) systems. The microgrid must have an energy management system to control power exchanges, generation, load, storage, and demand response and load-management controls to balance supply and demand.

Note that microgrids are not a replacement for traditional utility infrastructure, but instead form a self-contained organization of distributed generation and demand management that is capable of self-balancing when necessary. Individual microgrids may, in fact, spend most of the time operating in a grid-tied mode, with power flowing both ways between the microgrid and the surrounding system. A parallel bidirectional connection can achieve operational goals, such as improved reliability, cost reduction, and diversification of energy sources. The option to separate from the grid provides a backup or emergency operation mode.

> "It is not the type of generation, load, or its associated intelligence that defines a microgrid, but rather **the ability of the local power-generating system to alter its association with the larger grid."** - EPRI

Microgrids may contain elements of other grid-modernization technologies such as renewable generation, demand response, and energy storage, but these are not required for the existence of a microgrid. In most microgrids in which full-time distributed generation has been installed, the solution is based on conventional generators which use local waste fuels, or which operate as cogeneration facilities such as combined heat and power systems. Backup and emergency systems, such as diesel generators in hospitals, may operate in parallel with the grid for the purpose of routine testing. Including reliability and economic applications, some of the basic "building blocks" of microgrids may already reside in many networks. A very important feature is also to provide multiple end-use needs such as heating, cooling, and electricity at the same time since this allows increased energy efficiency due to waste heat utilization for heating, domestic hot water, and cooling purposes.

Electric Utility Power Industry

To understand the place for microgrids, it helps to have a broad understanding of the electric power industry. The electric power industry is huge, with over $400 billion in annual sales and 150 million customers. The industry is divided into three distinct categories: Generation, transmission, and distribution. Many utilities – especially large utilities - own assets in all three categories while some only own assets in one or two categories. See Figure 1.

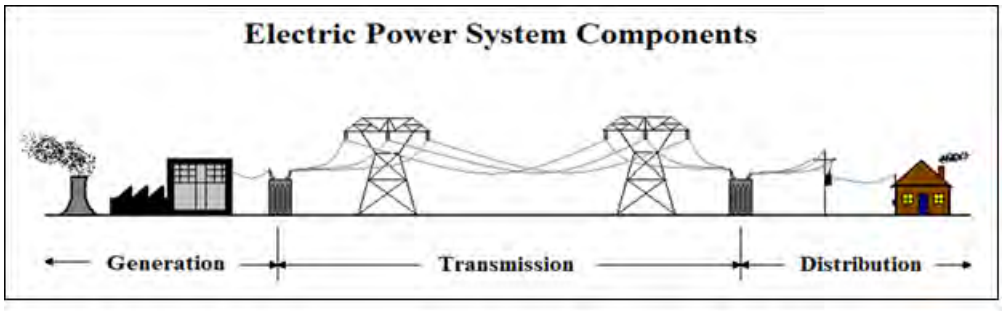

Figure 1

The distribution component of the electric power industry is where practically all-electric energy consumers receive their power. This segment of the power industry comprises about 30% of the market capitalization and has over six million miles of power lines. Distribution lines are typically operated at between 15kV to 25kV, and – unlike the transmission system – it is predominately a radial, one-way system. It was never intended to operate with bi-directional power flows, and this creates some issues with distributed energy resources and microgrids.

Some microgrids may be connected directly to the transmission system, where bi-directional power flows are the norm. We hear the term "the grid" a lot when talking about the electric utility industry. Technically there are three official "grids" in the United States. These transmission grids include The Eastern Interconnect, the Western Interconnect, and the Electric Reliability Council of Texas. See Figure 2.

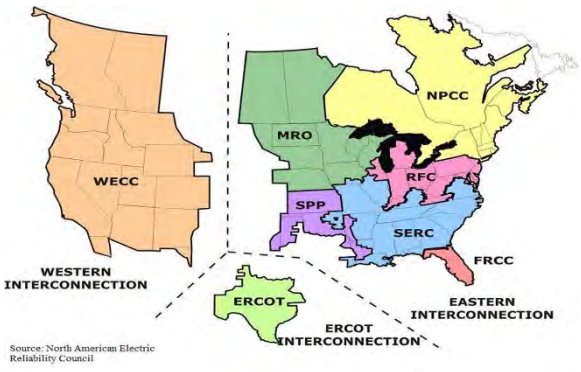

Figure 2

The electric power industry is governed by the Federal Power Act, which is administered by the Federal Energy Regulatory Commission (FERC). FERC has delegated grid reliability management to the National Electric Reliability Corporation (NERC). Local utility oversight is provided by State utility commissions and other local governing organizations.

A unique feature of a microgrid is that – from the utility's perspective – it appears as a single self-controlled entity; that is, it appears to the grid as indistinguishable from other currently legitimate customer sites. Maintaining this profile relies on the flexibility of advanced power electronics that control the interface between micro sources and their surrounding utility systems. See Figure 3.

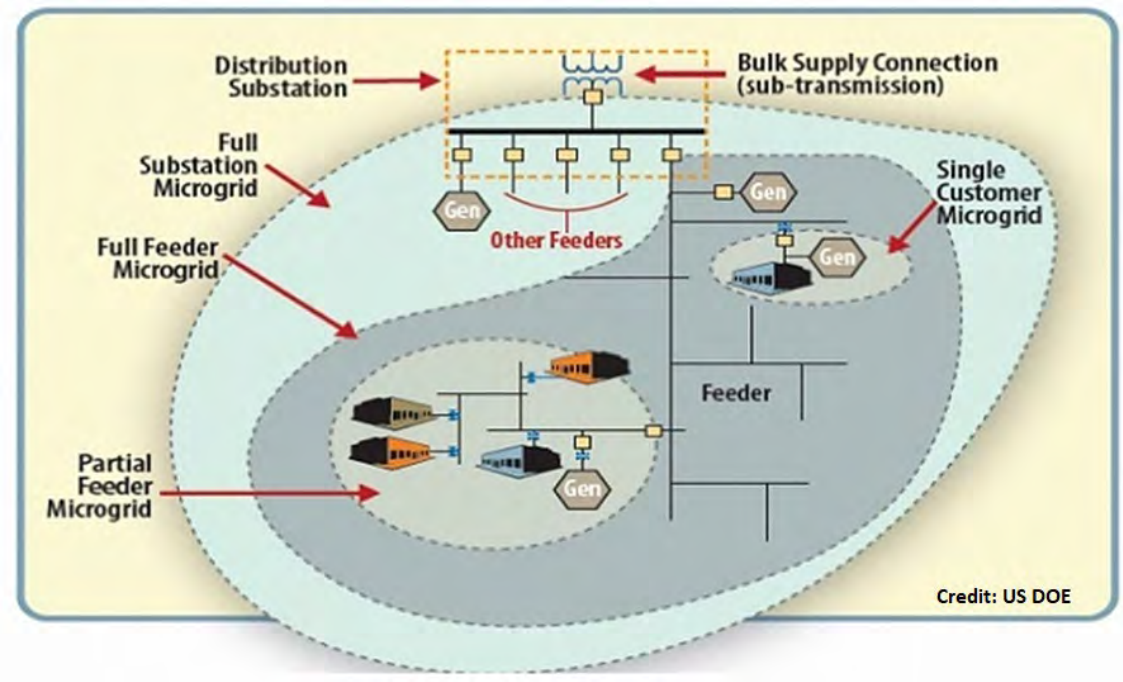

Figure 3

Current attention tends to focus on assessing how many DERs can be *tolerated* before their collective electrical impact begins to create problems, such as excessive current flows following faults and voltage fluctuations. The microgrid architecture is designed to ensure it complies with grid rules and does no harm beyond what would be acceptable from an existing customer. An attractive proposition is that the microgrid could provide interruptible load and serve as a small source of power or ancillary services to help maintain the reliability of the grid. The benefits it could offer to the distribution system are congestion relief, postponement of new generation or delivery capacity, response to load changes, and local voltage support.

From the grid's perspective, the central advantage of a microgrid is that it can be regarded as a controlled entity within the power system that can be operated as a single aggregated load. The microgrid can establish binding contractual agreements with the bulk power provider covering its pattern of usage that are at least as strict as those covering existing customers, and it potentially could provide additional services.

Customers benefit from a microgrid because it is designed and operated to meet their local needs for heat and power as well as provide uninterruptible power, enhance local reliability, reduce feeder losses, and support local voltages/correct voltage sag.

Electric utilities, and especially distribution utilities, are adopting microgrid concepts that:

- Enhance reliability and increase the efficiency of the power delivery system;
- Allow for the integration of renewable energy sources and their balancing; and
- Increase the resilience of the distribution grid by enabling the integration of dispatchable distributed generation.

Control and protection are challenges for microgrids, and this concern will be discussed in Chapter 4.

Microgrid Features

The following five key features characterize a microgrid:

1. **Local.** Traditional electric grids serve enormous service areas. Generation is often many miles from the end-user, and power must be transmitted long distances, which creates inefficiencies. In contrast, microgrids are a small collection of generating sources – called micro-sources – that supply just enough power for the customers in surrounding the generation.

2. **Independent.** Typically, a microgrid operates in parallel (connected to the utility grid) though it has the capability to disconnect from the utility grid and operate as an independent mini-grid or micro-grid. This is known as *islanding* and allows the system to continue to provide utility-grade electricity during power disruptions on the utility grid.

3. **Smart.** A key feature which is a computer system that manages generation, energy management systems, and load control devices. The microgrid controller may provide many services from selling power to the utility grid when economical to preserve its own load during critical peak pricing.

4. **Reliable.** The electric grid's average outage record (known as SAIDI) is 8,760 hours in one year, this equates to "3-nines" (almost "4-nines") reliability. Microgrids have outage rates of 99.999% or "5-nines," which is unrealistic. To be fair, most utilities also have at least "4-nines" or even "6-nines" reliability. Approximately 90% of outages occur on the distribution system where microgrids reside. Therefore, dedicated microgrids will likely be very reliable for their customers.