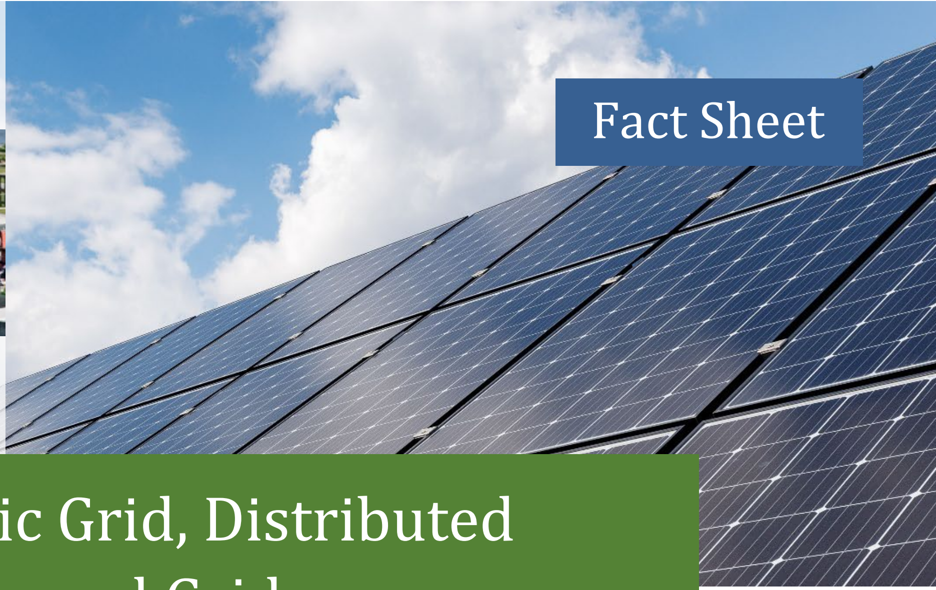
Community Planning for Solar

UMassAmherst | Clean Energy Extension



Fact Sheet

The Electric Grid, Distributed Generation, and Grid Interconnection

2. Solar Assessment

This fact sheet is part of the *Community Planning for Solar* toolkit designed to help Massachusetts municipalities and others proactively plan for solar development in their communities. For more information, please visit: https://ag.umass.edu/solarplanning

This fact sheet will walk you through the electricity system, and help you understand how the grid is changing as distributed generation (DG) electricity sources become more common.

Components of the Electricity System

The electricity system in North America is comprised of many individual components:

- Electricity is produced at **electricity generation facilities**, which include large power plants (e.g., nuclear, hydropower, fossil fuel) as well as small “distributed generation” facilities (e.g., rooftop solar systems).
- Electricity is consumed by **businesses, institutions, residential households, and government buildings** for a variety of purposes, including lighting, running appliances, powering technology, heating, and industrial processes.
- The electricity **“grid” of transmission and distribution lines** carries electricity from generation facilities to consumers.

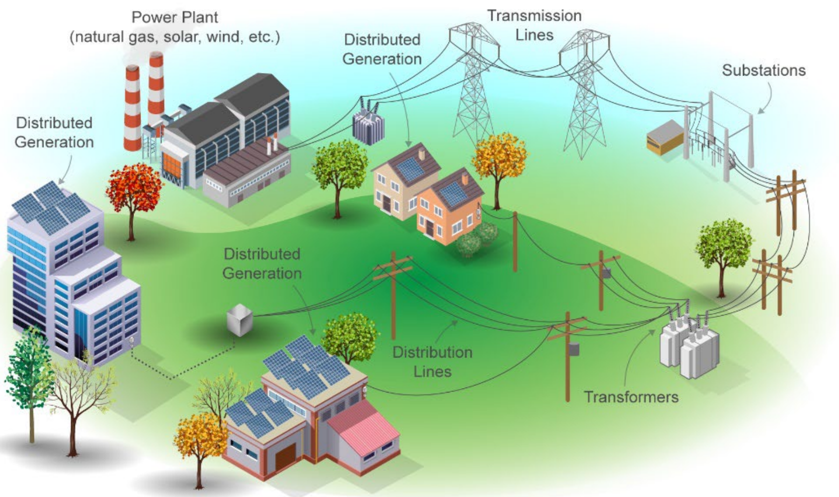


Figure 1. Conceptual illustration of the electricity system’s various components and connections. *(Credit: National Renewable Energy Laboratory)*

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Electricity Grid Basics

Power lines that carry electricity are often described in terms of their voltage, which is measured in kilo-volts (kV).

Transmission lines are high-voltage lines that carry electricity over long distances; the high voltage reduces power losses when electricity is transported over hundreds of miles. The "interstate highways" of the grid are transmission lines that carry electricity at quite high voltages – 345, 500, or even 765 kV. Smaller transmission lines, typically 69 or 138 kV, are like two-lane state highways, carrying electricity from a power plant to an area with many electricity consumers, or connecting two metropolitan areas.

When transmission lines reach a **substation**, electricity is "stepped down" to a lower voltage and transferred to **distribution lines**. Distribution lines are lower voltage lines (typically 13-34 kV) that distribute power to individual businesses and households. Some distribution lines are **three-phase** lines, designed to serve large commercial or industrial buildings that use large amounts of electricity or have sensitive equipment that requires high power quality and consistency. Other distribution lines are **single-phase**, suitable for residential-scale lighting and heating loads.[1]

Alternating Current vs. Direct Current

The North American grid carries electricity primarily in the form of ***alternating current*** (AC). Most transmission lines – and all distribution lines – carry AC electricity. This is the same form of electricity that comes through electricity outlets and is used by most appliances and lighting in our homes. Traditional, large-scale electricity generation plants (like coal and natural gas plants) produce AC electricity. The other form of electricity is ***direct current*** (DC) - the form stored in batteries and used by flashlights, cell phones, and other devices. Electricity generated by solar photovoltaic arrays is in the form of DC. This DC electricity must be converted to AC using an inverter before it can be distributed through the grid. A few high-voltage DC transmission lines exist around the country; these DC lines offer some advantages over AC, but are not yet common in the United States.

[1] Single-phase lines typically have one line that carries power and one neutral line; three-phase lines have three wires which are all carrying power out of phase with each other, exactly 120 degrees apart.

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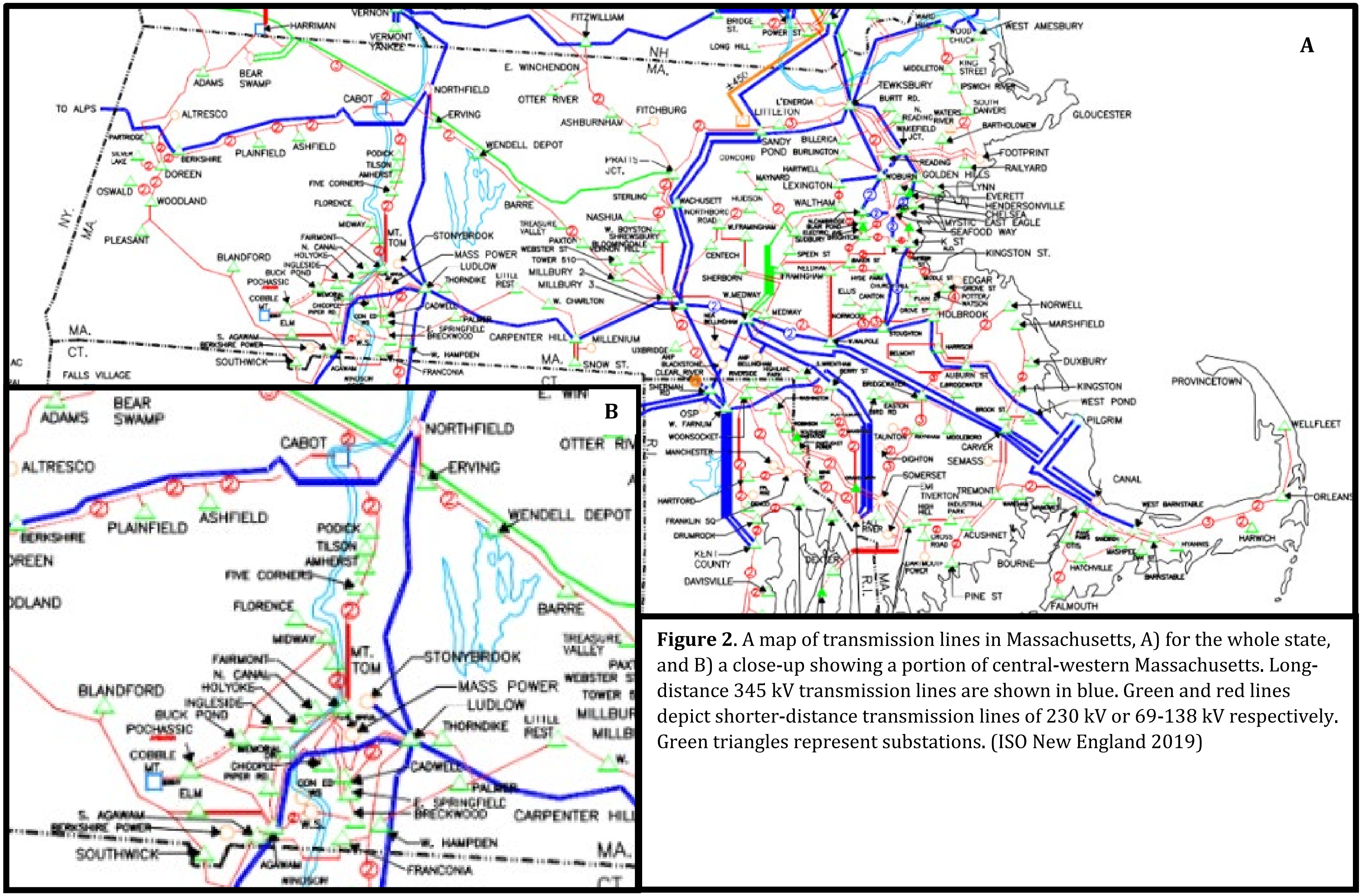

Figure 2. A map of transmission lines in Massachusetts, A) for the whole state, and B) a close-up showing a portion of central-western Massachusetts. Long-distance 345 kV transmission lines are shown in blue. Green and red lines depict shorter-distance transmission lines of 230 kV or 69-138 kV respectively. Green triangles represent substations. (ISO New England 2019)

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Grid Ownership & Oversight

Transmission lines are typically owned by major electricity utilities operating in a region. In Massachusetts, for example, most transmission lines are owned by Eversource (formerly NSTAR and WMECO) or National Grid.

Independent organizations called **regional transmission operators** (RTOs) or **independent system operators** (ISOs) oversee the electricity system in many regions of the country. They are responsible for ensuring there is sufficient electricity generating capacity to meet demand, maintaining the reliability of the grid infrastructure, and providing a platform for electricity market transactions. ISO New England (www.iso-ne.com) is the non-profit organization that serves the states of Massachusetts, Maine, New Hampshire, Vermont, Connecticut, and Rhode Island.

Distribution lines are typically owned and maintained by the local electricity distributor that delivers power to consumers. This may be the same utility that owns transmission lines, or a cooperative or municipal utility that purchases power to deliver to customers. In Massachusetts, distribution lines are typically owned by Eversource, National Grid, Unitil, or a municipal utility.

The distribution system of the Massachusetts electricity grid is overseen by the Massachusetts Department of Public Utilities Commission (MA DPU), which regulates electricity prices and performance of electricity providers in the state.

Distributed Generation Electricity Sources

Transmission and distribution lines in the electricity grid were originally designed to function similarly to one-way streets: power flowed from large, centralized power plants to transmission lines, from transmission lines to distribution lines, and finally from distribution lines to homes and businesses. Increasingly, however, we are beginning to see many smaller electricity-generating systems that connect to the grid via distribution lines rather than transmission lines. These electricity-generating facilities are often referred to as **distributed generation**, or DG, electricity sources. They are "*distributed"* both in the sense that they connect to electricity distribution lines, and that they are more widely distributed as smaller facilities spread across the landscape, located on small tracts of land, parking lots, and rooftops.

DG electricity sources include many types of renewable energy systems – like rooftop or ground-mounted solar arrays, or small clusters of wind turbines – but they also include diesel-powered back-up generators and combined heat and power facilities. The size or *capacity* of energy-generating facilities is typically measured in megawatts (MW). Where a coal power plant might have a capacity of 50-150 MW or a nuclear power plant might be upwards of 3,000 MW in size, DG facilities are often much smaller. In Massachusetts, for example, the large majority of solar PV facilities are DG electricity sources. The largest solar arrays in the state are typically no more than 5 MW in size, and residential rooftop solar systems may be as little as 5 kW (0.005 MW). Small and medium-sized solar facilities are often built and connected to the grid at buildings or other sites where electricity is used; these are often referred to as "behind-the-meter" sites. Larger facilities may be constructed as "stand-alone" systems that connect directly to the grid at locations where there is no on-site electricity use (except for components like lights that aid in facility operation).

Interconnecting DG Systems to the Grid

DG electricity facilities require that distribution lines act as two-way streets rather than one-way streets, allowing both for energy to flow into the grid from DG sources *and* for energy to continue to flow outward into individual homes and businesses. Balancing this two-way flow of electricity is more complex than managing a one-way flow. In some cases, components of the grid may need to be upgraded to ensure reliability and safety as DG sources are connected to the grid. This is especially true when electricity sources like wind and solar are added to the grid, because they supply electricity in an intermittent and variable manner.

Before a DG electricity facility is built, it is necessary to ensure it will be able to connect to the grid without compromising the safety and reliability of the electricity system. **Interconnection** is the process via which the owner, developer, or installer of the DG facility receives permission from the local utility to connect to the grid at a specific location. For small, residential-scale solar systems, this may just be a matter of filling out a short application form. For large, commercial-scale facilities, utilities typically conduct a study to understand the potential impacts of the proposed facility and determine if any upgrades are required to grid components, such as transformers, before interconnection can occur. The facility developer typically pays for the study. In Massachusetts, the developer and utility then commit to an *Interconnection Service Agreement* (ISA) for the project, which may include a requirement for the developer to cover the cost of grid upgrades. In some states, including Massachusetts, multiple projects proposed on the same distribution line or portion of the grid may be considered together as one group for the purposes of interconnection. This can help streamline the review process for projects being proposed on the same line or same portion of the grid.

Hosting Capacity

The *hosting capacity* of a distribution line describes the combined capacity of DG electricity facilities that can interconnect via that power line without the need for significant equipment upgrades.

In most locations – including those served by single-phase distribution lines – multiple small solar systems of up to 50 kW (0.050 MW) can typically be incorporated without adverse impacts on grid reliability. In areas served by three-phase power lines, multiple solar systems of up to 200 kW can often be interconnected without significant challenges. However, for larger systems, it is necessary to ensure that there is sufficient hosting capacity available on the distribution line before these facilities can be built and interconnected. Otherwise, power lines or substations may require upgrades before additional facilities can be interconnected, in order to avoid compromising reliability. While not true across the board, an industry rule-of-thumb is that a total of 6 MW of energy facilities can be connected safely to every 13.8 kV distribution line.

In urban areas, large DG electricity facilities may be able to connect to the grid without significant challenges. In rural areas, however, where many towns are served by one or a few low-voltage lines, the local grid can quickly become *saturated*. When a distribution line is saturated, it essentially is full – there is not sufficient hosting capacity to incorporate additional medium-sized or large energy facilities without significant (and potentially expensive) upgrades.

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If circuits are currently saturated, it does not mean that no more DG systems can be added to that portion of the grid, but it does suggest that upgrades may be needed before additional projects can be interconnected. Companies developing large solar projects that will be lucrative may be willing to pay for significant upgrades to certain circuits, either individually, or as part of a group with cost sharing. These upgrades may open new hosting capacity for other projects. Available hosting capacity may also change with new regulations or programs. In Massachusetts, for example, new DPU policies regarding grid upgrades may make available additional hosting capacity.

Hosting Capacity Maps

Some states, including Massachusetts, now require that regulated utilities like National Grid and Eversource provide publicly available maps indicating the hosting capacity of distribution lines in their service territories. These maps can help inform decisions about where new DG energy facilities can be located. Figure 3 is an example of a hosting capacity map in Massachusetts.

For information on how to determine the current status of hosting capacity in your municipality, see the guide *Conducting a Solar Resource and Infrastructure Assessment* (Step 2, Item b).

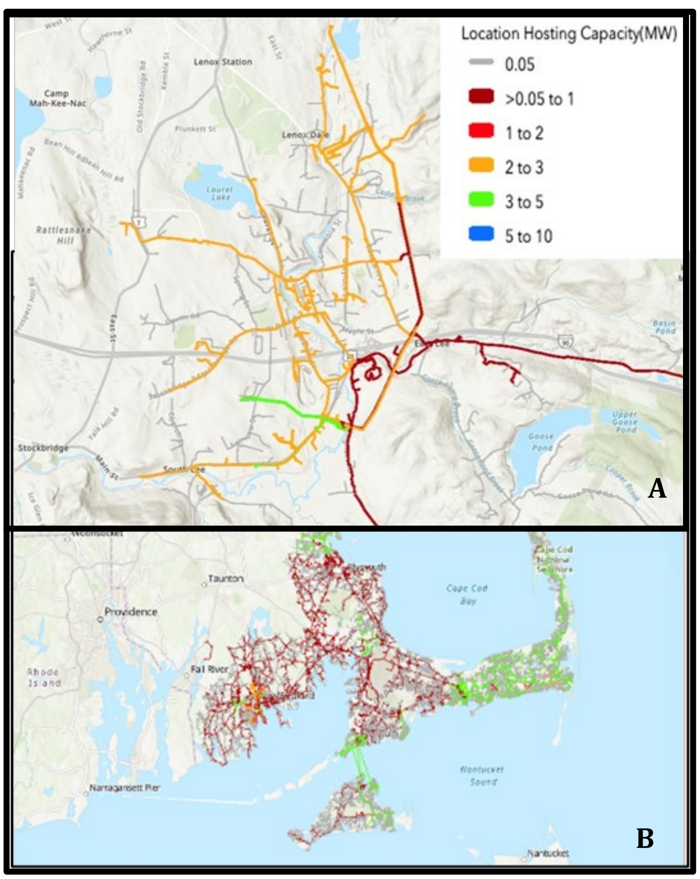

Figure 3. Examples of hosting capacity maps from Massachusetts (Eversource 2020), showing (A) a close-up view and (B) southeastern Massachusetts. The green lines show distribution lines that can host an additional 3 to 5 MW of distributed generation, the orange lines can host 2 to 3 MW of additional capacity, and the dark and light red lines can host less than 1 MW or 1-2 MW of capacity respectively. In the close-up (A), note the distribution lines outlined in gray; these are single-phase lines which can typically host up to 0.050 MW, or 50 kW, of capacity.