NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Energy Analysis

Solar Power and the Electric Grid

In today's electricity generation system, different resources make different contributions to the electricity grid. This fact sheet illustrates the roles of distributed and centralized renewable energy technologies, particularly solar power, and how they will contribute to the future electricity system. The advantages of a diversified mix of power generation systems are highlighted.

Grid 101: How does the electric grid work?

The electric grid—an interconnected system illustrated in Figure 1—maintains an instantaneous balance between supply and demand (generation and load) while moving electricity from generation source to customer. Because large amounts of electricity are difficult to store, the amount generated and fed into the system must be carefully matched to the load to keep the system operating.

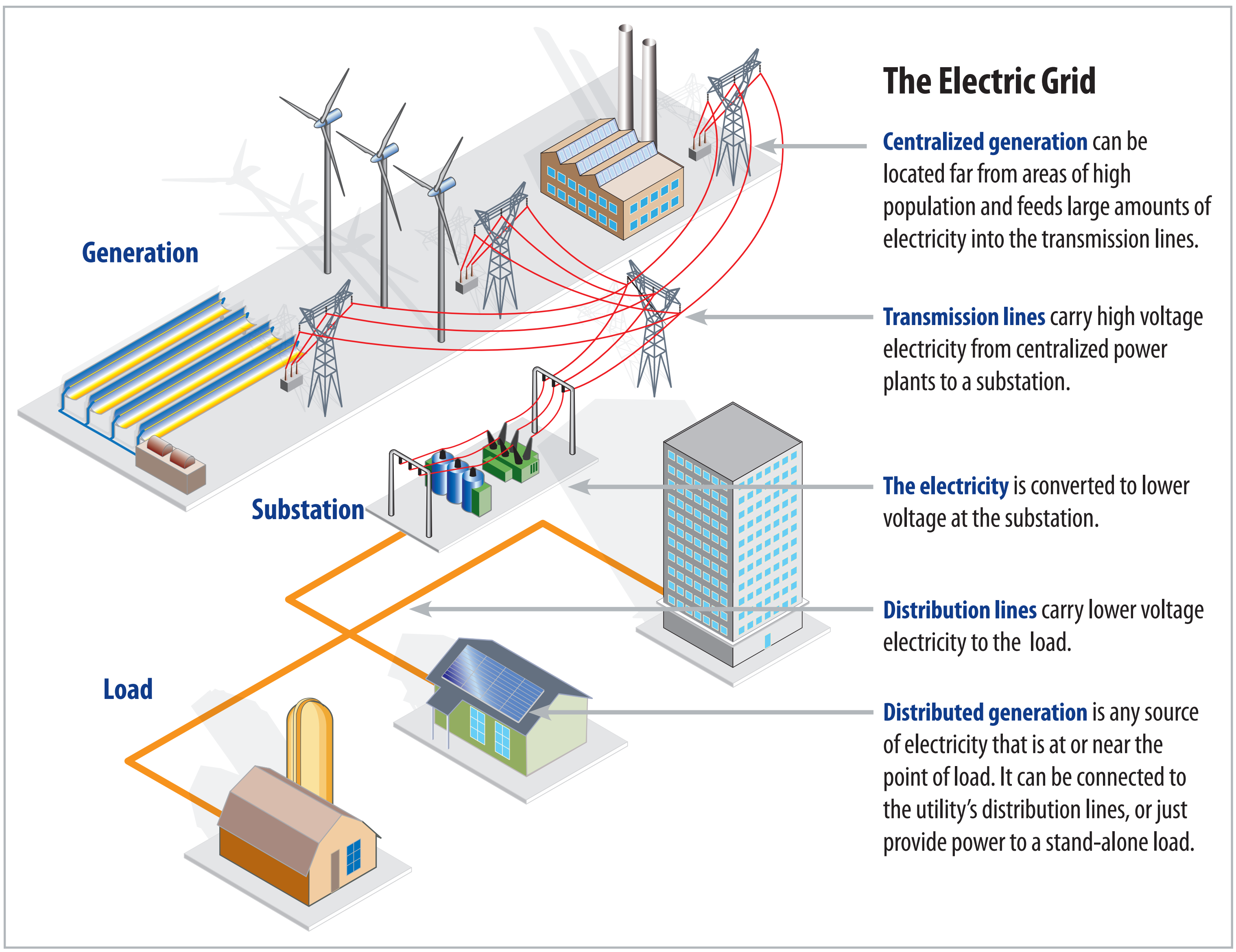


Figure 1. The electric grid

Why do we need an electric grid and what are the benefits?

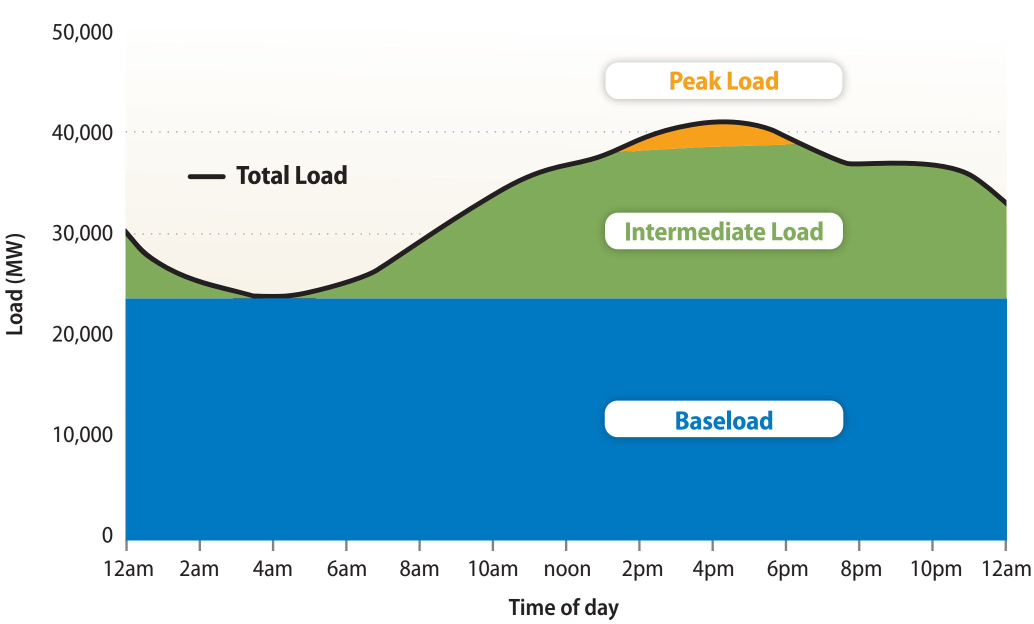
The level of demand for electricity in any one area is so variable that it is more efficient to combine demand from many sites into an overall regional load. This regional electric load is then met by the output of a fleet of generators that can be controlled and managed for optimal performance. In part, the grid was developed to allow generators to provide backup to each other and share load.

The grid also allows generators to be located closer to resources (e.g., fuel supply, water, available land) and ship electricity over the transmission and distribution network to different load centers. Utility-scale solar and wind power plants are conceptually similar to conventional generators—they generate electricity where the necessary resources are located, typically in remote areas where the fuel (sunlight or wind) is most abundant. These attributes—consolidating variable individual loads into more predictable regional loads, siting plants near their resource base, and extensive transmission lines—help the grid provide electric power with good reliability and low cost.

What roles do the various types of generation play in the grid? Where does renewable energy fit in?

Different types of electricity users demand power in different amounts and at different times; this results in a load curve (Figure 2) that varies by time-of-day and season.

Figure 2. 2009 Summer Day Load Curve for California



Generation technologies do not simply provide kilowatt hours to the grid. In varying degrees, they also provide ramping ability to follow load, stay ready to meet demand peaks (dispatchability), and adjust their operating conditions to maintain grid stability. Power plants meeting baseload must run 24/7 with low operating costs. Power plants providing intermediate load must be able to follow demand throughout the day. Peak load occurs only during times of highest demand. Power plants supplying peak load must ramp up and down quickly to meet sharp increases and decreases in demand, but only run for a few hours at a time. No single generation technology meets all these needs.

Table 1 lists the various loads that must be met by the electric grid and outlines which generation technologies typically meet these needs. Generation fleet diversity is important for reliability. Important features are:

- Some renewable energy technologies provide power only when the resource is available. These resources are often contracted as “must-take” generators, where their output is always used when it is available. However it is difficult to integrate a large amount of “must-take” generation into the grid because its availability is uncertain and constantly changing.
- Photovoltaics (PV) may be centrally located in large plants or distributed on rooftops. Distributed PV has benefits, such as low land use and no transmission needs. Both distributed and central PV are usually “must-take” generators.
- Storing large amounts of electricity is difficult, while storing thermal energy is relatively easy (consider the complexity of a car battery versus an insulated bottle). Because concentrating solar power (CSP) plants collect and convert thermal energy into electricity, they can collect and store thermal energy for later conversion into electricity. CSP plants with thermal energy storage provide assurance that the generator will be available when needed. These CSP plants are dispatchable and can meet intermediate and, potentially, baseload demands.

Table 1. The Role of Different Types of Generation in the Grid

Generator type	Attributes of generator	Technology (typical)	
		Conventional	Renewable
Must-take	Dependent on variable resource Requires additional generation capacity		CSP w/o storage PV Wind
Peak Load	Provides power during peak demand Ramps up and down quickly	Natural gas combustion turbine	PV and CSP[1]
Intermediate Load	Varies production to follow demand Predictable availability	Natural gas combined cycle	CSP with storage[2] Hydropower
Baseload	Low fuel and operating costs Constant rate of production Often very large to benefit from economy of scale	Coal Nuclear	Biomass Geothermal Hydropower

CSP = Concentrating Solar Power; PV = Photovoltaics

[1] Although they do not meet the rapid response requirements of peaking generators, solar PV and CSP generation coincide with summer demand peaks caused by air-conditioning loads, especially in the sunny southwest.

[2] With sufficient thermal energy storage, CSP plants can run as baseload generators. The US Dept of Energy is funding research to explore baseload CSP systems.

Why a mix matters

Our electric supply must keep up with a constantly changing demand for electricity. This effort requires generator technologies with different characteristics. Similar to all generation sources, different renewable technologies have different advantages. For example, wind energy is inexpensive compared to solar, distributed PV provides power at the user with little impact to land, CSP with energy storage contributes dispatchable power to the grid, while geothermal and biomass can provide baseload renewable power. Employing a combination of energy efficiency and renewable energy sources—including wind, solar, geothermal, small hydro, biomass, and ocean power—can reduce fossil fuel consumption and minimize the environmental impact of electricity use, while maintaining reliability.

Why can't all future energy needs be met with rooftop PV and energy efficiency?

Grid-connected, distributed generation sources such as rooftop PV and small wind turbines have substantial potential to provide electricity with little impact on land, air pollution, or CO2 emissions. However, these technologies do not provide all of the characteristics necessary for a consistent electricity supply. Primary limitations on distributed PV generation include ability to provide energy at all times that it is needed and cost.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Rooftop PV has potential to help meet environmental goals for electricity generation.

- Analysis of available roof space indicates that a good fraction of electricity supply, perhaps 10% to 25%, could be met with roof-mounted PV arrays [1]. However, per watt produced, rooftop PV is expensive compared to large-scale, ground-mounted systems. Even when transmission is included, centralized PV and CSP power plants remain the least costly deployment of solar power due to economies-of-scale in construction and operation, and the ability to locate in the areas of best solar resource.
- Without energy storage, PV generation does not provide all of the characteristics necessary for stable grid operation. For example, PV provides the most electricity during midday on sunny days, but none during evenings or at night. PV output can increase and fall rapidly during cloudy weather, making it difficult to maintain balance on a grid with a large penetration of PV. Without a steady supply, additional generating capacity must be

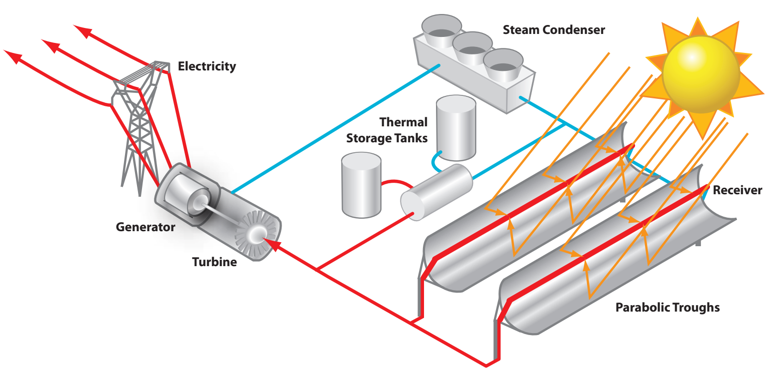
kept available, especially if PV makes up a significant fraction of the generation mix. Finally, while small amounts of PV power can be incorporated into the grid with few changes, the development of grid-monitoring technologies (i.e., the so-called Smart Grid), and more cost-effective electricity storage systems will be needed to deploy large amounts of PV power.

Careful integration of distributed generation and careful deployment of utility-scale generation are needed to maximize our use of solar power.

Although PV deployment may be hampered by integration issues, most CSP plants respond more slowly to changing weather and, especially when combined with thermal energy storage, output from these plants is easier to forecast and integrate into the electric grid. A few hours of thermal energy storage allows CSP plants to cover the evening load curve typical of the Southwest states. The highest penetration of solar power will be possible with a combination of PV and CSP.

Photo courtesy Solar Millennium AG

The 50-MW Andasol-1 CSP plant in southern Spain includes 7.5 hours of thermal energy storage, allowing the plant to continue operation after sunset. Energy storage is provided by holding hot molten salt in large, insulated tanks.



Simplified schematic of a parabolic trough CSP plant with thermal energy storage tanks. Excess solar energy is stored as hot fluid in the tanks during the day and released to power the turbine and make electricity during cloudy periods or at night.

Conclusion

The electric grid is a complex network that is an integral part of our society. Running the grid in the presence of increasing fuel costs and growing environmental concerns will require new technologies and ways to use them. While renewable power technologies will be an essential part of our energy future, no one technology can provide all of the energy and services we need. Careful integration of distributed generation and careful deployment of utility-scale generation will be needed to provide the mix of power and reliability that we require for a healthy electric supply as renewables contribute an increasingly larger share of our energy needs.

For more information:

1. "Supply Curves for Rooftop Solar PV-Generated Electricity for the United States," by Paul Denholm and Robert Margolis and Margolis, NREL/TP-6A0-44073, November 2008, http://www.nrel.gov/docs/fy09osti/44073.pdf

2. Western Governors Association, Western Renewable Energy Zones Study, http://www.westgov.org/wga/initiatives/wrez/index.htm

3. National Renewable Energy Laboratory, http://www.nrel.gov/solar/

4. Solar Energy Industries Association, http://www.seia.org/

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