POWER GRID AND ELECTRICITY DELIVERY

Overview

Available at:
www.powernaturally.org
October 2005
NYS Energy Research & Development Authority
17 Columbia Circle
Albany, NY 12203-6399
www.nyserda.org

Prepared by:
Global Energy Concepts

This document is one of a series of reports and guides that are all part of the NYSERDA Wind Energy Tool Kit. Interested parties can find all the components of the kit at: www.powernaturally.org. All sections are free and downloadable, and we encourage their production in hard copy for distribution to interested parties, for use in public meetings on wind, etc.

Any questions about the tool kit, its use and availability should be directed to:
Vicki Colello; vac@nyserda.org; 518-862-1090, ext. 3273.

In addition, other reports and information about Wind Energy can be found at www.powernaturally.org in the on-line library under "Large Wind."

NOTICE

Table of Contents

List of Figures

Power Grid and Electricity Delivery Overview

The history of the U.S. electric power grid is a complex and lengthy topic that is beyond the scope of this paper. However, it is important to realize that the power grid, in its current form, was built through an amalgamation of much smaller utility systems. Originally, the smaller utility systems were constructed and operated to serve local power needs and were rarely interconnected to other neighboring systems. These small systems were dominated by a large, central generating station that delivered power over a small radial network of high-voltage transmission lines and lower voltage distribution lines. Over time, operators and utilities realized that reliability improved when systems were interconnected and generation sources diversified. This interconnection of neighboring power systems offered the ability to transfer power on a local or regional basis. However, the system was never designed to transmit large quantities of power over long distances, such as from the Mid-west to the Northeast.

Therefore, although vast quantities of wind energy are available in the Mid-West and Western states, the existing power grid is incapable of delivering that power to the high load areas of the Northeast in a cost-effective manner. This limitation of the power grid explains why wind farms, like all electrical generating facilities, need to be located relatively close to the load centers they will serve.[1]

The electric transmission and distribution system connects generating stations with power users. Figure 1 shows a simplified view of the transmission and distribution systems and how a wind power facility interconnects with the system. It consists of high-voltage transmission lines, which convey large quantities of power; substations, which convert electricity from one voltage to another; lower voltage distribution lines, which serve neighborhoods and individual customers; and safety and control systems to keep the grid operating safely.

Most of the power delivered to power grids comes from large central power stations, such as coal- and natural gas-burning plants, with capacities of roughly 50 to 2000 MW. Because they use fossil fuels, these power plants can control how much power they generate by increasing or decreasing how much fuel they burn. Wind power projects differ in that wind is an intermittent resource. Individual turbine units within a project are also much smaller than fossil fuel plants (roughly 200 kW to 3 MW), and wind power projects use different types of electrical generator hardware.

Regardless of their source, once electrons are pushed onto the transmission system, they follow the path of least resistance to ground, eventually traversing distribution lines to be delivered to industrial or residential users. The path from the bulk transmission system to a home includes various step-down transformers that convert electricity from high-

[1] For more information on the development of the electric system in the U.S., see Thomas Hughes' book, *Networks of Power: Electrification in Western Society 1880-1930*.

voltage transmission lines (100 kV to 500 kV) to a distribution level voltage such as 12.5 kV to 34.5 kV. Before entering a home, the electricity passes through another transformer that steps the voltage down to a level that appliances and electrical systems can use. Within households and businesses, typical voltages are 120 or 240 volts. Commercial and industrial customers typically use power at 120 to 600 volts (and greater). Neighborhoods and large industrial users are served at 10 kV to 50 kV.

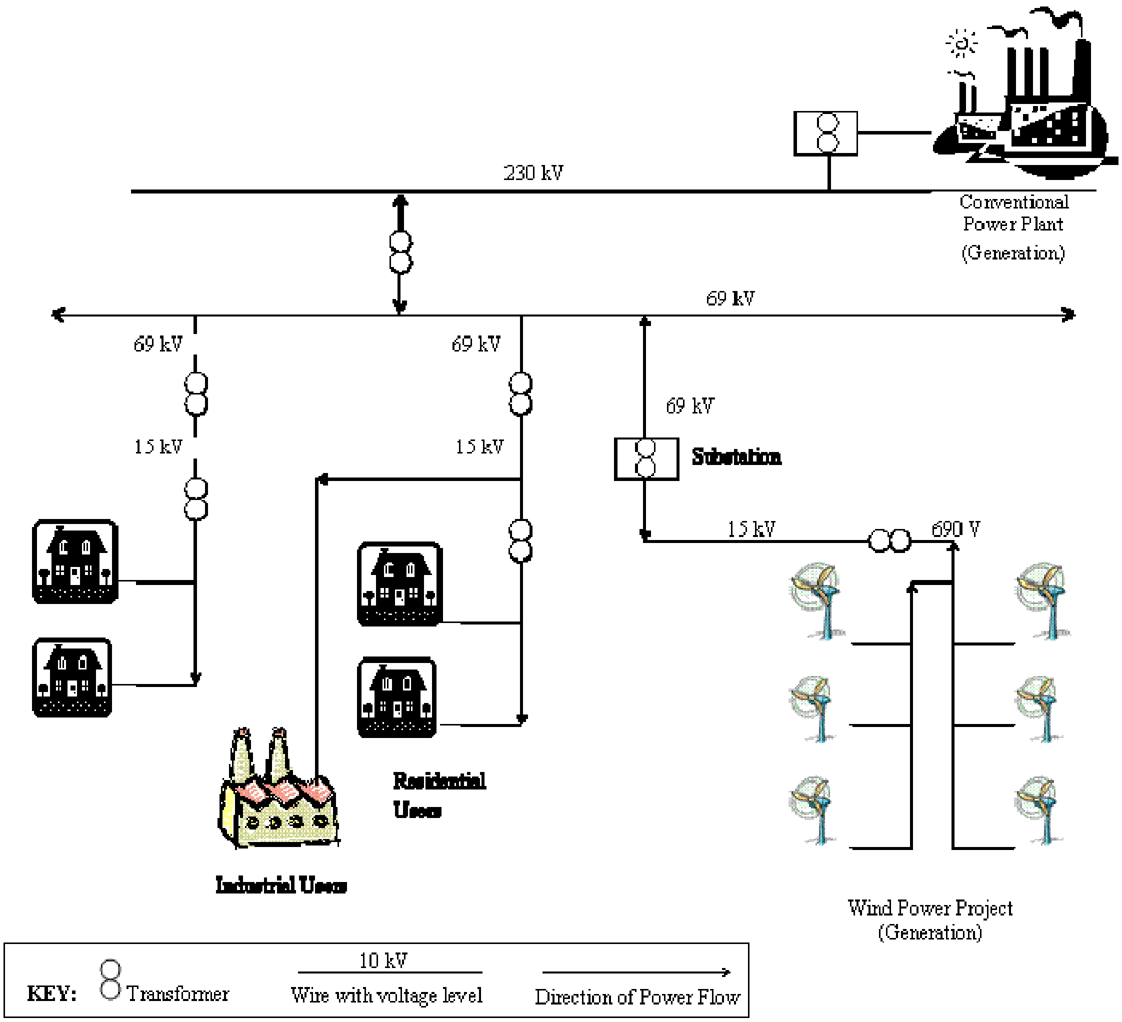

Figure 1. Power Grid Schematic

Utility-scale wind turbines typically generate power at 690 volts, and this voltage is typically stepped-up to 20 to 50 kV for collection in underground wires within the wind farm, and potentially to a higher level at a substation located at or near the project for transmission to power users.

Electrons generated by specific energy sources cannot be delivered to specific locations via the power grid. There is no way of knowing if the electrons delivered to a home were generated by coal, natural gas, nuclear, hydroelectric or wind power. Instead, electricity from all these sources goes into one big pool, and users draw from this pool. When new wind farms are built, more renewable power flows into the pool, displacing older, "dirtier" generation sources. More wind farms in a region mean a larger percentage of that region's electricity is from renewable, non-polluting sources. Highly accurate revenue meters used by the utilities and power station owners allow determination of the mix percentages and provides a means for accounting of all renewable power delivered.

The only way to guarantee that a consumer receives electrons exclusively from a renewable energy source is to install that source on the consumer's side of the utility meter. A small-scale wind turbine is one example of such a direct-delivery system. **Figure 2** shows how energy produced by the small wind turbine first serves the load at the house, with any excess sold into the power grid. Power from the grid can also supplement energy produced by the wind turbine at times when the wind is not blowing.

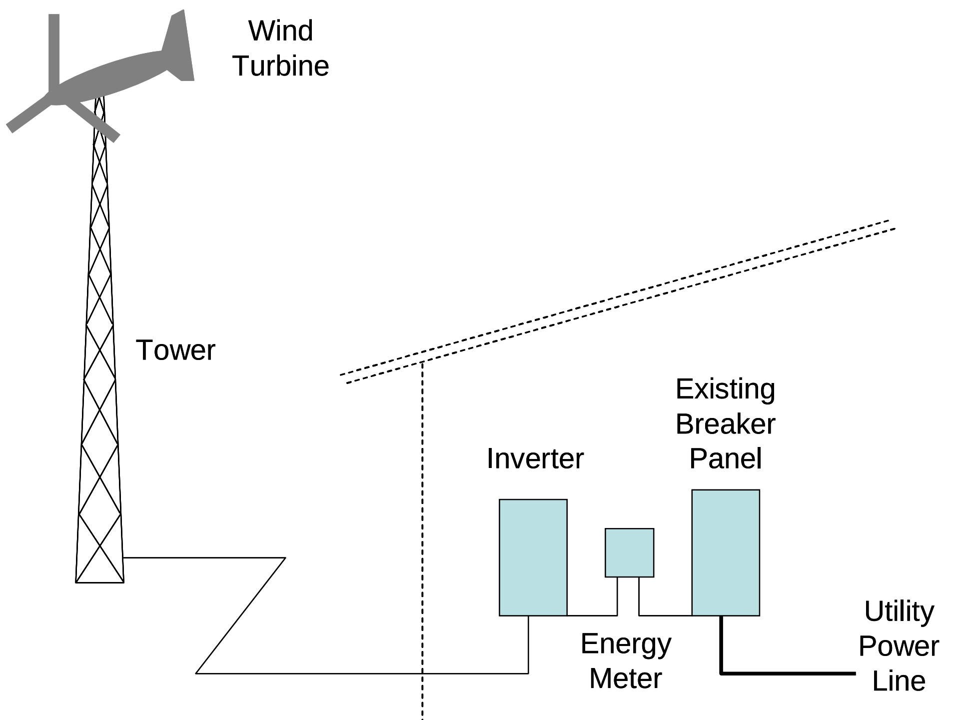

Figure 2. Schematic of Direct Power Delivery to the Home

Although the electric grid cannot selectively deliver renewable energy to your home, consumers can help promote the development of renewable energy by purchasing "green" power—that is, through the electric grid, consumers can pay for the generation of electricity that has been certified as renewable under strict accounting practices. Accounting of wind power generation is based on meter readings at the project and at the customer's location. Certification programs such as Green-e (www.green-e.org) and the Green Pricing Accreditation Initiative (www.resourcesolutions.org/greenpricing.htm) have been created to audit and verify that green product suppliers truly deliver the green energy purchased by customers.

Wind Power: Reliable but Intermittent

One distinctive feature of electricity is that it cannot be stored[2]. At any time on a grid, there is an instantaneous balance between production and consumption. When a customer turns on a light or appliance, a power station somewhere on the grid must slightly compensate to accommodate the increased load. Relatively few power users schedule their consumption, so grid and power plant operators routinely vary power production to match the demand.

Similar to the constant fluctuations in electricity demand, wind power production also fluctuates. This is because wind farms only produce electricity during certain wind speeds, typically between 4-25 m/s (9-56 mph) at hub height. The variations in wind farm generation output affects the balance of production and consumption in much the same way that varying consumption does.

The amount of energy an electrical generator is capable of producing is referred to as its energy capacity. For a 100 MW wind energy project, the instantaneous capacity could vary between 0 and 100 MW on any given day. This type of delivery is termed 'intermittent.' Because the wind is always blowing somewhere, the more wind farms there are in a region, the less intermittent their power generation is likely to be. However, some intermittency will remain. For any given wind turbine, its output over the course of one year will average to about 35% of its rated capacity.

It is important to remember that intermittent power is not the same as unreliable power. Reliability measures the amount of time the plant is available to produce energy.

For example, A 100 MW coal, gas or nuclear plant can typically deliver the 100 MW whenever called upon, allowing for the different response times of different technologies (e.g., minutes for a natural gas fired plant to hours for a coal burner to respond to changes in demand). Thus, their power delivery is not intermittent. However, these plants will have a certain number of forced outage hours a year as well as scheduled outage hours. Forced outages are random, and for example could be 10% of the hours in the year. In this case, there would be a 90% chance that the unit(s) would be available when needed, meaning their reliability factor would be 90%.

Wind turbines tend to be highly reliable. However, unlike these thermal plants, a wind power plant will have outages due to seasonal and daily variations in the wind resource. Because of this, wind power plants may have a capacity factor of 30%-40%. This represents the average amount of time during the year that the plant produces its rated

---

[2] "Electricity storage" technologies do not store electricity itself; they always convert the electricity to other forms for storage (chemical reactions in batteries, gravity storage in the case of pumped storage, etc.).

amount (in this case, 100 MW). The capacity factor will also vary depending on the time of year. These variations can be quantified and reasonably predicted based on the seasonal and daily patterns of wind speeds.

Figure 3 shows an example of daily capacity factor patterns in New York for three years. The plot is based on actual wind speed data and the modeled operation of 3,300 MW of wind capacity[3]. The Y-Axis shows average capacity factor. Higher capacity factors correlate to higher wind speeds. Wind speeds between 6 p.m. and 10 a.m. result in capacity factors that exceed 40%, while they are lower than 25% during the other hours.

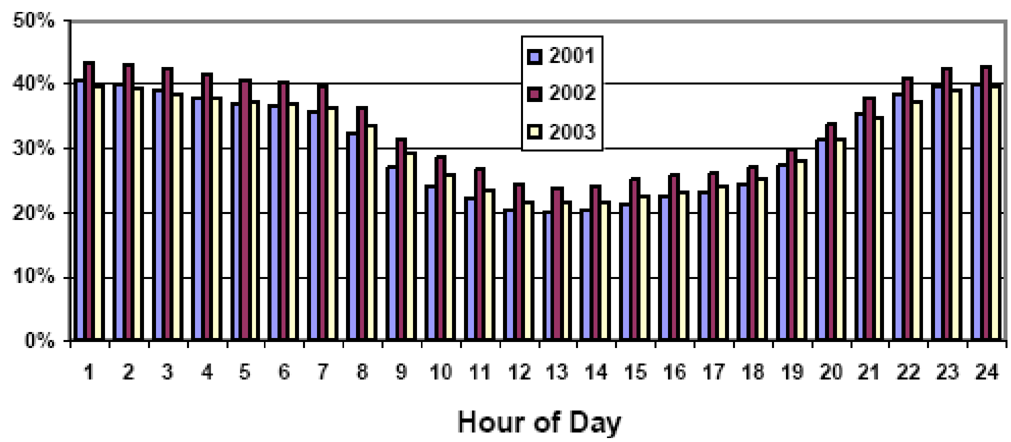

Figure 3. Hourly Daily Capacity Factor Pattern Averaged over the Year

At the levels of wind energy currently being generated in New York State, the intermittency of wind does not cause a problem for the electrical grid, and it is not necessary to build new thermal generation plants or increase thermal plant spinning reserves to “back up” wind farms. It is estimated that at least 10% of the state’s peak load, or 3,300 MW of installed wind capacity, could be accommodated by the state’s power grid with little or no adjustment to existing planning, operating and reliability practices.

Additional Resources

How Stuff Works Website: How Power Grids Work. This source provides a very simple explanation with pictures of power plants, generators, the transmission grid, the distribution grid, and interconnection with a home.
http://science.howstuffworks.com/power.htm/

[3] Figure is from the NYSERDA study, *The Effects of Integrating Wind Power on Transmission System Planning, Reliability, and Operations,* prepared by GE Wind Energy (2005), p.7.2. The study is available on the NYSERDA website.

Utility websites often provide an interactive section (usually geared towards teachers and children) that provides an explanation of how power is generated and delivered to the home.

Thomas P. Hughes, *Networks of Power: Electrification in Western Society 1880-1930*. John Hopkins University Press, Baltimore and London, (1983) 1993, 3rd Edition. Chapters 2 and 8 focus on the historical development of the electric grid in the U.S.