Wind Power and Reliability: The Roles of Baseload and Variable Resources

Federal Energy Regulatory Commission (FERC) Chairman Jon Wellinghoff has stated that "baseload capacity is going to become an anachronism" and that no new nuclear or coal plants may ever be needed in the United States.[1] This fact sheet explains why baseload power is only one of many ways to meet the power system's need for energy and capacity, particularly in a world where a variety of other resources can provide these commodities at competitive prices. In addition, this fact sheet illustrates that, because baseload power has little or no flexibility, baseload power alone is insufficient to meet all power system needs. A combination of a large amount of renewable energy, combined with flexible natural gas plants and demand-response and efficiency, can ensure that our electric system has sufficient energy, capacity, and flexibility, and operates reliably and cost-effectively. The marketplace is already pointing in the direction described by Chairman Wellinghoff: since 2005, natural gas and wind power have accounted for nearly 90% of all new U.S. generating capacity.[2]

Energy, Capacity, and Flexibility

Reliable and cost-effective operation of the electric grid requires a mixture of three types of resources: energy (electricity), capacity (ability to generate electricity at a certain point in time), and flexibility (ability to "turn up" or "turn down" electricity generation as needed). Each of the various types of power plants that generate electricity – nuclear, coal, gas, hydroelectric, wind and others – may specialize in providing one or two of these attributes, but no power plant excels at providing all three.

"Baseload" plants, a term typically applied to nuclear or coal-fired power plants, provide energy and some capacity. Interestingly, other types of power plants can provide these resources, often at costs competitive with baseload plants. Wind plants can produce energy just as well or better than nuclear or coal plants, while natural gas plants can provide capacity at lower cost than nuclear or coal plants. Thus, baseload power is only one of many ways to provide the power system with energy and capacity.

Moreover, baseload power plants provide almost zero flexibility, even though flexibility is a power system need that is just as essential as energy or capacity. In contrast, wind energy makes very valuable contributions towards ensuring that the grid has the right mixture of energy, capacity, and flexibility.

First, let us explore further what is meant by "energy," "capacity," and "flexibility." Energy on the grid is a measure of power provided over time, and can be calculated by multiplying the amount of power used or generated by the time that it was used or generated. Thus, energy is measured in watt-hours, or more commonly kilowatt-hours (the unit used on household electricity bills) and megawatt-hours (1 megawatt-hour, MWh, is equal to 1,000 kilowatt-hours, kWh). For grid operators and planners, having enough energy largely means having enough fuel that can be converted to electricity, and having a diversity of fuels that will be available at a reasonable cost.

Capacity is a measure of power provided or used in a single instant, and thus is measured in watts, kilowatts, and megawatts. Operators of the electric grid must ensure that they have enough generating resources to provide the power capacity that will be needed at any point in time. Typically, grid operators think about capacity on years-ahead basis when they are deciding what power plants to build, on a day-ahead basis when they are deciding what power plants they should have ready to operate the next day, and on a real-time basis when they decide what power plants to operate.

Flexibility is the ability of power output, or capacity, to change over a given period of time. One can speak about the flexibility of a single power plant or the combined flexibility of all power plants on the grid. Flexibility is critical for accommodating changes in electricity supply and demand that occur, often unexpectedly, as power plants go offline or as consumers turn appliances on and off. Demand for electricity can vary by a factor of three or more depending on the weather and the time of day and year, which means that hundreds of gigawatts (GW)[3] of flexibility must be built into the power system. Flexibility can be measured over different time periods: e.g., a power system might have the flexibility to increase generation by 1 GW over 1 hour and 3 GW over 5 hours, with each capability being important for reliable system operation.

Specialization and the Division of Labor Among Power Plants

A power plant may specialize in providing one or two of these power system needs, but no power plant excels at providing all three. As a result, it is important to have a diversity of generation resources on the grid. Table 1 lists the ability of different types of power plants to provide the attributes of energy, capacity, and flexibility.

Table 1: Energy, Capacity, and Flexibility Provided by Different Types of Power Plants

	Energy	Capacity	Flexibility
Wind	X+	Some	Great for turning output down, but not up
Nuclear	X	X	None
Coal	X	X	Very little
Natural gas turbine	Typically too costly	X+	X+
Natural gas comb. cycle	Often too costly	X+	X
Hydroelectric	Some	X	X

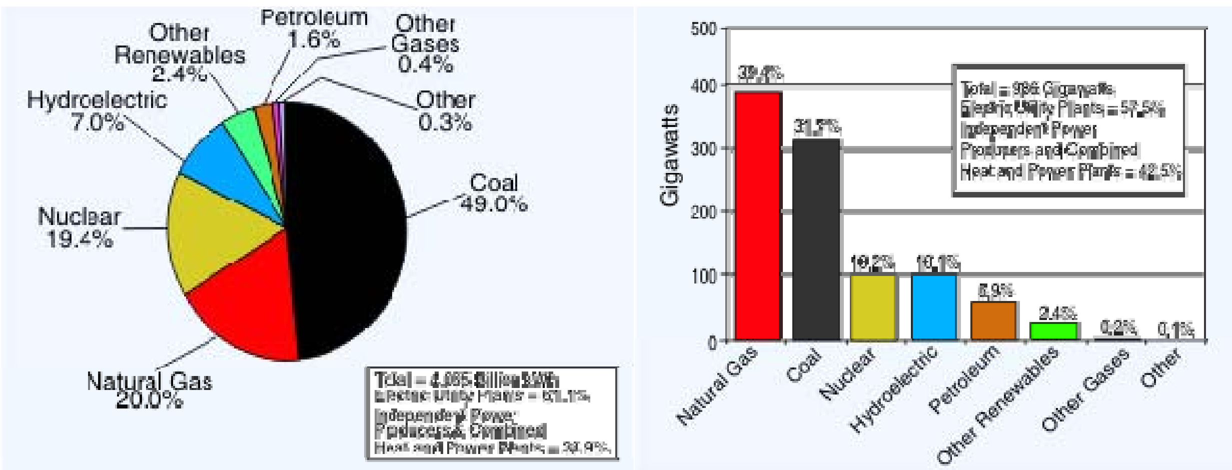
As the table illustrates, wind excels at providing energy, as its fuel source is free. Wind also provides some capacity, typically in a ratio of about one unit of capacity for every two units of average energy output.[4] A wind plant's exact amount of capacity varies depending on a number of site-specific factors, as well as the time horizon being considered.[5] Wind plants can also rapidly and precisely reduce their output on command, giving them excellent flexibility for reducing supply. Flexibility to increase power supply is much more difficult for wind plants, as doing so requires holding the plant below its potential output, sacrificing a significant amount of energy that could have been produced for free.

Nuclear and coal plants, conventionally thought of as "baseload" plants, are remarkably similar to wind plants in that they are predominantly energy resources. Like wind, their fuel costs and operating costs are very low. Nuclear and coal plants are capable of providing capacity at a level close to their maximum output. Even so, no power plant can be counted on to reliably provide capacity at its maximum output, as all plants experience mechanical, electrical, or other failures from time to time and must go offline with little notice. For example, nuclear power plants in the southeastern U.S. have been forced to shut down, some for periods of several weeks, because summertime heat waves raised the temperature of the water in the rivers they rely on for cooling their steam generators. Wind energy, by contrast, uses no water.

Coal and nuclear plants have very little flexibility -- it is difficult for them to increase or decrease their output in response to commands from the grid operator. Changing the output of a nuclear or coal plant requires changing the amount of heat traveling through the plant's steam system. The resulting temperature fluctuations can cause thermal stress to plant equipment, significantly increasing maintenance expenses and causing safety concerns. In fact, because of these safety concerns, Nuclear Regulatory Commission regulations largely prohibit nuclear plants from changing their output.

Natural gas power plants are generally the opposite of nuclear and coal plants, providing significant amounts of flexibility and capacity but very little energy. This is not because natural gas plants are incapable of generating large amounts of energy, but rather due to the fact that gas power plants typically have very high operating costs because, as a fuel, natural gas is generally more expensive than coal.

However, gas plants, particularly combustion turbine (CT) plants, do excel at providing capacity and at changing their output rapidly. Combined-cycle (CC) natural gas plants are more efficient and thus have lower operating costs than combustion turbine plants, but the tradeoff is that they are generally less flexible. Gas plants are also stellar for providing capacity whenever it is needed, with a plant's capacity value typically many times higher than its average capacity factor. The comparisons in Figure 1 below of what resources provide the U.S. grid's mix of energy and capacity illustrate how coal and nuclear plants are used predominantly to provide energy, while natural gas plants specialize in providing capacity and flexibility.



Energy by fuel | Capacity by fuel

Figure 1: U.S. Generation Fleet, 2006[6]

Hydroelectric plants are capable of being used for energy, capacity, or flexibility, but there are tradeoffs between these that limit any one dam from providing significant amounts of all three. For example, an increase in the dam's energy and capacity output causes a decrease in its flexibility, and vice versa. In addition, there are also tradeoffs between energy and capacity, because using up the water stored behind the dam to provide energy limits the ability to provide capacity at a later time.

What Does our Power System Need?

Through the generation mix illustrated in Figure 1, our current power system successfully balances the need for energy, capacity, and flexibility. However, recent increases in the price of fossil fuels and growing impetus to reduce carbon dioxide emissions are creating tremendous pressure to reduce the use of coal and natural gas as sources of energy. These are not capacity or flexibility challenges, but rather energy challenges. Wind energy, being predominantly an energy resource, is ideally suited to solve these challenges.

Of course, the grid will continue to need capacity and flexibility. As explained above, wind energy can provide these resources to some extent, although not as well as other types of power plants. Fortunately, natural gas power plants can provide capacity and flexibility at very low cost. Building more natural gas plants does not harm efforts to reduce natural gas use, as power plants that are being used to provide capacity and flexibility only run during the small number of hours per year when those services are needed. Demand response, in which electricity consumers reduce or delay non-essential electricity use in response to price signals, can also be used to provide capacity and flexibility at very low cost. Plug-in hybrid electric vehicles also have significant potential to serve as sources of capacity and flexibility.

Increasing the amount of wind energy and other variable renewable resources on the grid is likely to decrease the need for baseload power. Why? As explained above, wind and baseload plants are both primarily energy resources. In addition, neither is an ideal source of capacity or flexibility. Inflexible baseload plants can actually be a significant impediment to the growth of wind energy, as the inability to turn baseload plants off during periods of low electric demand can cause the supply of electricity to exceed demand. This causes an extremely inefficient outcome in which wind plants must employ their superior flexibility and reduce their output, wasting free, zero-emissions energy. This is already occurring in some regions of the country with large amounts of both wind energy and baseload plants.[7]

The argument that baseload power is an essential power system need fails to hold up under scrutiny. Baseload power is only one of many ways to meet the power system's need for energy and capacity. In addition, because baseload power has little or no flexibility, baseload power alone is insufficient to meet all power system needs. Instead, a diverse portfolio of resources, of which wind energy can be a major component, is the best way to operate the power system reliably and cost effectively.

References

1. http://www.nytimes.com/gwire/2009/04/22/22greenwire-no-need-to-build-new-us-coal-or-nuclear-plants-10630.html
2. http://www.awea.org/publications/reports/AWEA-Annual-Wind-Report-2009.pdf
3. A gigawatt (GW) is a measure of electric generating capacity equal to 1,000 megawatts (MW) or 1 million kilowatts (kW). One gigawatt of generating capacity is enough power the equivalent of about 800,000 average American households.
4. A typical wind plant's average energy output is 30-40% of the nameplate rating (**capacity factor**), while a typical **capacity value** (how much of the wind plant's capacity can be counted on for meeting electric demand) is 15-20% of the nameplate rating.
5. http://www.nrel.gov/wind/systemsintegration/pdfs/2008/milligan_wind_capacity_value.pdf
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