Renewable Energy Research Laboratory, University of Massachusetts at Amherst

Wind Power:
Capacity Factor, Intermittency,
and what happens when the wind doesn't blow?

Wind Power on the Community Scale

Community Wind Power Fact Sheet # 2a

RERL—MTC Community Wind Fact Sheet Series

In collaboration with the Massachusetts Technology Collaborative's Renewable Energy Trust Fund, the Renewable Energy Research Laboratory brings you this series of fact sheets about Wind Power on the community scale:

1. Technology
2. Performance
3. Impacts & Issues
4. Siting
5. Resource Assessment
6. Wind Data
7. Permitting

   Case Studies

Introduction: the variability of wind

Wind turbines convert the kinetic energy in moving air into rotational energy, which in turn is converted to electricity. Since wind speeds vary from month to month and second to second, the amount of electricity wind can make varies constantly. Sometimes a wind turbine will make no power at all. This variability does affect the value of the wind power, but not in the way many people expect.

In this supplement to Fact Sheet 1, "Wind Power Technology", and Fact Sheet 2, "Performance and Economics", we give more precise definitions of a number of terms used in the wind power industry and the power generation industry in general. These concepts are important to understanding the integration of renewable energy onto the grid, and how we benefit from wind power, one of the lowest impact forms of electricity available to us today.

Capacity Factor is an indicator of how much energy a particular wind turbine makes in a particular place.

What is a "capacity factor" and why does it matter?

Definition:
Capacity factor is the ratio of the actual energy produced in a given period, to the hypothetical maximum possible, i.e. running full time at rated power.

Example:
Suppose you have a generator with a power rating of 1500 kW. Hypothetically if it ran at full power for 24 hours a days for 365 days, that would be:

(1500 kW) x (365 x 24 hours) = 13,140,000 kW-hr

in one year. Suppose that in fact it made 3,942,000 kWh in one year. Then in that year, the generator operated at a:

13,140,000 / 3,942,000 = 30%

capacity factor that year.

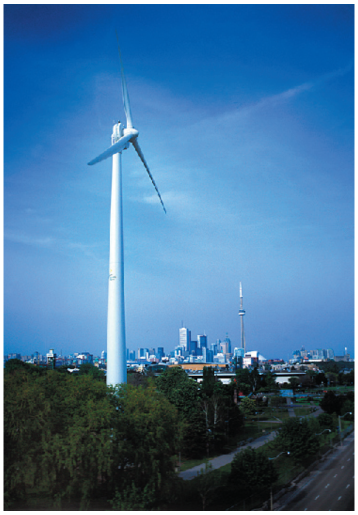
What are common values for capacity factor?

All power plants have capacity factors, and they vary depending on resource, technology, and purpose. Typical wind power capacity factors are 20-40%. Hydro capacity factors may be in the range of 30-80%, with the US average toward the low end of that range. Photovoltaic capacity factors in Massachusetts are 12-15%. Nuclear capacity factors are usually in the range of 60% to over 100%, and the national average in 2002 was 92%. The capacity factors of thermal plants cover a wide range; base-loaded thermal power plants (e.g. large coal) may often be in the range of 70-90%, and a combined cycle gas plant might be 60% depending

All power plants have a capacity factor

Continued on page 2

Inside this Edition:
Capacity Factor



Urban-sited community wind, Toronto's WindShare project. (Photo courtesy Toronto Hydro)

Capacity Factor

continued from page 1

on gas prices, whereas power plants in the role of serving peak power loads will be much lower. One might expect a new biomass thermal plant to have an 80% capacity factor.

Is capacity factor the same as efficiency?

No, and they are not really related. Efficiency is the ratio of the useful output to the effort input – in this case, the input and the output are energy. The types of efficiency relevant to wind energy production are thermal, mechanical and electrical efficiencies. These efficiencies account for losses, most of which turn into heat in the atmosphere and water. For instance, the average efficiency of the US electricity generation infrastructure is about 35% – this is because in most thermal plants, about two thirds of the input energy is wasted as heat into the environment. The mechanical conversion efficiency of commercial wind turbines is a fairly high, in the range of 90%.

Capacity Factor is not an indicator of efficiency.

Wind power plants have a much lower capacity factor but a much higher efficiency than typical fossil fuel plants. A higher capacity factor is not an indicator of higher efficiency or vice versa.

Is a higher capacity factor "better"?

Within a given technology or a given plant, yes, you can generally say that a higher capacity factor is better and in particular, more economical. But it does not make sense to compare capacity factors across technologies, because the economics of both production and capacity are so different from one technology to the next – the capacity factor is just one of many factors in judging if a power plant is feasible. Instead, more useful is to compare the cost of producing energy among the various technologies.

Intermittency, and the value of wind power

The wind does not always blow; sometimes a wind power plant stands idle. Furthermore, wind power is really not "dispatchable" – you can't necessarily start it up when you most need it. As wind power is first added to a region's grid, it does not replace an equivalent amount of existing generating capacity – i.e. the thermal generators that already existed will not immediately be dismantled.

Wind power is by nature intermittent

Does intermittency imply that wind power cannot have beneficial impact on the environment?

No. We need to distinguish here between capacity and production. The first is the amount of installed *power* in a region, and is measured in MW. Production is how much *energy* is produced by that capacity, and is measured in MWh.

While wind power does not replace an equal amount of fossil-fuel *capacity*, it does replace *production* – for every MWh that is produced by a wind turbine, one MWh is *not* produced by another generator. The damage done by our existing electricity generation is primarily a function of production, not capacity. Burning less coal has a positive environmental impact, even if the coal plant is not shut down permanently.

In Massachusetts, the avoided production would mostly be from fossil-fuel plants. So for every MWh that is produced by a wind turbine here, that causes about two thirds of a ton of CO_2 not to be produced (see page 4 for a discussion of marginal emissions in New England.)

The impact of intermittence on the grid

Intermittency does have an impact on the grid, though it is not the impact that wind power critics usually assume. When the concentration of wind power in a region is low, the impact is negligible. Keep in mind that loads fluctuate constantly, so a small amount of

Continued on next page...

Intermittency

continued from page 2

fluctuating generation can be said to act as a "negative load" and have almost no measurable impact on the grid. Many modern wind turbines can supply some grid support as well (referred to as "ancillary services," e.g. voltage support), just as most power plants do. As the concentration of wind power increases in a region, though, intermittence and the difficulty of forecasting wind power production do have a real cost associated with them.

For every MWh that is produced by a wind turbine, one MWh is not produced by another generator.

Recent studies of wind power installed on United States grids have attempted to determine the actual cost of intermittency, They indicate it is currently in the area of a 2-5 tenths of a cent per kWh, depending on penetration. The higher costs were for 20% penetration. A few tenths of a cent per kWh is not insignificant, but it is still a small percentage of the total cost of generating power (which for wind power might be in the range of 2-6 ¢/kWh). Intermittency does impose a cost but that cost is typically not prohibitive, as some people imagine.

Will wind power ever make all our electricity?

There are places in the world where wind power provides nearly all of the electric power used. These high-penetration wind grids tend to be in remote areas. While high-penetration wind systems are not impossible, no one is suggesting that we will make the bulk of New England's power with wind in the near future.

Today, Denmark and northern Germany are the examples of large-scale grids with the highest penetration of wind power. Though more densely populated than New England and not particularly more windy, they produce about 20% of their energy from the wind. Wind power is a proven generation technology that is working in today's electrical grids around the world.

The need for back-up generation

Wind power plants have been installed in the United States for long enough that detailed studies have been completed on the impacts and costs of its intermittency. A recent study concluded that,

"...the results to date also lay to rest one of the major concerns often expressed about wind power: that a wind plant would need to be backed up with and equal amount of dispatchable generation. It is now clear that, even at moderate wind penetrations, the need for additional generation to compensate for wind variations is substantially less than one-for-one and is often closer to zero."

- Utility Wind Interest Group (UWIG) "Wind Power Impacts on Electric-Power-System Operating Costs, Summary and Perspective on Work Done to Date, November 2003"

Renewable Energy Research Laboratory

University of Massachusetts at Amherst

160 Governors Drive
Amherst, MA 01003
413–545–4359
rerl@ecs.umass.edu
www.ceere.org/rerl/

Mass. Technology Collaborative
Mass. Renewable Energy Trust
75 North Drive
Westborough, MA 01581
508–870–0312
www.mtpc.org/RenewableEnergy/index.htm

Availability, Reliability,
& some other terms defined

The discussion of wind power's capacity factor and intermittency often brings up other terms that bear defining.

Reliability
Modern commercial wind power plants are fairly reliable, which is to say, they are not shut off for maintenance or repairs very much of the time. "Dispatchability" is not synonymous with "reliability".

Dispatchability
Dispatchability is the ability of a power plant to be turned on quickly to a desired level of output. Wind power plants are not dispatchable.

Availability
All power plants must be taken down for maintenance, both scheduled and, at times, unscheduled maintenance. The percentage of time that a wind power plant is not down for maintenance and is able to operate is called its availability. Because the wind isn't always blowing, the percentage of time that the machine is actually producing electricity will be lower than the availability. Modern wind turbines may have a guaranteed availability of 95% while under warranty.

Penetration
Wind power penetration is the amount of energy produced by wind power, as a percentage of total energy used, in a given region. In the United States as a whole, the wind power penetration is a small fraction of a percent.

Marginal emissions
Each year the operator of our electric grid, ISO New England Inc., analyzes and reports on the marginal emissions rate for our region. "Marginal" means the change in emissions that would occur if one more or one fewer MWh were generated. These figures are specifically intended to be an indicator of the value of conservation, efficiency, and renewable energy.

For instance, the annual marginal average emissions rates for 2002 were:

Pollutant	A major impact of this pollutant	Marginal emissions rate
SO_2	Acid rain	3.27 lbs/MWh
NO_X	Smog, asthma	1.12 lbs/MWh
CO_2	Global climate change	1337.8 lbs/MWh

So for instance, one wind turbine rated at 660 kW with a 28% capacity factor (i.e. about 1.5 million kWh/year) eliminates the production of about:

Pollutant	Emissions avoided
SO_2	5,300 lbs
NO_X	1,800 lbs
CO_2	1,100 tons

These numbers are the annual averages; see the full ISO New England report for a more complete discussion of regional, seasonal, and time-of-day variations.

For More Information

The Utility Wind Interest Group's Operating Impacts Studies analyze the costs and impacts of integrating wind power into the grid: www.uwig.org/operatingimpacts.html

Danish Wind Industry Association: thorough and very accessible technical information: www.windpower.org

Wind Energy Explained: Theory, Design and Application, Manwell, McGowan, & Rogers, Wiley, 2002

ISO New England's 2004 Marginal Emissions Rate analysis is available at www.iso-ne.com/genrtion_resrcs/reports/emission/2004_mea_report.pdf

For the on–line version of this Fact Sheet with the complete set of links, see RERL's website: www.ceere.org/rerl/about_wind/ . Here you will also find links to Fact Sheets 1 and 2, "Wind Power Technology" and "Performance and Economics," which include an introduction to wind power and many of the concepts used above (e.g. energy vs. power, and the grid.)

For links to more sources of information, see www.ceere.org/rerl/rerl_links.html