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What every policymaker needs to know about wind power

This monograph is a product of the Future of Energy Initiative, a working group chartered by the Chesapeake Chapter of the International Council on Systems Engineering (INCOSE).

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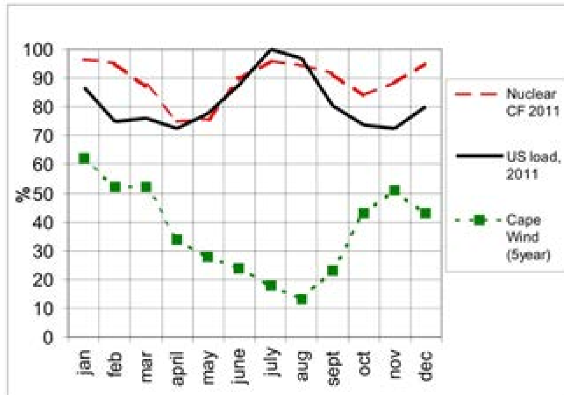
What is Wind Capacity?

The term "capacity" can be confusing because it is used several different ways. There are three types that are important for wind farms.

Nameplate capacity, sometimes called rated capacity is the maximum power that can be produced. A 200 MW wind farm refers to a nameplate rating.



Monthly capacity factor

Capacity Factor is the fraction of the nameplate rating that is actually used. It is the average power produced by a specific installation over a certain time period (yearly, monthly) divided by the potential power that could be produced if the generator was operating at full power.

The solid black line in the figure shows how the demand for electricity in the US varies over the course of a year.[1] US demand peaks during July and August. The dashed red line is the monthly capacity factor for the US fleet of 104 nuclear reactors.[2] The annual nuclear capacity factor was about 85% but most of the down time is off-peak scheduled maintenance. During peak demand, monthly capacity factor is about 97%. The remaining 3% is forced outages where some problem forces a reactor to shut down.

The green dots are monthly capacity factors for a simulated offshore wind farm at Cape Wind Massachusetts. The simulation is good, based on buoy wind data,[3] and is roughly what you might expect for Maryland offshore wind. Each monthly capacity is an average includes time at 100% production and 0% no wind. The annual capacity is excellent (for wind), about 37%. But as you can see, monthly capacity does not follow load and is lowest during peak demand.

Firm capacity refers to the amount of power than can be relied upon during peak demand. For conventional generators firm capacity is determined by forced outages and is frequently in the 90 percentile. Wind firm capacity is controversial. Bonneville Electric Power uses 0% because they experienced 9 days no wind during high demand in 2009.[4] Maryland's PJM uses 13% because they have not (yet) experienced such an event. In my professional opinion more experience will drive wind firm capacity to 0%. There is no guarantee that wind will always blow even with interconnected wind farms. A 0% firm capacity implies the need for full redundancy; each 1 KW wind turbine needs 1 KW conventional generator backup.

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[1] EIA Monthly Energy Review, Dec 2012, http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf

[2] EIA Monthly Energy Review, Dec 2012, http://www.eia.gov/nuclear/generation/index.html

[3] Kempton, W. et al, Electric power from offshore wind, Fig. 4., Proceedings National Academy Sciences, 107:16, pp. 7240-7245

[4] Taylor et al, The Hidden Cost of Wind Electricity, American Tradition Institute, 2012, table 12, p. 24

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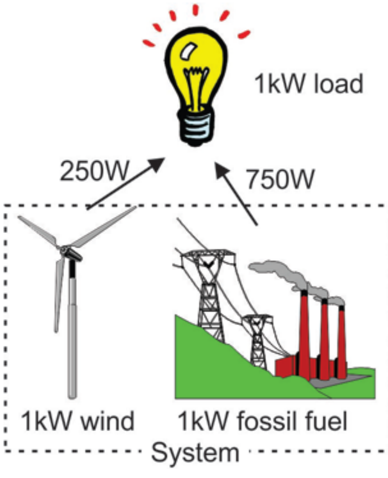
Technology vs. Systems

Can't swap a wind farm for a coal plant. Wind turbines cannot stand alone; the rest of the system must provide power when there is no wind. This means that cost and performance assessments need to address the whole system. While wind turbines are a mature technology, the technology is useful only in the context of a system. There is much controversy about wind systems.

Classic system development starts with ultimate goals. Engineers then develop simple concept models to identify constraints, boundaries, principles and relationships. Levels of complexity are added in steps to develop real systems. While classic system development starts with ultimate goals and works backwards, the popular approach is to start where we are and work forward. This difference in perspectives is a primary source of conflict.

Classic system development starts with a simple constant load (1 kW light bulb) model in the adjacent figure. The system consists of a 1 kW wind turbine plus a 1kW fossil fuel plant. When there is no wind, the fossil fuel plant is running at 100% of capacity. When the wind turbine is operating at full power, the fossil fuel plant is shut down. That fossil fuel plant needs to efficiently stop and start to backup wind, and 75% of the energy comes from the fossil fuel backup. This simple subsystem is an accurate representation of a single wind turbine or a single wind farm. It can be extended to include variable load, storage, long distance transmission and all the complications of a modern electric power grid. Yet this simple model teaches a number of important lessons:



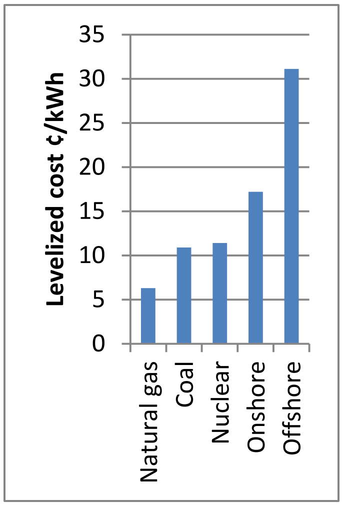
- The model explains a 25% impasse. A national average capacity factor might be 25%. This means that on average, a 1 kW wind turbine will deliver 250W. But we cannot add more than 1kW wind to the model because there will be periods of more wind than load. We are stuck.
- Wind farms have no firm capacity or reliability. System reliability is provided by the fossil fuel plants and full redundancy is necessary. (Some wind advocates strongly disagree with this.)

The popular approach is taken by the Easter Wind Integration and Transmission Study (EWITS), the best wind system simulation model to date. EWITS adds wind to the existing grid. EWITS concurs that the impasse, a serious cost and performance degradation, occurs at 20-30% penetration. Two complaints:

- EWITS does not acknowledge that it has committed the remainder of the system to start and stop as required to backup wind. The rest of the system cannot include solar, which may not be available, or nuclear, which cannot cycle. The only practical option is fossil fuel
- EWITS seriously underestimates reserve requirements because it simulates only one year. The system needs sufficient reserves to reliably manage the worst event, no wind anywhere.

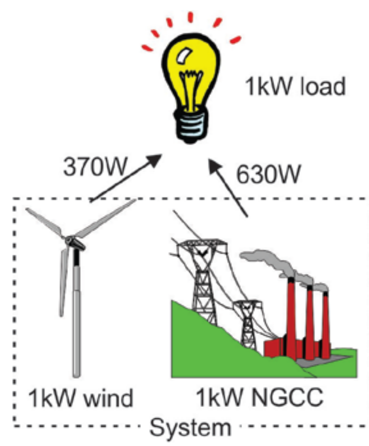
Competitive system costs

Competitive system costs measure investment value. The 2012 OSW bill included a (fuzzy) cap of 20¢/kWh. It is natural to compare this 20¢ with a residential electric bill, about 12 ¢/KWh. That comparison is inaccurate for two reasons. First, it is comparing wholesale costs (the wind plant) with retail prices (your bill). Your bill includes transmission, distribution, social taxes and market inefficiencies. Second the 20¢ is a technology cost that does not include a variety of system costs, the largest of which is idle backup generators.



A better comparison is "levelized cost" of electricity from new generators at the system level. Levelized cost is a life cycle analysis that excludes subsidies, includes fuel escalation, inflation, and annualizes capital expenses. Think of levelized cost as the average cost of electricity over the life of the system.

The levelized cost for natural gas, coal and nuclear are taken directly from Energy Information Administration (EIA) estimates for 2016 installations.[5] These numbers are directly comparable because the generators are interchangeable. EIA cautions that the technology cost of electricity from wind plants cannot be compared with gas coal and nuclear because the wind plant is not interchangeable, wind cannot stand alone. To compare costs we need to calculate an OSW system cost where the system is interchangeable with gas, coal and nuclear.



A constant power wind system consists of a 1kW turbine plus a 1kW natural gas plant. Assume an optimistic 37% OSW capacity factor. Whenever the wind blows the fossil fuel plant can throttle back reducing the variable part of the natural gas plant. This means that the levelized cost of electricity is the technology cost of the wind plant (which EIA estimates to be 24.3¢/kWh), plus the cost of the gas generator (6.3¢), minus 37% of the variable part of the gas cost. Variable cost includes fuel plus operations and maintenance proportional to power production which EIA estimates to be 4.2¢/kWh for natural gas. The calculation is: $24.3 + 6.3 - (0.37 \times 4.2) = 29.1$¢/kWh.

Wind has additional system costs for transmission upgrades, balancing and storage. These estimates are controversial because they depend on penetration levels and the sophistication of grid management. Current estimates range between from 0.5 to 5¢/KWh.[6] For this comparison we assume 2¢/KWh which raises OSW system cost to 31.1¢/kWh. OSW is 4.9x more expensive than new natural gas.

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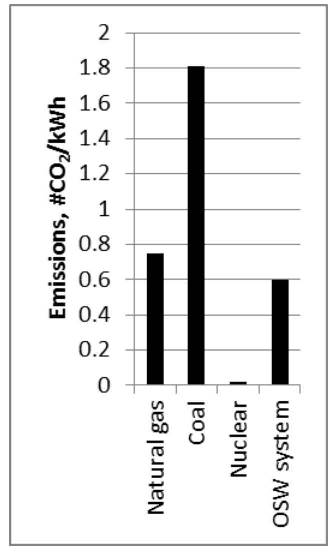
[5] US Energy Information Administration, Levelized cost of New Generation Resources in the Annual Energy Outlook for 2011, November 2010, table 1, available at: http://www.eia.gov/oiaf/aeo/electricity_generation.html

[6] Taylor, G. et al., The Hidden Cost of Wind Energy, American Tradition Institute, Dec 2012, available at: http://www.atinstitute.org/wp-content/uploads/2012/12/Hidden-Cost.pdf

System emissions

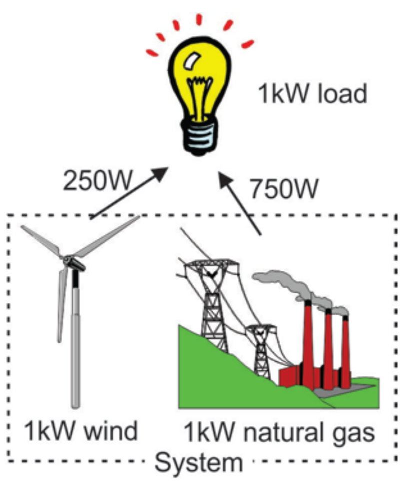


Clean technology is not the same as clean systems. We cannot use wind to reduce system emissions by 20%, and then get the other 80% "some other way." Wind commits 80% of the system to fossil fuel because it is the only technology we have that can start and stop to backup wind.

The US Energy Information Agency estimates CO_2 power plant emission for new 2016 plants.[7,8] The numbers, in pounds (#) of CO_2 per kilowatt hour, for natural gas combined cycle, advanced coal (gasification), and advanced nuclear, are presented in the adjacent bar chart. Shifting from coal to natural gas reduces CO_2 emission a lot, from 1.81 to 0.75#CO_2/kWh.

As with cost comparisons, the emission impact of wind must compare system with equivalent reliability. A reliable offshore wind (OSW) system consists of a wind plant and a natural gas plant. This system is interchangeable with a base load generator.

The popular assumption is that emissions are proportional to power production. If that were true adding wind (with a national average capacity factor 0f 0.25) would reduce the natural gas emissions by 25%. But the gas is no longer operating at constant power. It is continuously starting and stopping to backup wind. It is like driving a car in city traffic rather than at constant highway speed, efficiency drops. Katzenstein et al.[9] is the best available studies of the impact of wind on system emissions. They use real wind data and a data-based model of the generator. At 20% penetration they predict 77% effectiveness in reducing CO_2 emissions from natural gas. 77% of the 25% reduction is a 19% overall reduction in CO_2 emission. This means that a wind + natural gas system can reduce natural gas CO_2 emission by 19% from 0.75 to 0.60#CO2/kWh.



For nitrous oxides Katzenstein estimates 30-50% effectiveness. A 40% effectiveness and a 0.25 capacity factor means that wind systems reduce nitrous oxide emission by 10% below gas emissions.

All systems have insignificant particulate emissions. Shifting from coal to natural gas provides big CO_2 emission reductions. Adding 25% wind to natural gas reduces CO_2 by 19%, nitrous oxide by 10%. A shift from coal to natural gas makes a big difference. Adding wind does not accomplish very much.

7 EIA, Electric Power Annual 2010, Table A.3 Carbon Dioxide Uncontrolled Emission Factors, available at: http://www.eia.gov/electricity/annual/pdf/tablea3.pdf

8 EIA, Updated estimates of Power Plant Capital and Operating Costs, November 2010, available at: http://www.eia.gov/oiaf/beck_plantcosts/excel/table1.xls

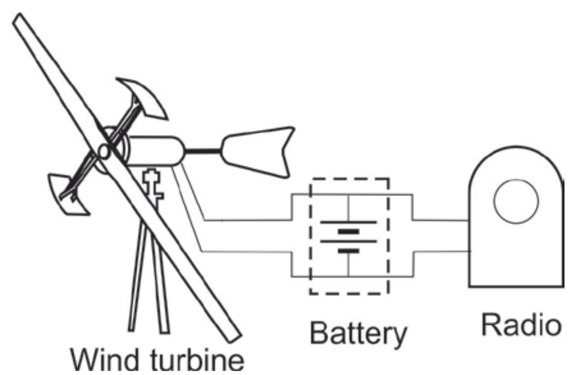
9 Katzenstein, W., Apt, J., Air Emissions Due to Wind and Solar Power, Environmental Science and Technology 43, 2009, pp. 253-258

Marching down a dead end street

Clean technology is not the same as a clean energy system. Even though a wind turbine is clean, a wind system is not because the wind turbine is not a reliable source of power.

Wind is technically capable of providing 25% of our electric power. The other 75% of the system is committed to start and stop as required to backup wind. The best backup technology is natural gas. So a good wind system consists of 25% wind, 75% natural gas, one part wind, three parts fossil fuel. Compare the cost and performance of this wind system with an all natural gas system. An offshore wind version would be 5x more expensive than natural gas. While the wind provides 25% of the power, best estimates are that it reduces CO_2 emissions by 20% and nitrous oxide emissions by 10% because of the additional starting and stopping of the backup generators.

But the most serious question is what happens next? How to get rid of the 75% natural gas? We cannot add more wind because on windy days the system is already getting 100% of its energy from wind. We cannot replace the natural gas with nuclear or solar or geothermal-electric because all of these zero carbon technologies cannot start or stop to backup wind. Indeed, if we had a clean technology capable of wind backup, why have wind? There is no solution. We just walked down a dead end street and we are stuck with an expensive dirty system.



There is precedence for all wind-electric systems. In the 1930s Zenith Radio sold a system called Wincharger. This was an elegant concept for the time, a killer app. It consisted of a small wind turbine trickle charging a battery to power a vacuum tube radio. Zenith sold nearly a million of these systems during the depression and the 1940s. The electricity was expensive, using modern technology about $2/kWh. But the radio did not need much. The system did not work well during the low wind months of July and August, but the farmers did not care. When the wind blew they had quality radio! While Zenith sold nearly a million systems during the depression and WWII, Wincharger did not survive rural electrification. Reliability and cost led to its demise. Society became intolerant of no wind no power. Has anything changed?

Do we really have to invest trillions of dollars on wind farms and long distance transmission before we see the dead end? Ultimately we need big (>90%) reductions in greenhouse gas emissions. If we used that knowledge to search for the best ways to achieve that goal, we could avoid huge mistakes and focus our limited resources. Instead, Maryland and other states are contemplating a big 20 year commitment to offshore wind based on the popular belief that clean technologies are the same as clean energy systems. We are blindly marching down a dead end street.

The five part set: "What every policymaker needs to know about wind" can be found at: www.pavlak.net/WEPNTKAWP

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