Output Variability as an Issue Surrounding the Integration of Wind in Ireland

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Wind integration issues have fostered considerable debate recently with the dialogue increasingly focused on the variability or 'intermittency' of wind output.[1] This Briefing Paper explores wind variability as it affects conventionally structured electricity systems and markets, although the last section outlines a proposed set of network protocols that allow a *discrete load-matching* of wind output to appropriate 'dispatchable' applications in a manner that does not burden the overall system with additional reserve or balancing requirements.

Wind variability creates cost consequences in today's network systems since each added MW of wind requires additional reserves that system operators can 'dispatch' in order to balance supply against load in the event wind output unexpectedly declines. When it comes to backing up system assets, however, wind is not alone. Every system component— whether a 500-MW gas generating plant or a substation transformer— requires back up in case it unexpectedly fails or is down for scheduled maintenance. Along these lines wind has an advantage— the overall system effects of shutting down a 3-MW wind turbine are insignificant. Not so for a 500-MW fossil plant.

All system assets fail. All system assets experience downtime for planned maintenance. In Ireland, for the years 2003-2005, conventional fossil generation was available for dispatch 76%–83% of the time.[2] Plant availability affects overall requirements for installed capacity. Total installed dispatchable capacity in Ireland is about 6000 MW, against a peak demand of 4450 MW.[3] Even during the once-annual 30-minute peak-interval therefore, over one-third of Ireland's generating assets stand idle, providing reliability— assuming they are not down for maintenance— but no energy. During summer and winter system troughs— when demand averages only 2000 MW, Ireland has three times as much generation capacity as it needs.

Of the total installed dispatchable 6000 MW of capacity, 5465 MW comprises conventional fossil plant. Operated continually, it would produce nearly 48,000 GWH a year,[4] although it actually

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[1] The widely used *intermittency* notion is misleading. Wind blows a high percentage of the year, at least at better sites, although its force varies so that output is variable. There are very few fully calm days implying that *variable-output* is a better concept.

[2] Although it reached levels as high as 88% in 2002; figures based on 52-week rolling average; availability reflects forced and planned outages; Source: Eirgrid, Generation System Performance, www.eirgrid.com/EirGridPortal/dataviewer.aspx?tabid=SO%20%20Generation%20System%20Availability&TreeLinkModID=1451&TreeLinkItemID=12#Forced.

[3] Eirgrid, Generation Adequacy Report 2005-2011

[4] 5465 MW × 8760 hours per year / 1000 = 47,870 GWH

produces less than 27,000 GWH, which yields a *capacity factor* of 56%.[5] Capacity factor expresses the fraction of theoretically feasible output a given asset produces in a year. System engineers will be quick to note that some of the installed capacity is *designed* to operate only a small fraction of the year and that reserves are needed to back up individual plants.[6] However, like fish that swim in water but obviously do not feel it, system engineers have become all too accustomed to the significant flaws and design limitations of the fossil-based central generation system.

Clearly, the common conception that fossil runs continually while wind is unreliable because it operates only a small fraction of the year is far from accurate. Ireland's wind capacity factors are 35%. Though among the highest in the world and sufficient to produce highly cost-effective electricity, this output level suggests to some that wind is idle and non-productive 65% of the time. In fact, Ireland's wind generators produce power over 90% of the time. Ireland's wind capacity factors undoubtedly exceed those of the grid itself, which in the US and other developed nations operates at 15%-20% capacity factors.[7] No system asset operates 100% of the year and most operate considerably below their theoretical potential. Ireland's conventional generation produces 56% of its theoretical potential output— two-thirds more than wind, which requires no fuel.

Capacity Credits: How much wind will be available to meet system peaks?

Reserve requirements are most crucial during system peaks. An important aspect of wind's variable output deals with the likelihood that wind power will be available when it is needed most: during system peaks. Planners worry that wind output may not be available for 'dispatch' in sufficient quantity during such critical peak periods so that the system operator may require additional conventional standby capacity for possible dispatch. The extent to which wind capacity must be offset by conventionally fired reserves is measured by its *capacity credit,* or its *effective load carrying capacity* (ELCC).[8] The capacity credit or ELCC differs from the capacity *factor* discussed earlier. Wind may not always be available during system peaks. The same holds for gas and coal plants although their unavailability rate is generally lower.

Every asset on the grid requires backup in case it unexpectedly fails. Noted wind integration expert Michael Milligan estimates that the ELCC for a 500-MW gas generator with a reliability factor of

[5] The figure is 26,647 GWH, see: Generation Adequacy Report, p. 82; 26647/47870 = .56;

[6] This is correct; in fact, the larger the individual plant, the greater the back up requirement calling into question the proliferation of large fossil plants on the small Irish system.

[7] S. Awerbuch, L. Hyman and A. Vesey, *Unlocking the benefits of Restructuring: A blueprint for Transmission*, PUR, 1999

[8] ELCC is a statistical measure representing the increase in available generation capacity attributable to deployed wind, assuming loss-of-load probability remains constant (R. Perez, R. Seals and R. Stewart, "Assessing the Load Matching Capability of Photovoltaics for US Utilities Based Upon Satellite-Derived Insolation Data," 23rd PV Specialists, Louisville, KY, *IEEE Transactions,* 1993, pp. 1146-1149).

85%[9] might be 390 MW or 78% of its installed capacity.[10] System planners would therefore provide a minimum of 110 MW of reserves for this plant— 22% of its capacity— to offset the probability that it fails during system peaks. That 110 MW reserve will require still further backup.[11]

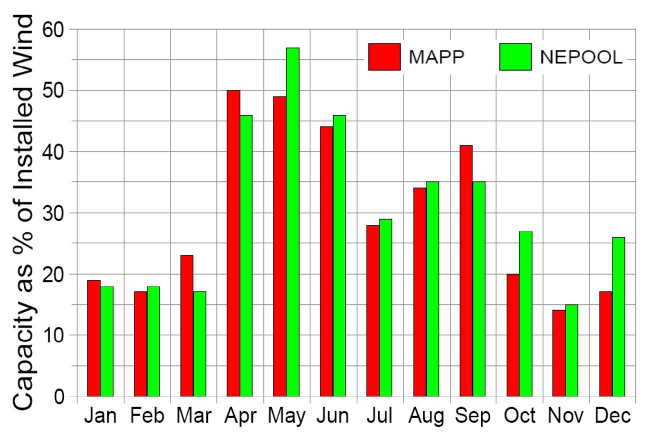

Figure 1: Hypothetical wind plant operational capacity credit using 10-year actual load and wind data
Source: Michael R. Milligan, *Modeling Utility-Scale Wind Power Plants Part 2: Capacity Credit*, National Renewable Energy Laboratory, March 2002, NREL/TP-500-29701, p. 3

In the case of wind, the backup issue is affected by a number of factors ranging from the nature of individual system operating protocols and assumptions to the manner in which planners estimate the probabilistic availability of wind resources during system peak periods. Research over the last two decades suggests that wind resources are diversified and certainly do not need anywhere near 100% or 80% backup as some still think.[12] For example, Milligan (Figure 1) estimates monthly ELCC values for two US power pools in the range of 15%–57%, with an approximate annual average of 35%.[13] Milligan's figures imply an average 65% reserve requirement that falls to 43% during late spring. In some settings, thoughtful planned outage schedules that respond to this seasonal cycle could significantly reduce any added reserve requirements imposed by wind.

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[9] By comparison, Ireland forced outage rates for 2003-2005 ranged 11%-16% on a 52-week rolling average basis and 5%-23% on a 4-week average basis. (hwww.eirgrid.com/EirGridPortal/dataviewer.aspx?tabid=SO%20-%20Generation%20System%20Availability&TreeLinkModID=1451&TreeLinkItemID=12#Forced).

[10] Michael R. Milligan, *Modeling Utility-Scale Wind Power Plants Part 2: Capacity Credits*, National Renewable Energy Laboratory, March 2002, NREL/TP-500-29701.

[11] Required reserves are affected by reliability and size. Amory Lovins reports that a new 2250-MW coal station comprising nine 250-MW units provides the same ELCC as a 3000-MW station comprising four 750-MW units— a 25% decrease in station capacity "to do the same task just as reliably." (A. Lovins, e. al., *Small is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size*, Rocky Mountain Institute, 2002, p. 203-204). Similarly, (Lovins, p. 184) an isolated system seeking 100 kW of firm capacity from dispatchable units with an assumed 5% forced outage rate can get that capacity from five 50-kW units, totaling 250 kW, twenty-five 5.26-kW units (131.5 kW), or one hundred 1.16-kW units (116 kW). Rather than a moratorium on wind, the Ireland CER might consider a moratorium on fossil plants exceeding, say, 2% of total installed capacity.

[12] As early as 1987, Michael Grubb showed that dispersed wind turbines could economically displace thermal baseload and generate more than half of total British power requirements (*The Integration and Analysis of Intermittent Source on Electricity Supply Systems*, Ph.D. thesis, Kings College, University of Cambridge)

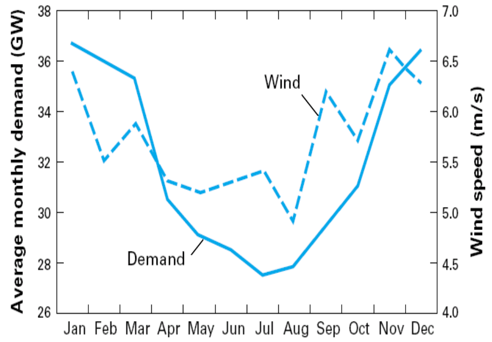
[13] Michael R. Milligan, March 2002.

ELCC value rise and reserve requirements fall where wind resource availability coincides with system peaks as it does in the UK (Figure 2). Similarly, the Solano (California) 2.5-MW experimental wind turbine achieved an 80% ELCC,[14] meaning it would have required just 20% backup, less than Milligan's illustrative 500-MW gas generator.

In spite of the overwhelming evidence, Ireland and other electricity systems still give no capacity credit— and hence make no capacity payments to wind. Wind ELCC values obviously vary and are generally lower than those for fossil plants. Clearly however, their value is greater than zero.

While planners consider wind to be unreliable because it is intermittent and hence *non-dispatchable,* Lovins concludes that it is ***non*****renewable** systems that have "serious reliability problems."[15] Neither is wind integration too costly. A widely cited study by UK's National Grid finds that wind deployment imposes only small additional system costs in the range of fractions of a Euro-cent per kWh,[16] and finds no technical reasons why a "substantial proportion" of electricity could not be delivered by wind.

Figure 1:
Correlation of Wind and Electricity Demand in England
Winds are strongest in winter when electricity demand is highest and the power is therefore worth the most



Distributed Resources Conference, November 1996), given in, Lovins, *Small is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size,* RMI, 2002.

Must Wind Integration Increase System Cost?

The previous sections argue that traditional system planning measures— capacity factors and capacity credits (ELCCs)— suggest that wind contributes both useful energy and capacity. Yet in many ways, the debate about how to manage wind's variable-output is misdirected. It is improperly conceived in terms of our century-old electricity production-delivery system, a system designed specifically for dispatchable, fossil-fired central-station generation. System engineers, who have been weaned on centrally dispatched technologies, see the challenge as making wind fit into the existing system, when the emphasis, rather, needs to be on re-engineering the electricity production-delivery process to accommodate a variety of 21st Century needs, including the integration of wind and other variable-output sources.

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[14] Lovins, et. al. *Small is Profitable*, 2002, p. 173

[15] Lovins, et. al. p. 187

[16] L. Dale, D. Milborrow, R. Slark & G. Strbac, *Total Cost Estimates for Large-scale Wind Scenarios in UK*, National Grid Transco and UMIST (*Energy Policy*, Vol. 32, No. 17, 2004); another widely cited study is the *DENA Grid Study: Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore up to the Year 2020* (February, 2005). Both yield similar results, finding that the cost of integrating wind into today's system is on the order and 0.5 pence in the UK and 0.4 Euro-cent in Germany.

How do system engineers want to integrate wind? By making it act— as much as possible— like a gas turbine so it can be dispatched by the control room operator, just the way things have been done for a century. Wind produces power, just like gas turbines. But that does not mean that the products have the same properties. Wind output is different. The trick is to recognize that difference and figure out how to accommodate it. Fully integrating wind will likely require new approaches, including different system architecture and protocols to manage electricity grids in a decentralized, market-responsive manner.

This involves adopting *mass-customization* concepts from manufacturing that will enable electricity customers to contract for power, reserves and other ancillary services in forms that best match their various applications.[17] Wind is a highly economic, fixed-cost alternative yet we need to better understand and exploit its unique attributes. Output variability is a shortcoming only if we try to shoehorn wind into today's antiquated system.

Recent research has led to proposals involving *discrete load matching* and other electricity network protocols that exploit wind variability and obviate the need for centrally managed reserves and system balancing.[18] These proposals involve the idea of matching variable wind output to power dispatchable or interruptible load applications that are indifferent to the variability. For example, wind-based electricity can be used to store thermal energy in residential and commercial heating equipment.[19] When wind output diminishes, the process temporarily terminates. The heaters do not draw system power so that no system balancing or system reserves are needed. If needed, dispatchable applications can contract directly for backup power.[20] Discrete load matching will ultimately require a system of *parallel information networks*[21] to monitor usage and insure that load applications supplied in this manner do not "lean" on the grid system. Discrete Load Matching will enable wind generators to introduce products that exploit wind's low cost along with its variability. Load Matching recognizes that wind is different and does not require it to compete with gas on a commodity-electron basis.

Current efforts to improve wind integration focus on better fitting the technology into today's system. For example, better ways of predicting wind resources might improve the ability of wind generators to bid system power. But in spite of the fact that day-ahead bidding accuracies for wind are improving, such protocols are conceived for fossil generation where they are better suited.

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[17] S. Awerbuch (July-August, 2004), Restructuring Electricity Networks: decentralization, mass-customization and intermittency, *Cogeneration and On-Site Power Production*; S. Awerbuch (March, 2004), "Restructuring Our Electricity Networks to Promote Decarbonization: Decentralization, Mass-Customization and Intermittent Renewables in the 21st Century," *Tyndall Centre Working Paper No. 49*; www.tyndall.ac.uk/publications/working_papers/wp49.pdf

[18] e.g. S. Awerbuch, "Restructuring Our Electricity Networks," March, 2004.

[19] see: B. Fox and D. Flynn, **"**Managing Intermittency of Wind Generation with Heating Load Control," in collaboration with P. O'Kane, *The Queen's University of Belfast*, 2005.

[20] Awerbuch, Hyman and Vesey, 1999. Awerbuch, "Restructuring Our Electricity Networks," March, 2004.

[21] Ibid.

Trying to extend them to wind may be a worthwhile endeavor, although the effort may ultimately prove to be like trying to fit the proverbial square peg into a round hole.

Electricity is created using century-old mass-production concepts that do not fit wind's variable output characteristics.[22] Mass production has since been abandoned in manufacturing in favor of flexible manufacturing and mass-customization. In order to integrate wind effectively we will need to similarly re-engineer the electricity production and delivery system so it better accommodates a variety of 21st century needs, including the need to integrate a large number of wind and other new technologies. Modern manufacturing produces complex products such as automobiles and airliners with millions of parts, using no manufacturing inventory. Properly challenged and given proper incentives, electricity system operators can be induced to develop innovative *just-in-time, mass customization* concepts that integrate wind and similar variable output technologies without imposing additional system reserve and balancing requirements.

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[22] Mass-production produced large, inflexible product batches but could not create an individual customized product at reasonable cost. By contrast, *mass-customization* produces custom-tailored computers and other products. Similarly, wind power imposes costs on today's electricity production-distribution system just as a custom product would in a mass production system. A re-engineered electricity system accommodates wind the same way mass-customization enables manufacturers to deliver custom products at reasonable cost.