Case Study
on
Methods of Industrial-scale Wind Power Analysis

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Introduction

A great deal has been published about the characteristics of industrial-scale wind power, covering a range of points of view. This paper is a case study of some of the approaches and considerations that can be used in the analysis of such papers.

The subject of this case study is a recently published paper by Charles Komanoff[1] who takes the wind proponent view. In general Komanoff:

- Uses emotive and pejorative language in referring to those of an opposing opinion. On the other hand, those with the same views as his are treated with complimentary descriptions. Both are indicators of a questionable position that warrants closer analysis.
- Does not sufficiently distinguish between very small and larger wind penetrations
- Provides incomplete treatment of wind's capacity value.
- With respect to backup requirements for wind plants, focuses on the normal operating reserves within a small wind penetration jurisdiction, Pennsylvania, without addressing the extensive and continuous amount of mirroring/shadowing backup required to render wind's highly volatile output useful in higher wind penetration jurisdictions.
- Appears to depend upon a report by Gross et al, which is itself not convincing. See Appendix A.
- In dealing with the load following capability of nuclear and coal-fired plants, focuses on the ability of these to ramp output up and down without incurring stress and reliability problems in normal operating conditions (often cycling once per day). In the case of coal plants, in addition to greater reliability problems, he does not address the fossil fuel and emissions impact of large and frequent output variations during the day if used as wind shadowing/mirroring backup. In the case of nuclear plants, any ability to perform in this capacity is questionable and ignores the lack of any opportunity for reducing fossil fuel use or CO_2 emissions.

At the beginning Komanoff quotes what he wrote a few years ago in a magazine article:

> *"[S]ince wind is variable, individual wind turbines can't be counted on to produce on demand, so the power grid can't necessarily retire fossil fuel generators at the same rate as it takes on windmills. The coal- and oil-fired generators will still need to be there, waiting for a windless day. But when the wind blows, those generators can spin down."*

The underlying assumption, which appears to be the basis for most of the following arguments, is that when the wind blows it does so steadily, and when it ceases it remains so for long periods. Unfortunately it does not, and this is at the heart of the issue, which can be summarized as follows:

- On days of little or no wind, wind plants make their most useful contribution of any period by allowing the other generation plants to be utilized in their normal mode of operation, which is their most efficient in terms of fossil fuel use and CO_2 emissions.
- On days when wind is available, even in moderate amounts, it must be remembered that the electricity output variation of wind turbines is related to the cube of the wind speed, that is any change in wind speed by a factor of two is magnified by eight times (and 3 times the wind speed change produces 27 times the change in electricity output). Significant variations can occur over the period of a fraction of an hour, ranging over the full scale of wind plant capacity, and greater variations can occur over multiple wind plants. As a result wind output must be "mirrored" or "shadowed" by conventional generation means to render it useful.

[1] Komanoff, Charles*, Wind Power's Displacement of Fossil Fuels*, April 2009, http://www.komanoff.net/wind_power/Wind_Power%27s_Displacement_of_Fossil_Fuels.pdf

Wind output volatility is a major factor in the discussion about the effect on the wind mirroring/shadowing backup plant. Even on days of moderate wind, significant, random variations in wind output occur, but the variations are most violent during high wind periods. Because the conventional plants have to mirror wind's volatility, different plant types are required (e.g. increased use of OCGT plants, which are more responsive but less efficient than CCGT plants) and those involved are forced to operate at a lower level of average production, increasing their costs per megawatt-hour (MWh). As they are being used in a more inefficient mode than normal operations, they consume more fossil fuel and produce more CO2 emissions per MWh. This is like a car in continuous stop/start speed-up/slow-down city traffic as opposed to steady highway driving. This mode of operation can totally offset any reductions claimed in fossil fuel consumption and CO2 emissions as a result of the presence of wind.

Assertions made in this paper will undoubtedly be challenged and this is appropriate. The purpose is not to declare a winner but to illuminate the necessary considerations.

Use of Language

Critical treatment of a subject should avoid questionable and unbalanced language in describing either the author's views or those of opponents. Table 1 supplies examples from Komanoff`s paper.

Table 1 – Examples of Questionable Language Used

Opposing views	Supporting views
litany (a tedious recital) vociferous (noisy, clamorous) insinuation (introduced deviously) canard (unfounded rumour or story) misleadingly simply incorrect	comprehensive

Effect of Wind Penetration

One of the main observations on Komanoff's paper is that the majority of the conclusions are based on electricity systems with very small wind penetration. At this level, the effect of wind's volatility is generally not significant enough to cause noticeable effects. As wind penetrations are increased above about 1-2 per cent, in energy (MWh) terms, the problems cannot be ignored. This is confirmed by experience in Germany, Denmark, Spain, Texas, U.S. Pacific Northwest, Alberta and Ireland, for example. To say that problems may be eventually solvable ignores economic realities, as essentially everything is solvable if enough money is thrown at it. The real-world costs for solving these issues are typically not completely considered.

Significant emphasis (about one-third of Komanoff's paper) is placed on the experience of the PJM grid in Pennsylvania, which has a penetration of all renewables (of which wind is a portion and excluding hydro) of only 1.1 per cent in 2007.[2]

Denmark

Early in the paper Komanoff slips into the discussion the almost always misunderstood notion that Denmark's domestic use of wind-generated electricity is 20 per cent. Although Denmark does produce somewhat less than this amount, it exports most of it at very low prices to Norway, Sweden and Germany. Why does Denmark do this? It is because its electricity system cannot withstand this level of volatile production and must get rid of wind output above about 5-6 percent of the total electricity system production. A Danish energy consulting firm reports that a country's fleet of wind plants can operate like a single, virtual out-of-control power plant.[3] Claims that this reduces fossil fuel use and CO2 emissions elsewhere are questionable. In Norway/Sweden it is balanced by hydro plants and in Germany may be balanced with fossil fuel plants running inefficiently.

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[2] DOE/EIA http://www.eia.doe.gov/cneaf/electricity/st_profiles/pennsylvania.html

[3] Sharman, Hugh, Incoteco (Denmark) ApS, *Planning for Intermittency: The Importance of **Evidence** from Germany and Denmark*, slide 24, UK ERC Workshop, Imperial College, July 2005 (emphasis is Sharman's) http://www.ukerc.ac.uk/Downloads/PDF/05/050705TPASharmanpres.pdf

The claim that the electrical energy thus "stored" in Norway's and Sweden's hydro system and later "retrieved" (at higher costs) can be countered with Denmark would likely be further ahead by eliminating its wind plants, (including wind generation's high costs and two way transmission losses), and buying the hydro-produced electricity when needed. Further, Denmark still has to vary fossil fuel generators to balance the wind-produced electricity used domestically, with all the implications of increased fossil fuel use and CO2 emissions production.

Wind's Capacity Value

Komanoff uses a flawed analogy by claiming that a backup quarterback contributes value to a team even if he never plays. This is now analyzed in some detail as it illustrates important points. It is interesting to think about the "never plays" aspects. First, the concept of "never playing" is arguably a reasonable notion with respect to industrial wind power. Second, the analogy applies more correctly to operating reserves, which are needed to fill in for the other generation means if, as and when needed. These operating reserves have similar characteristics to that which is being replaced, that is they provide steady reliable power at the call of the system operator (football coach). The appropriate analogy with wind would be to have a basketball player sitting on the football team bench to back up the quarterback. I submit that the basketball player has different characteristics and does not add value to the team. If you prefer, substitute a guard or tackle as the quarterback backup. In these cases a duplicate, and effective, backup quarterback would have to be added. Table 2 further illustrates this point.

Table 2 – Comparison of Characteristics

	Role	Characteristics
Football team	Quarterback	• Speed and agility • Can manage team on the field and call the plays • Understands football strategy and rules • Can run with the ball effectively • Excellent passer • Needs to constantly asses abilities of all team members on the field
	Backup Quarterback	• Can reliably be expected to perform as a quarterback replacement[*] • Speed and agility • Can manage team on the field and call the plays • Understands football strategy and rules • Can run with the ball effectively • Excellent passer • Needs to constantly asses abilities of all team members on the field
	Basketball player backup for quarterback	• Speed and agility • Dribbling, passing and shooting the basketball • Understands basketball strategy and rules
	Tackle or guard backup for quarterback	• Strength and ability to resist force • Understands football strategy and rules • Need to focus on immediate team players and opponents • Good blocking and tackling capabilities
Electricity System	Fossil fuel and other plants	• Steady reliable supply of electricity • Can respond to calls for production by the system operator • Subject to scheduled and unscheduled maintenance • Low operating costs when used in appropriate role (base load, intermediate and peaking)
	Industrial wind plants	• Volatile output on a frequent, random and often extensive basis, especially during high production periods • Cannot reliably respond to calls for production by the system operator. • Subject to scheduled and unscheduled maintenance • In addition to normal system reserves, require almost 100% mirroring/shadowing backup to render output useable • High operating costs

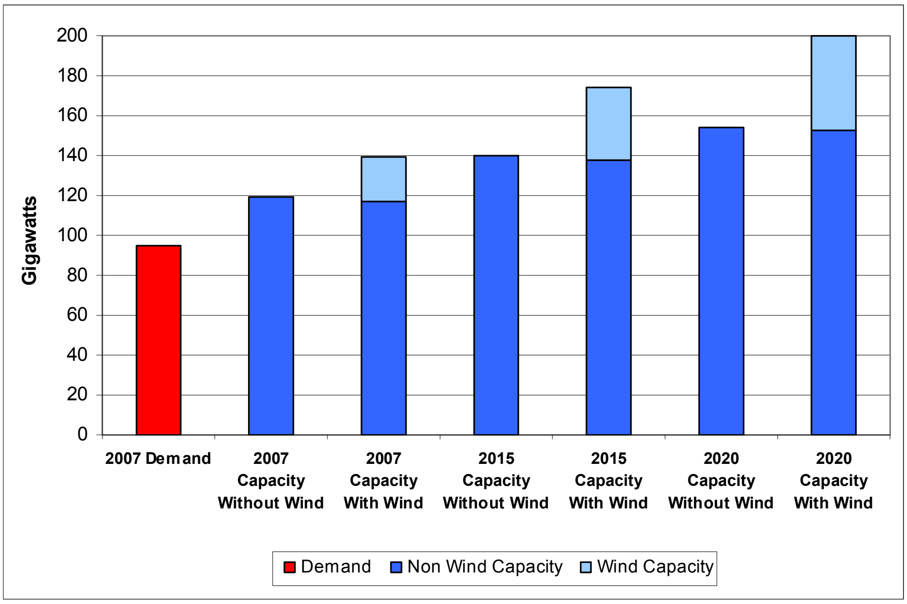
[*] This speaks to another aspect of the analogy, which would be a qualified backup quarterback who has an extensive, "wild", social life. He might just not show up for some games. Other times, he'd be there but would be hung over. Alternatively he may just exhibit erratic behavior in his play, e.g. kicking on first down, passing on third and one or running out of a good "pocket" with receivers in the clear. (Don't ask me how he got the job).

Komanoff suggests that the capacity value of wind is 20 per cent based on what the PJM grid in Pennsylvania "projects".[4] This level of wind capacity value is confirmed by two different analyses and reported by the EWEA.[5] The first is a study performed by ILEX which attributes about this amount to wind and the second a German Energy Agency (dena) analysis which attributes this amount only at low wind penetrations. In the dena study the capacity value of wind falls dramatically as wind penetration increases. At the then current penetration level in Germany, it is about 8 per cent and approaches zero at higher penetrations. A significant difference in these two analyses is that the ILEX report assumes overall electricity system reliability requirements to be 91 per cent, whereas the dena report assumes 99 per cent,[6] a more reasonable level, considering the importance of electricity to us all.

Komanoff then makes the assertion, citing the PJM system as an example, "Nevertheless, it should be noted that grid operators increasingly are recognizing that wind turbines do have some capacity value." It is a reasonable statement that all grid operators recognize that wind has some capacity value. The question is how much, and Komanoff's statement does not speak to this. There appears to be no grid operators with significantly greater experience with industrial wind than PJM that have any illusions about the latter point, especially one of the German system operators with extensive wind experience, E.ON Netz.[7]

Komanoff`s point that wind need not displace fossil fuel plants, but the production from them, is reasonable, although the notion appears to be held to some degree by wind proponents that coal plant elimination (existing or planned) is the expectation. Wind may replace fossil fuel electricity production, but the extension to fossil fuel consumption and emissions savings is not necessarily the case. Another interesting observation is that, as wind penetration approaches the level in Germany, the introduction of wind increases the total system capacity needed to satisfy a given level of demand by almost the total wind capacity. This has been clearly stated by E.ON Netz in its above-referenced wind report and confirmed by Hoppe-Klipper.[8] A representation of the referenced slide in the Hoppe-Klipper presentation and the above-referenced E.ON Netz report is shown in Figure 1 and illustrates this duplication of capacity.

Figure 1 – Redundancy of Wind Power in Germany



[4] I have been informed that PJM has since changed this to 13% based on actual experience and continues to monitor this consideration.
[5] European Wind Energy Association, *Large Scale Integration of Wind Energy in the European Power Supply*, 2005, pages 123-124, http://www.ewea.org/fileadmin/ewea_documents/documents/publications/grid/051215_Grid_report.pdf
[6] European Wind Energy Association
[7] E.ON Netz, *Wind Report 2005*, page 9. http://www.eon-netz.com/Ressources/downloads/EON_Netz_Windreport2005_eng.pdf
[8] Hoppe-Klipper, Martin, *System studies and best practices – Germany*, Managing Director, deENet, Energie mit System (a consortium of 90 research institutions and service providers in Germany) http://www.deenet.org/ . Presentation (see slide 13) was made at the Large Scale Integration of Wind Energy EWEA Policy Conference in 2006, and can be accessed through the European Wind Energy Association site at http://www.ewea.org/fileadmin/ewea_documents/documents/events/2006_grid/Martin_Hoppe.pdf. I caution the reader to be aware that the CO2 emissions reductions and additional costs (based on the dena study) in the deENet presentation have to be examined carefully and understood before drawing conclusions and making associated claims.

The first column in Figure 1 is the demand for 2007. The second, shown in the darker blue, is the conventional generation capacity to meet the 2007 demand including reserves. The third column is the effect of significant wind presence, shown as lighter blue, and illustrates the increased total electricity system capacity as a result. The increase is almost the total wind capacity. Subsequent years show projected growth in demand and wind capacity. The substantial growth in wind has no significant increased impact on reducing other generation means and continues to add to the total capacity requirements by almost the total wind capacity. This effect is due to the diminishing capacity credit for wind as its penetration increases to the 2015 and 2020 levels for Germany as shown in Figure 1, which is based on information from the sources given above.

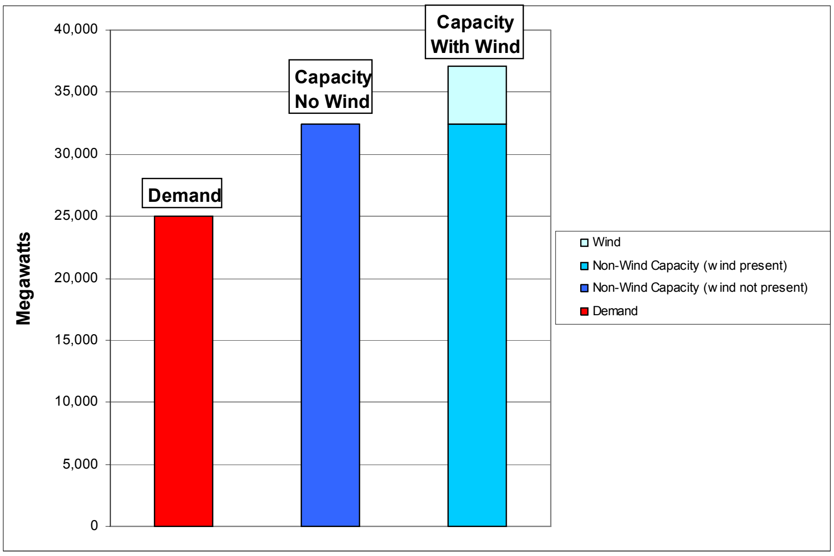
Table 3 – Redundancy of Wind Power in Germany

	2007	2015	2020
Installed wind capacity (MW)	22,000	36,000	48,000
Wind capacity credit (approximate)	7.5%	5%	4%
Other capacity that wind can displace (MW)	1,700	1,800	1,900

The conclusion from Figure 1 is not that the wind component impacts the reserves portion, although it might look this way in the representation. The non-wind and wind capacities shown are simply the total amounts for each.

This is also indicated in capacity projections for Ontario in 2020, as shown in Figure 2.

Figure 2 – Redundancy of Wind Power in Ontario



Source: Ontario Power Authority (OPA)[9]

Returning to Komanoff's point on wind production (MWh) versus capacity (MW), the increased wind presence does result in higher wind production, but this does not translate into reductions in fossil fuel use or CO_2 emissions on a one for one basis, which is generally claimed by wind proponents. Arguably the effect of wind's volatility on the shadowing/backup plant offsets any gains at the point of wind production. Even Gross does not attempt to size this effect, although he claims the offset is only partial.[10]

[9] OPA, *Ontario's Integrated Power Supply Plan*, 2006. Domestic Supply (excluding Conservation) – Exhibit D-9-1, p 8/32 Table 7 (with and without Wind component), Reserve Requirements – Exhibit D-2-1, p7/17, Demand (after Conservation), Exhibit D-1-1, p 3/34, less Conservation, Exhibit d-9-1, p 8/32, Table 7. For references to all the exhibits see http://www.powerauthority.on.ca/Page.asp?PageID=122&ContentID=6214&SiteNodeID=320&BL_ExpandID=

[10] Gross et al, *The Costs and Impacts of Intermittency*, 2006, Imperial College London, page 21, http://www.ukerc.ac.uk/Downloads/PDF/06/0604Intermittency/0604IntermittencyReport.pdf

Operating Reserves

Komanoff devotes about 3 (out of 10) pages to a discussion of reserves based on the PJM grid system, which, as already stated, has a very low penetration of wind power. Based on PJM's actual experience, the impact of this minimal amount of wind on the "supplementary reserve" component, which is called up when the immediate synchronized reserve component is overused (PJM terminology) is itself minimal. This is consistent with the experience in most jurisdictions with very low wind penetrations, where normal reserves are reasonably sufficient to balance the wind volatility, along with the fluctuations in demand, without jeopardizing system reliability.

This PJM discussion portion starts with the following quote from the PJM chief, Karl Pfirrmann;

> *"Wind is not as variable as people may think. Our experience shows that, if a wind generator is operating at a certain level at present, there is an 80 percent probability that it will be operating within ±10 percent of that level one hour from now. And, there is a 60 percent probability that it will be operating within ±10 percent of that level five hours from now. We're also encouraged that better forecasting will enable us to better predict the output from the wind generators on our system."*

This displays misunderstanding of the performance of wind plants, especially during periods of high production. Within the course of each hour the wind output can fluctuate between almost 0-100 per cent of full capacity, to say nothing about a five hour period. It could well be the case that the level of wind output at hour intervals will not display this high degree of volatility. The quote from Pfirrmann by no means supports Komanoff`s conclusion that "This suggests that rapid changes in wind output requiring rapid turndown or ramp-up of fossil plants on the grid are relatively infrequent…".

Even if wind could be forecast with 100 per cent accuracy over 5 minute intervals, this does not change the need for the mirroring/shadowing backup to have to follow the high level of volatility, which is the major source of the problem with respect to the consumption of fossil fuel and production of CO_2 emissions, not forecast accuracy.

Pfirrmann goes on to say that in connection with the impact of wind's volatility on the synchronized reserve, which serves as protection against a sudden loss of the single largest generating unit on the entire system, and the amount they (PJM) maintain is based solely on the size of that [sic] largest generating unit, Komanoff concludes:

> *"Since the largest generating unit on almost every U.S. grid is on the order of 1,000 megawatts, whereas individual wind turbines are only several megawatts and even entire wind farms are rarely more than several hundred megawatts, it's clear that wind power imposes no additional synchronized reserve requirements on power grids."*

The 1,000 megawatts is a reasonable size for this consideration, but to compare this to the loss of output from a single wind plant of a few hundred megawatts does not stand close scrutiny. If the wind plant failure was an equipment failure within a single wind plant, then the conclusion applies. However on a relatively frequent basis (even intra-day) it is not unusual for a fleet of wind plants within hundreds of miles of each other to show large variations.[11] In a jurisdiction with greater wind capacity, variations across the fleet can be significant, with quite possibly the same effect as more than one 1,000 megawatt-sized unit of conventional generation. As this can happen relatively frequently to this extent compared to conventional plant failures, the risk is that this could easily overwhelm the "normal" synchronized reserve and render it unavailable in the event of a conventional plant failure, which is the purpose for which it was designed.

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[11] Adams, Tom, *Transforming Ontario's Electricity Paradigm: Lessons Arising from Wind Power Integration*, May 2009, keynote address for the Annual General Meeting of the Professional Engineers of Ontario. http://tomadamsenergy.com/wp-content/uploads/2009/05/keynote-for-peo-may-2009-transforming-ontario_s-power-system.pdf. See also Hugh Sharman note 3 above.

Komanoff's following conclusion (albeit qualified to the PJM experience) is very questionable.

> *"We thus have, for the PJM system, the answer to the central question of wind power's displacement of fossil fuels…88%-96% of the "theoretical" fossil fuel savings for wind power — the savings that would be calculated from equating each kilowatt-hour of wind generated with a kilowatt-hour of fossil fuels avoided — remain after allowing for reserve requirements."*

Again all this relates to the PJM system, (We thus have, *for the PJM system*,...), which is not illustrative of the impact of any consequential amount of wind penetration. Further, the fossil fuel savings are determined to be a slight reduction of the "theoretical" (note Komanoff concedes that the 100 per cent level is only "theoretical"), based on allocating the use of observed supplementary reserves within the system. Finally, and somewhat understandably considering the minimal amount of wind penetration involved, no consideration is made of the necessarily increased inefficient operation of the reserves due to wind, and the effects of this on fuel consumption and CO2 emissions in systems with greater wind penetration.

Komanoff goes on to claim, "The takeaway from the PJM interview — that reserve maintenance uses up only a small percentage of the fossil fuel savings from wind power generation — is evidenced in essentially every major study of wind integration on utility grids." If Komanoff is relying on the UK paper (Gross et al) for this, which he cites, it should be noted that a large number of the studies reviewed in the report predate the turn of the century. Further the dena study from Germany, (dated 2005) does not extend results past about 17 per cent penetration, whereas many of the others project to 30-40 per cent, which is totally unrealistic based on practical experience in Denmark and Germany. The author of the UK report (Gross) labels Germany's dena low results as "outliers". This is interesting considering that Germany is the most experienced and its report one of the most recent of those reviewed by Gross. The use of the term "outlier" may be significant if all the observations (theoretical projections in the majority of cases cited) relate to a natural phenomenon or underlying process with a central tendency, which they do not. They are individual theoretical projections based on models.

Continuing on from the Komanoff quote in the previous paragraph, he cites two reports he selected "at random" in support of his claim, but both are from low penetration jurisdictions, the state of Minnesota and the UK (Gross), the latter of which can be questioned, as already indicated. As a simple example, Gross appears to attempt to further discredit the dena study results, which is not favourable to wind, by referring to two other "German" studies, whose results lie within the more favourable (and more populated) range. They do not originate from German sources, but are Austrian (2004) and European Union (1992) studies. For a more detailed analysis of the Gross report see Appendix A.

There are many published analyses that cover the related considerations more completely.[12]

In summary, although normal operating reserves appear to be adequate in very small wind penetrations, the situation changes significantly when penetrations exceed a few per cent in MWh terms. The requirement for additional backup of a different, and more extensive, nature solely for wind becomes apparent. This is the result of the need to have

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[12] A sampling includes:
- White, David, *Reduction in Carbon Dioxide Emissions: Estimating the Potential Contribution from Wind Power*, December 2004, Renewable Energy Foundation http://www.ref.org.uk/Files/david.white.wind.co2.saving.12.04.pdf
- Nedic, Dusko et al, *Security Assessment of future UK electricity Scenarios*, Tyndall Centre for Climate Change Research, July 2005, http://www.tyndall.ac.uk/research/theme2/final_reports/t2_24.pdf
- White, David, *Danish Wind: too good to be true*, The Utilities Journal, July 2004, page 39, http://www.aweo.org/White-DenmarkTooGood.pdf
- Sharman, Hugh, *Why UK wind power should not exceed 10 GW*, Proceedings of ICE, Civil Engineering 158, November 2005, pages 161-169. http://www.incoteco.com/upload/cien.2005.158.4.161.pdf. See page 168
- Campbell, Arthur, *Government Support for Intermittent Renewable Generation Technologies*, April 2009, MIT Dept of Economics http://econ-www.mit.edu/files/3563
- Oswald, James et al, *Will British weather provide reliable electricity?*, April 2008, http://www.wind-watch.org/documents/wp-content/uploads/oswald-energy-policy-2008.pdf
- Liik, O. et al, *Estimation of real emissions reductions caused by wind generators*, International Energy Workshop, June 2003, http://www.etsap.org/worksh_6_2003/2003P_liik.pdf
- Steinberger, J., *Solar Power Should Replace Wind Energy*, Times Online, May 27, 2009, (doesn't qualify as "more completely", but is noteworthy) http://www.timesonline.co.uk/tol/news/environment/article6368156.ece

capacity other than normal reserves to mirror/shadow wind production, which can extend to almost 100 per cent of wind capacity in order to render wind's volatile output useful and better ensure electricity system reliability.

Load Following Capabilities of Fossil Fuel and Nuclear Plants

With respect to coal plants, Komanoff recalls the rule of thumb that "…to accommodate diurnal variations [between day and night] in aggregate demand, large, modern coal-fired units could be banked down from 100% load to as little as 25% of full capacity, and then back up again, without incurring "thermal stress" that could lead to tube leaks, pipe cracking, or other damage, so long as the transition was gradual rather than abrupt." He goes on to suggest "*If* this rule of thumb still holds…" (emphasis added), that coal plants could follow wind's continuous volatile output throughout the day. Let alone the very questionable major jump in logic from one "cycle" per day to many, the focus is on damage to the coal plants' components (which is important enough), but no mention is made of fossil fuel consumption and CO_2 emissions resulting from this abnormal and inefficient mode of operation, which are at least equally important considerations.

With respect to nuclear plants, Komanoff claims that "Most nuclear power plants also have *considerable* load-following capability…" (emphasis added), implying that they would be able to respond to wind's continuously volatile output. France, which has substantial nuclear plant capacity, is cited as an example of the need for nuclear plants to respond to daily changes in demand and this is suggested to illustrate their ability to mirror wind's volatility. As previously indicated, the daily changes in demand are a different consideration than having to respond to wind's continuous volatility. Further, France has less than 1 per cent wind penetration and also has gas and hydro generation capacity, both of which are more likely candidates to be used to respond to demand and wind fluctuations throughout the day.

For a more in-depth analysis of Komanoff's comments on the variability of nuclear plants, Appendix B contains comments from a qualified GE employee with 25 years experience in the nuclear industry.

Conclusion

Recognizing that all papers on the subject make a contribution, it is necessary to look further than Komanoff or Gross for a definitive analysis of the impact of industrial-scale wind power in an electricity system.

Appendix A

Comments on Gross Study

General

The Gross report[13] contains a great deal of material, and comments in this appendix are definitely not exhaustive. No attempt has been made to look at all the detail, as there appears to be enough to suggest caution even at a higher level of review. In sum, it appears impressive but is very questionable when looked at more closely. In general, although a contribution to the topic, it reinforces the view that one should be cautious in attributing too much to any one report, regardless of the extent of sources cited.

The main focus of the 64 documents that use "statistical and/or time series simulation" versus "review" (presumably literature review) referenced by Gross (out of a total of 212) is on reliability, reserves and balancing, which can be interpreted to mean reserves directly required to maintain overall grid security, with restrictions as noted below. The E.ON Netz report which shows very high requirements is labeled an "outlier" because it deviates substantially from most of the others. This is remarkable as E.ON Netz is one of the most wind-experienced electricity system operators in the world and its report one of the most recent. Table A1 provides a breakdown by date of publication, and other considerations, of all the reports mentioned.

Table A1 – Summary of Reports Referred to by Gross

Primary Aspect Covered	Method/Approach	Number of Documents by Time Period	Total Number
Reliability, reserves and balancing	Statistical and/or time series simulation (plus one categorized as "other")	1978 -1989 – 19 1990-1999 – 23 2003-2004 – 23	65
	Review		57
Connection, transmission and network issues	N/A		19
Resource characteristics	N/A		13
Total included			154
Total excluded as "irrelevant" or "duplicative"			58
Total all documents			212

65 per cent of the documents addressing reliability, reserves and balancing were produced before 2000 when wind power was not a significant factor in electricity systems. See Table A2 below for information on installed wind capacities. Further restrictions are:

- With respect to system balancing, only 10 show any metrics of the effect of penetration (the percentage of installed wind measured in MWh), and two of these had to be dropped from Gross' Figure 3.1 as they did so in a way that could not be represented. Of the remaining 8, three graphed did not specify the penetration level.

- Fifteen, all after the year 2000, were graphed in Gross' Figure 3.2, showing the cost of reserves. Of the 15, eight were from the UK and three from the US, both having low wind penetration experience and representing a total of over 70 per cent of the reports. They typically showed lower costs. Two were from Denmark, with one showing costs in the higher range. One was from Spain, again showing costs in the higher range.

- Nineteen were graphed showing capacity credit values, for a wide range of penetration values, but 58 per cent pre-dated the turn of the century, increasing to 74 per cent if the period 2000-2002 was included.

[13] Gross, Robert et al, *The Costs and Impacts of Intermittency*, March 2006, Imperial College London http://www.ukerc.ac.uk/Downloads/PDF/06/0604Intermittency/0604IntermittencyReport.pdf

Here are selections from general observations by Gross (page 36) with respect to the information studied:

> *"One striking characteristic of the data is the range of different metrics used to assess the impacts. This means that for each of the categories of impact identified above, the numbers are presented in several different formats. This creates the potential for confusion and the risk that comparisons between results is not on a genuinely like for like basis. Attempts to normalise data from a range of studies to facilitate comparison run the risk of losing important detail or, at worst, suggesting that figures are comparable when they are not."*
>
> *"Even where studies have used ostensibly the same metric it is not always possible to compare the results because a study has focussed on a particular element of a metric, or other system dimensions are not declared. Examples include studies which do not identify the extent to which intermittent generation displaces existing plant. Other studies are not explicit regarding total intermittent generation levels, total system capacity, or total system demand, all of which hamper the derivation of the penetration level."*
>
> *"These issues do not imply a criticism of the studies reviewed – they are used to illustrate that it is prudent to exercise caution when drawing comparisons between results."*

One comment that can be made is that it appears that most do not provide a complete analysis of the elements to make a comprehensive determination. Gross also explains that wind penetration levels analyzed are not always clear. This is an important consideration as low levels of penetration may have a relatively small impact.

In this regard it is interesting to note that a number of the reports evaluate wind penetration up to 30-40 per cent, whereas many, including the two for Germany, stop at 20 per cent or less. There is no basis to assume wind penetrations at the higher levels are supportable in any jurisdiction, and there is sufficient confirmation based on actual experience in Germany and Denmark, for example, that the limit is well within single digits of wind penetration percentage.

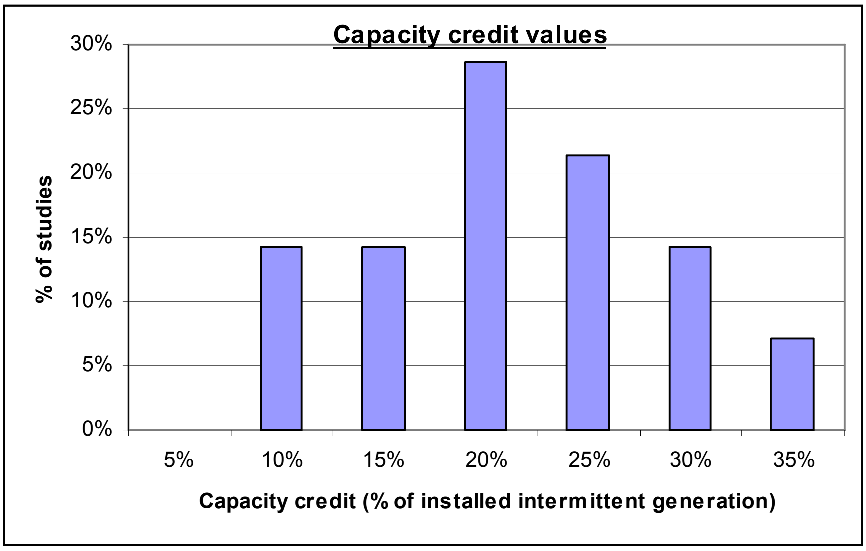
Returning to the question about the impact of wind on system reserves, Gross states that "Different analysts use different definitions of 'reserves', which means that a range of impacts are captured." However, there is a further consideration beyond reserves. This is the requirement for wind mirroring/shadowing backup on a continuous basis to render wind's output useful. This is arguably separate and additional. Gross refers to it in note 54 with the comment that "Eon Netz introduce [sic] the term 'shadow capacity' which is not used in any other literature and its precise meaning is unclear." The meaning relates to this additional requirement. I refer again to E.ON Netz' real, practical experience with wind power compared to most, if not all, the other documents reviewed. E.ON Netz claims that 80 per cent backup for wind is required in its Wind Report 2004, and increases this to 90 per cent in the 2005 edition.

This consideration is shown in capacity credit values and in the amount of total capacity required in an electricity system, over and above that which would be required without the presence of wind, as discussed in the main body of this paper. In penetrations above about 1 per cent, this approaches the full wind capacity on a statistical basis over time. On an instantaneous, or even a very short term, basis the range of involvement of shadowing/mirroring wind backup could be any value between 0-100 per cent of installed wind capacity.

Capacity Credit Details

These and other considerations bring into question the display in Gross' Figure 3.4 of a frequency distribution of findings of the Gross report at the 10 per cent wind penetration level. Given Gross' own questioning of comparing results, it is suggested that such a representation may be misleading. Gross' Figure 3.4 is represented in Figure A1.

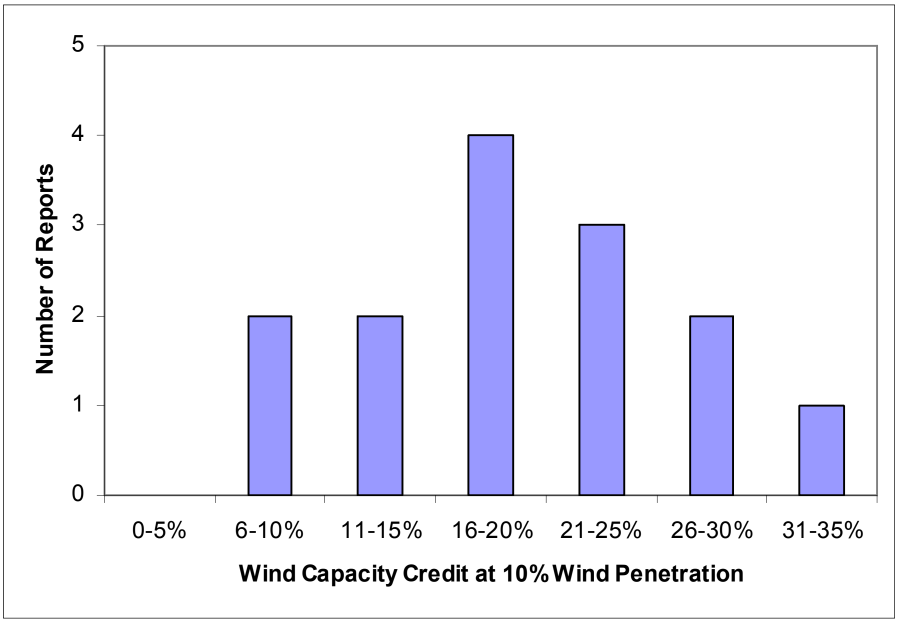
Figure A1 – Gross' Figure 3.4



Frequency distribution of findings for capacity credit where intermittent generation provides 10% of energy

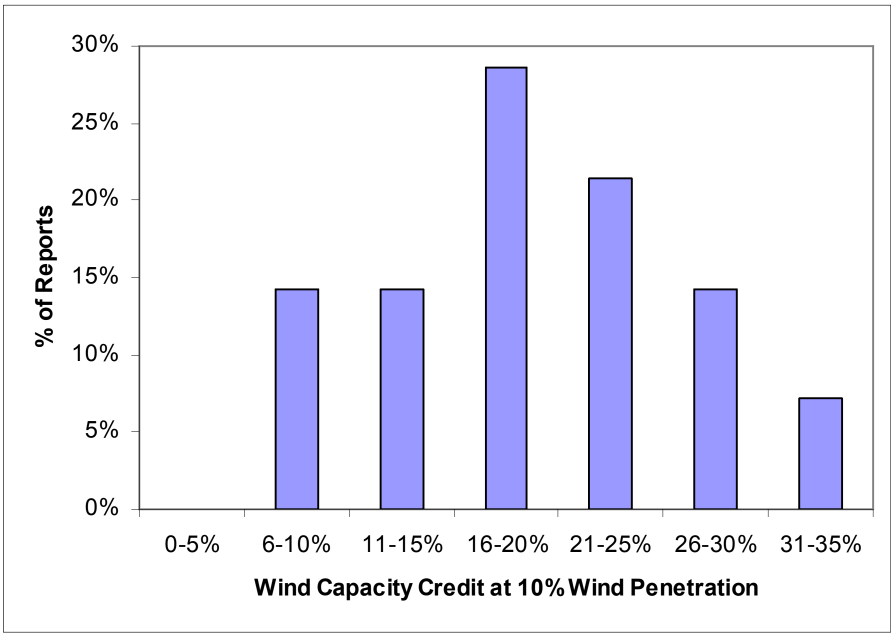
A closer look at this representation is interesting. The first point is that the classification of results as 5, 10, 15…, introduces a distortion. A better representation would be to show these as a range e.g. 0-5, 6-10 etc. Otherwise there is a "rounding up" of results.[14] For example, within the 10 per cent class the specific values are 6 and 8. Figures A2 and A3 show the results represented this way maintaining the same upper range of intervals. Figure A2 shows the actual number of reports, and A3, the percentage distribution.

Figure A2 – A Better Representation of the Study Results



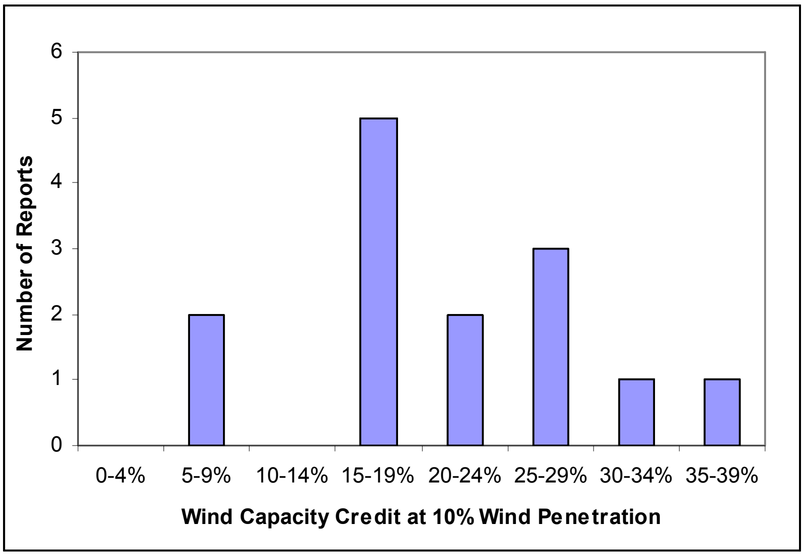
[14] Gross acknowledges this in footnote 59 on page 43.

Figure A3 – A Better Representation of Study Results in Percentage Terms



Even this distorts the results as the first interval has 6 class frequencies (0,1,2,3,4,5) and the remainder 5, (6,7,8,9,10 for example). Correcting this to show 5 class frequencies for all intervals changes the upper limit for each as shown in Figure A4.

Figure A4 – A Better Representation of the Study Results (with consistent intervals)



This looks less like a "normal" probability distribution than Figures A1-A3, and raises the possibility that more than one group of reports with different characteristics may be represented. The following examines this in more detail.

One of the interesting details of the Gross results is the number of reports that predate the turn of the century, when there was relatively little wind power deployed world-wide compared to 2007. Table A2 shows this information

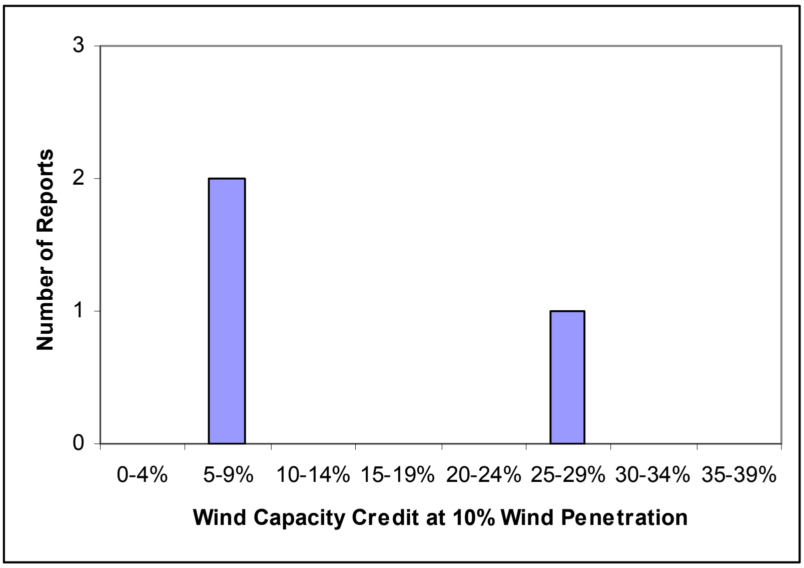
Table A2 – Installed Wind Capacity in Megawatts (MW)

Year	World-wide (MW)	Percent of 2007	US (MW)	Denmark (MW)	Germany (MW)
1980	10	0.01%	8	5	0
1990	1,930	2.1%	1.484	343	62
1999	13,600	14.4%	2,490	1,718	4,445
2000	17,400	18.5%	2,578	2,300	6,105
2006	74,133	78.8%	11,575	3,136	20,622
2007	94,122	100%	16,818	3,125	22,247

Source: Earth Policy Institute

The earliest dated report in this group is 1983, at which time only just over 200 MW was installed world-wide. As can be seen, more than 80 per cent of the total wind capacity world-wide has been installed since the year 2000, the turn of the century. It seems reasonable to conclude that real experience in wind power before that time would not be as realistic as experience since 2000. Since 2000, Germany has had more experience than any other country, especially with both large wind implementations and high wind penetrations. What would Gross' Figure 3.4 look like if the studies that pre-dated the turn of the century were eliminated? Figure A5 shows this result.

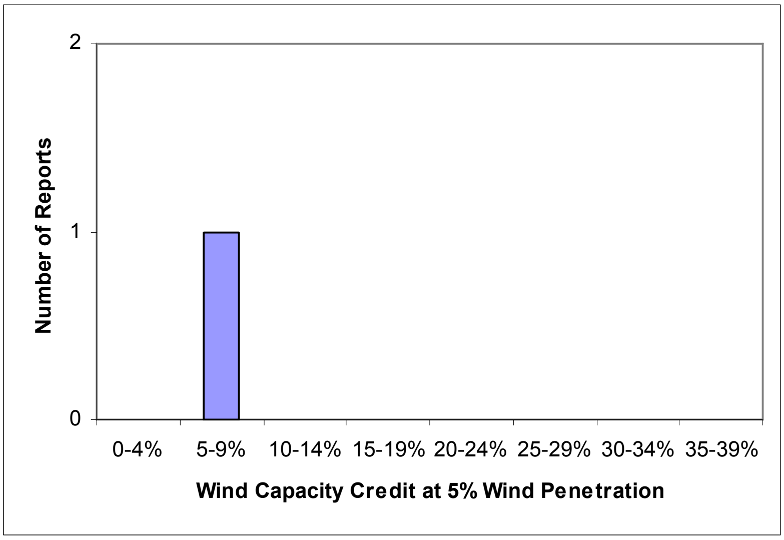
Figure A5 – Gross Results Eliminating the Studies Dated Before 2000



The two studies in the 6-10 per cent class were both German and dated 2005. The one in the 26-30 per cent class is English, dated 2003, and is a literature review based on many of the studies eliminated. It comes closer to being viewed as an "outlier" than the German studies that Gross classifies as such.

The next question is: what do the Gross results look like when the pre-2000 reports are excluded and at 5 per cent wind penetration? As 5 per cent penetration is a realistic maximum that an electricity system can withstand based on real, practical experience, this is perhaps the most meaningful of all. See Figure A6 for this.

Figure A6 – Figure A4 Results at 5% Wind Penetration



The one report that remains is the E.ON Netz report.

Any argument that this is now based on only one report and therefore hardly significant can be countered with the consideration that one report of a recent nature from the most experienced jurisdiction can arguably outweigh many reports from a time when there was little extensive, practical experience world-wide and from jurisdictions with minimal levels of wind.

In any event, the purpose here is not to argue the veracity of the E.ON Netz report by itself, but to illustrate the need to carefully analyze the Gross report, amongst others, on this subject.

Appendix B

Further Comments on the Variability of Nuclear Plants

1. PWRs [pressurized water reactors] and BWRs [boiling water reactors] can both load follow approximately equally. PWRs would primarily use chemical shimming to accomplish this (insertion of boric acid). BWR's would use flow control (an issue for the proposed ESBWR – but let's not go there right now). In fact, Duane Arnold (DAEC) in Iowa did load follow for a number of years in the 80's because there simply wasn't sufficient base load demand to allow it to run at 100% capacity. One of the few reactors around the world to do so for any length of time. For BWR's the trade-off of using flow is that operation is sub-optimized. There are nice energy benefits in operating at low flow for extended periods (higher voids, harder neutron spectrum, more plutonium created to be burned as fuel later in operating cycle.)

2. Physical reality – the nuclear chain reaction in core creates a number of fission products and the associated daughter products, including Xenon-135 which is a significant neutron absorber. When the reactor operates at steady state, it take the Xenon 24-72 hours to achieve steady-state concentrations in the core. When power level changes, the equilibrium of these daughter products is disturbed. Depending on the magnitude of the disturbance, both grossly and regionally in the core, it can make operation very complex while the equilibrium state is attained again.
If the load following is fairly cyclic and consistent (diurnal pattern), a pseudo equilibrium state can be obtained. Which is what was done at DAEC. Even so, significant additional operating margin had to be designed into the core. This meant that the core and fuel efficiency was significantly reduced and the relative cost of the power generated was therefore increased. Same would be true in a PWR. The unpredictable nature of responding to changes in the wind would make this far more complex and would have even greater impact on fuel efficiency.

3. Speed of demand response – Because of the physical reality of operation, nuclear power plants are not allowed to operate with automatic response demand by the IPOs. The NRC has concerns over inadvertent overpowers or margin impact. Thus, the grid operator must actually call the plant and request a power change. This makes dealing with rapid changes by making small power changes at a number of facilities impractical.

It is correct (at least with respect to PWRs), but vastly oversimplifying the realities of nuclear power's ability to follow load. He ignores the "over limited ranges" portion of this and implies that nuclear reactors can simply turn it off like a gas turbine… Here's a discussion of the true load following practice in France: http://www.world-nuclear.org/info/inf40.html.

In any case, the real argument comes from the fact that he is asking the LOWER COST power supply – nuclear (and coal, for that matter) to increase their relative costs and lower production in order to allow a HIGHER cost power supply to contribute to the grid. Makes no economic sense. AND in the case of nuclear, no ecological driver exists either.