Grid Flexibility and Research Challenges to Enhance the Integration of Variable Renewable Energy Sources

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www.erc.ucd.ie
Have you done your homework?

Recommended Reading:
- Unit Commitment With Dynamic Cycling Costs
- Evaluation of Power System Flexibility (May 2012)
- Special Report: Flexibility Requirements and Potential Metrics for Variable Generation, Implications for System Planning Studies (NERC)
- Special Report: Potential Reliability Impacts of Emerging Flexible Resources (NERC August 2010)

Was any of it relevant to you?
Overview

• Supply demand balance and defining flexibility
• Some sample systems and curtailment
• Quantifying flexibility and developing metrics
• Unlocking flexibility
  • Short term operational strategies
  • Longer term planning (investment) strategies
• Some possible negative consequences and mitigation strategies
• Future grids
• Conclusions
Supply Demand Balance & Flexibility
Grid Frequency Control

Supply

Frequency

Demand (MW)

Time (hours)
Italian blackout Sept 28th 2003

The Vatican
What is flexibility?

Flexibility is the ability of a system to deploy its resources to respond to changes in net load, where net load is the remaining system demand not served by variable generation.

Source: Eamonn Lannoye, PhD student, ERC, UCD


We consider flexibility to be the availability of resources, from the day ahead of delivery to the time of delivery, that can change their level of production or demand by defined amounts and sustain this position for a period of at least one hour in a reliable manner.

Frontier Economics “Study on flexibility in the Dutch and NW European power market in 2020” A report prepared for EnergieNed, April 2010
With variable renewables more flexibility is needed

Source: Michael Milligan, NREL
With variable renewables more flexibility is needed.

Steeper ramps
Lower turn-down

Solar will have similar impacts

Source: Michael Milligan, NREL
The flexibility paradigm

**Sources**
- Physical
  - DSM
  - Electricity Storage
  - VG
  - Interconnection
  - Conventional Generation

**Match Makers**
- Transmission Networks
- Fuel Storage
- Forecasting
- Gate Closure
- Grid Codes
- Ancillary Services Markets
- Cycling Costs
- Market Resolution
- Balancing Area Size
- Unit Commitment

**Sinks**
- Load
- Solar
- Wind etc..

**Planning**
- DSM
- VG
- Conventional Generation
- Electricity Storage
- Interconnection
- Conventional Generation

**Operations**
- Ancillary Services Markets
- Cycling Costs
Some sample systems
Wind curtailment estimates – US

Curtailment - negative “metric” for flexibility

<table>
<thead>
<tr>
<th>Company</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Reliability Council of Texas (ERCOT)</td>
<td>109 (1.2%)</td>
<td>1,417 (8.4%)</td>
<td>3,872 (17.1%)</td>
<td>2,067 (7.7%)</td>
<td>2,622 (8.5%)</td>
</tr>
<tr>
<td>Southwestern Public Service Company (SPS)</td>
<td>N/A</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0.9 (0.0%)</td>
<td>0.5 (0.0%)</td>
</tr>
<tr>
<td>Public Service Company of Colorado (PSCo)</td>
<td>N/A</td>
<td>2.5 (0.1%)</td>
<td>19.0 (0.6%)</td>
<td>81.5 (2.2%)</td>
<td>63.9 (1.4%)</td>
</tr>
<tr>
<td>Northern States Power Company (NSP)</td>
<td>N/A</td>
<td>25.4 (0.8%)</td>
<td>42.4 (1.2%)</td>
<td>42.6 (1.2%)</td>
<td>54.4 (1.2%)</td>
</tr>
<tr>
<td>Midwest Independent System Operator (MISO), less NSP</td>
<td>N/A</td>
<td>N/A</td>
<td>250 (2.2%)</td>
<td>781 (4.4%)</td>
<td>657 (3.0%)</td>
</tr>
<tr>
<td>Bonneville Power Administration (BPA)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>4.6* (0.1%)</td>
<td>128.7* (1.4%)</td>
</tr>
<tr>
<td><strong>Total Across These Six Areas:</strong></td>
<td>109 (1.2%)</td>
<td>1,445 (5.6%)</td>
<td>4,183 (9.6%)</td>
<td>2,978 (4.8%)</td>
<td>3,526 (4.8%)</td>
</tr>
</tbody>
</table>

Estimated Wind Curtailment in Various Areas, in GWh (and as a % of potential wind generation)

*Source: Charlie Smith, UVIG & ERCOT, Xcel Energy, MISO, BPA*
Wind Power in Ireland # 1

30% Total Energy Penetration on 22nd Jan 2012

7.5% Total Energy Penetration on 23rd Jan 2012

50% Instantaneous Wind Penetration
Wind Power in Ireland # 2

Some Statistics

- 103 days in 2011 when wind went over 40% demand
- Nov 26th 2011 – 38% of demand served by wind
- No storage in 2011 and limited interconnection
- Curtailed energy in 2011 – 2.3% (1/3 ERCOT)
- Capacity factor 2011 - 31%
- 16% wind energy year 2011 (2 x ERCOT)
- 65% electricity from gas

Source: EirGrid
Wind and demand, dance partners?

Wind curtailment in China

- In 2011 wind curtailment in China was 16.9% that is of the wind that is connected to the grid i.e. approx. 75% of the 80 GW installed.
- May well be just a legacy issue i.e. in China as the load grows the new thermal plant can be made more flexible and system will be designed around the needs.

Quantifying Flexibility
Who wants/needs to know
Different time frames

Planning

Unit Commitment (on/off)

Operations

Economic Dispatch (power level)

Real Time

Years

Weeks - Hours

Minutes

Time
Cost effectiveness of flexibility

Research needed to determine shape of Flexibility
Supply Curve and Quantify Costs - Metrics

- Markets
  - Real-Time
  - Day-Ahead
  - Price Responsive Load
  - Demand Response

- Flexible Generation
  - Simple Cycle GT
  - Combined Cycle GT

- Traditional Storage
  - Hydro
  - Pumped Hydro
  - Gas Storage

- Wind Curtailment
  - In Range of 1 or 2%

- Storage
  - Batteries
  - Flywheels
  - SMES
  - CAES
  - Capacitors
  - PHEV

UWIG
Utility Wind Integration Group
A complete integration study

Flexibility metric methodology # 1

Planning and operations merging

More metrics

Periods of Flexibility Deficit (PFD)

• For each time horizon
  • For each time period
    • Calculate the flexibility available from generation
    • Calculate the net load ramp
    • Add the outage of the largest online generator to the net load ramp
    • If there is insufficient flexibility to meet the ramp, increase the PFD counter by one.
  • Final PFD is the number of problem periods for that time horizon


Unlocking flexibility
short term operational strategies
Aggregation wind and larger balancing areas

http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch07
Hourly Average Wind and Forecast Wind (MW) for the period 6.-10. May 2009

Source: EirGrid, 2009
More regular dispatch – more flexibility

Bigger is better; faster is better

Average Total Regulation for 6 Dispatch/Lead Schedules by Aggregation (Dispatch interval - Forecast lead time)

- Faster

Source: Michael Milligan, NREL

Milligan, Kirby, King, Beuning (2011), The Impact of Alternative Dispatch Intervals on Operating Reserve Requirements for Variable Generation. Presented at 10th International Workshop on Large-Scale Integration of Wind (and Solar) Power into Power Systems, Aarhus, Denmark. October
New flexible products being investigated

http://www.eirgrid.com/operations/ds3/

Unlocking flexibility longer term planning (investment) strategies
Interconnection & Transmission
Transmission playing its part. Note the sag on the line.
Denmark’s wind is integrated by rest of Europe

**Figure 25:** Correlation between a storm hitting the Danish western coast, Danish wind production and the balance of flows between Denmark and Norway

Source: North European Power Perspectives (http://www.nepp.se/organisation.htm)

Eurelectric 2011 “Flexible Generation: Backing up Renewables” Published as part of EURELECTRIC Renewables Action Plan (RESAP)
What does transmission do to flexibility metrics?

- Planning wise it increases it but without the coordination with operations it may reduces it!
- Transmission constraints should schedule more units online when there is congestion
  - More part loaded units results in **more online flexibility**
  - Congestion will limit the additional export capacity of plants, **reducing flexibility**

Source: Eamonn Lannoye, PhD student ERC

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Can thermal power plant skip?

Table 3.2: The load following ability of dispatchable power plants in comparison

<table>
<thead>
<tr>
<th>Power Plant Type</th>
<th>Start-up Time</th>
<th>Maximal change in 30 sec</th>
<th>Maximum ramp rate (%/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open cycle gas turbine (OCGT)</td>
<td>10-20 min</td>
<td>20-30%</td>
<td>20%/min</td>
</tr>
<tr>
<td>Combined cycle gas turbine (CCGT)</td>
<td>30-60 min</td>
<td>10-20%</td>
<td>5-10%/min</td>
</tr>
<tr>
<td>Coal plant</td>
<td>1-10 hours</td>
<td>5-10%</td>
<td>1-5%/min</td>
</tr>
<tr>
<td>Nuclear power plant</td>
<td>2 hours - 2 days</td>
<td>up to 5%</td>
<td>1-5%/min</td>
</tr>
</tbody>
</table>


Flexible gas plant

Natural gas replacing coal

- As we introduce more efficient units they may also be more flexible!
Flexible coal plant?

Looking for Flexibility...
More Flexibility in Coal than Gas?

Darren Finkbeiner
Manager Market Development
UVIG – Spring Technical Conference
April 24-26, 2012
Cycling thermal plant
Cycling impact of increasing wind energy penetrations

Effects of Cycling
Impact of Dynamic Cycling Costs

Total system costs (3 years)

Multi-mode Operation of Combined-Cycle Gas Turbine
Future Grids

Targets for non-synchronous sources in European Systems

http://www.eirgrid.com/operations/ds3/

* Based on analysis of National Renewable Action Plans (NREAPs) as submitted by Member States
Operational boundaries with non synchronous generation

Very high penetrations “technical” flexibility is key

- Frequency nadir (lowest point) can be improved

Demand can be flexible

International Convergence

- **USA**
  - National Renewable Energy Laboratory
  - Electric Power Research Institute

- **China**
  - State Grid
  - Tsinghua

- **Europe**
  - Oxford
  - Danish Technical University

- **International**
Conclusions

- Flexibility in grids is important to help integrate variable renewables
- Every system is different and flexibility metrics are evolving slowly
  - Metrics allow us to quantify flexibility and potentially do cost comparison
  - A key metric is reduced curtailment
- Flexibility is both an operational and a planning (investment) issue
  - Operational aspects generally the most important at low penetrations
  - Planning (investment) aspects grow in importance with penetration levels
- There are many sources of flexibility and most cost effective should be used
  - Challenging to design a market to encourage correct actions
- The switch from coal to natural gas may be key in the US.
- Future grids have significant research challenges in “technical” flexibility and Energy Systems Integration
- International collaboration is critical

Was any of it relevant to you?
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• UCTE, Final Report of the Investigation Committee on the 28th September 2003 Blackout in Italy


• CaliforniaISO "Integration of Renewable Resources" Transmission and operating issues and recommendations for integrating renewable resources on the California ISO-controlled Grid, November 2007


References #2


References #3

- EirGrid and SONI, 2012; "2011 Curtailment Report"