Workshop on Grid Integration of Variable Renewable Energy: Part 1

Power System Systems Operations Analysis

March 14, 2018
Economics of Grid Integration of Variable Power

#### Relative Economics of Integration Options

- Involuntary Load Shedding
- Transmission Expansion
- Residential Demand Response
- Coal Ramping
- CT and CCGT Gas Ramping
- Transmission Reinforcement
- Advanced Network Management
- Inverter
- Hydro Ramping
- Pumped Hydro Storage
- Thermal Storage

Option costs are system-dependent and evolving over time

**Type of Intervention**

- Load
- Flexible Generation
- Transmission
- Storage

**System Operation**

- Services from Variable RE

**Cost**

- Expanded Balancing Footprint/Joint System Operation
- Upward Reserve and Dispatch
- Downward Reserves
- Frequency Support
- Voltage Support
- RE Forecasting

**Flexibility Reserves**

- Sub-hourly Scheduling and Dispatch

**System Integration**

- Load
- Flexible Generation
- Transmission
- Storage

3/16/2018
Net Load = Load – Wind Production

Source: NREL 61721
What is the reserve requirement?

1. Higher grid inertia and governor response
2. Modest amount of higher system-wide reserves, depends on accuracy of RE forecast
3. Higher ramp rate of conventional generators
4. More frequent start, stop and lower dispatch levels of some conventional generator
Need for higher grid inertia & governor response

Need for higher grid inertia & governor response

- High wind penetration implies dispatch of lesser number of conventional generators
- Most wind* and solar power plants do not provide inertial or droop response

- Wind forecast is 100% accurate: No change in reserve requirement
- Wind forecast is 90% accurate
- No wind forecast is done
Ramp rate impact
How to reduce reserves?
Move from hourly to sub-hourly dispatch
## Illustrative Example: Generator Details

<table>
<thead>
<tr>
<th>Generator</th>
<th>Capacity, MW</th>
<th>Minimum load, MW</th>
<th>Ramp rate, MW/min</th>
<th>Type</th>
<th>Marginal Cost, $/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>500</td>
<td>500</td>
<td>0</td>
<td>Base-load</td>
<td>50</td>
</tr>
<tr>
<td>B</td>
<td>300</td>
<td>270</td>
<td>0</td>
<td>Base-load</td>
<td>55</td>
</tr>
<tr>
<td>C</td>
<td>200</td>
<td>25</td>
<td>25</td>
<td>Flexible</td>
<td>58</td>
</tr>
<tr>
<td>D</td>
<td>200</td>
<td>25</td>
<td>25</td>
<td>Flexible</td>
<td>58</td>
</tr>
<tr>
<td>E</td>
<td>200</td>
<td>25</td>
<td>30</td>
<td>Flexible</td>
<td>60</td>
</tr>
<tr>
<td>Case 1, Wind farm</td>
<td>100</td>
<td>0</td>
<td>5</td>
<td>Wind</td>
<td>0</td>
</tr>
<tr>
<td>Case 2, Wind farm</td>
<td>300</td>
<td>0</td>
<td>15</td>
<td>Wind</td>
<td>0</td>
</tr>
</tbody>
</table>
• Maximum load ramp rate = 15 MW/min;
• Two scenarios of total installed wind capacity = 100MW and 300MW
• Maximum wind ramp rate with 100MW of total wind install = 5 MW/min
• Maximum wind ramp rate with 300MW of total wind install = 15 MW/min
• Reserve requirement (RR) = 100MW + 10% of total installed wind capacity
• High wind scenario
• Start-up and shut-down cost
• Fixed cost
• Start-up and shut-down time
• Minimum run- and down-time.
### Illustrative Example: Dispatch for 3 Scenarios

<table>
<thead>
<tr>
<th>Time</th>
<th>Load</th>
<th>No wind RR=100MW</th>
<th>Installed wind capacity=100MW, WF = 100%, RR=110MW</th>
<th>Installed wind capacity=300MW, WF=100%, RR=130MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>6AM, Load=800MW</td>
<td>A,B,C</td>
<td>A,C,D</td>
<td>B,C,D</td>
<td></td>
</tr>
<tr>
<td>9AM, Load=1,000MW</td>
<td>A,B,C,D</td>
<td>A,B,C,D</td>
<td>A,C,D</td>
<td></td>
</tr>
<tr>
<td>11AM, Load=1,100MW</td>
<td>A,B,C,D</td>
<td>A,B,C,D</td>
<td>A,C,D</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Load (MW)</td>
<td>No wind RR=100MW</td>
<td>Installed wind capacity=100MW, ED WF = 100% RR=110MW</td>
<td>Installed wind capacity=300MW, ED WF=100% RR=130MW</td>
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<tr>
<td>------------</td>
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<td>--------------------------------------------------</td>
</tr>
<tr>
<td>6AM, Load=800MW</td>
<td>A=500, B=270, C=30</td>
<td>A=500, C=175, D=25</td>
<td>B=300, C=175, D=25</td>
<td></td>
</tr>
<tr>
<td>9AM, Load=1,000MW</td>
<td>A=500, B=300, C=175, D=25</td>
<td>A=500, B=300, C=75, D=25</td>
<td>A=500, C=175, D=25</td>
<td></td>
</tr>
<tr>
<td>11AM, Load=1,100MW</td>
<td>A=500, B=300, C=200, D=100</td>
<td>A=500, B=300, C=175, D=25</td>
<td>A=500, B=270, C=30</td>
<td></td>
</tr>
</tbody>
</table>
Before new flexible generators are procured, the “hidden” flexibility in the existing network should be fully exploited

- Generators are profitable when dispatched at close to 100%
- Generators are profitable when there is very little cycling
- Generators do not want to incur shut down and start up cost
- Minimum loading requirement of IPP generators (Contractual)
- Demand: Dispatchability of load to exploit flexibility in load
- Increasing balancing area: Pooling reserves
- Shorter scheduling intervals
Conclusions

- Changes to System Operations is the least expensive solution to wind and solar PV grid integration issues
Thank You

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