Integrating New Technologies into the Power System

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Overview - MIT Thesis Research

- Long range system planning
  - Integrating non-dispatchable, renewable energy technologies in the New England power system
- Operating a distributed utility
  - Short term system operations with small-scale generators
Integrating DG into the Power System

Discussion Overview

- Long Term Integration - Planning Horizon
  - Terminology
  - Quantifying RET impacts
- Short Term System Operations
  - System stability
- Policy Questions
Long Term Integration: 
Quantifying RET Impacts

- Technology Characteristics
  - Net load duration curve
  - Energy capture - total GWh generated
  - Capacity credit - new dispatchable capacity rendered unnecessary by RET contribution
  - Capacity factor - equivalent available capacity
  - Cost of electricity

Quantifying RET Impacts

System Integration Parameters
  - Net load duration curve
  - Capacity displacement
  - Emissions reductions
  - Fossil fuel use reductions
  - Cost of electricity
The System:
New England Electricity Demand

New England Peak Demand
Analysis Overview

- Model wind resource in Maine and Massachusetts
- Model solar resource in Massachusetts
- Model contribution of wind and PV systems to the New England System
  - 1500 MW photovoltaics
  - 1500 MW wind

Energy Capture

Total energy (GWh) generated by technology
## Capacity Credit

Dispatchable capacity rendered unnecessary

![Graph showing capacity credit over time with different scenarios.]

### Capacity Factor

- Equivalent available capacity
- Expected value of output at time of system peak demand

<table>
<thead>
<tr>
<th>Technology</th>
<th>RET Installed Capacity</th>
<th>RET Capacity Factor</th>
<th>% of Total 2011 Capacity RET Installed Capacity</th>
<th>Equivalent RET Capacity *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Power</td>
<td>1500 MWp</td>
<td>25%</td>
<td>5%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Photovoltaics</td>
<td>1500 MWp</td>
<td>10%</td>
<td>5%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

* For example, 5% * 25% = 1.2%. Or, for wind power, 25% of 1500 MW is 375 MW, and 375 MW is 1.2% of total system capacity in 2011.
Cost of Electricity from PVs

Cost of Electricity from Wind

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- Cost of Energy
- COE with 1.5¢ tax credit
Quantifying System Impacts
Scenario-Based Multi-Attribute Tradeoff Analysis

Scenario Options

<table>
<thead>
<tr>
<th>Supply-Side Technology Mixes</th>
<th>Treatment of Existing Plant</th>
<th>Fuel Cost Uncertainties</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Gas/Oil</td>
<td>• Life Extension</td>
<td>• Base/Stable Fuel Costs</td>
</tr>
<tr>
<td>• Gas/Oil and Wind</td>
<td>• 20% Repowering</td>
<td>• Natural Gas Constraint</td>
</tr>
<tr>
<td>• Gas/Oil and PV</td>
<td>• Phase I NOx Controls</td>
<td></td>
</tr>
<tr>
<td>• Gas/Oil, Wind &amp; PV</td>
<td>• Phase II NOx Reductions</td>
<td></td>
</tr>
<tr>
<td>Demand Side Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 1992 Reference Level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Double Conservation Programs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Triple Commercial and Industrial Conservation Programs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Multiple Option Tradeoff Curve
(Average Load Growth)

Emissions Tradeoff Curve
Quantifying RET Impacts

System Integration Parameters

- Emissions reductions
- Capacity displacement
  - Which type of capacity does the inclusion of RETs displace (in terms of both short run operating and long run construction needs) peak, intermediate or baseload
  - Use the net load duration curve
- Fossil fuel use reductions
- Cost of electricity

Emission Reductions

- The benefits attributed to RETs, in terms of emissions reductions, decrease as system evolves to a cleaner, newer system overall
- Emissions decrease both from demand management/conservation and from new supply options
**Emissions Reductions: Base DSM**

Comparison of Impacts for Years 2007 and 2011

![Bar charts comparing emissions reductions for Base DSM with details on percent change for years 2007 and 2011.](chart1.png)

**Emissions Reductions: Double Conservation**

Comparison of Impacts for Years 2007 and 2011

![Bar charts comparing emissions reductions for Double Conservation with details on percent change for years 2007 and 2011.](chart2.png)
Emissions Reductions: Triple Conservation

Comparison of Impacts for Years 2007 and 2011

Capacity Displacement Net Load Duration Curve

Peak and intermediate capacity displaced, baseload unaffected
**Reduction in Fossil Fuel Use**

- The type of capacity displaced determines the extent of possible decrease in fossil fuel use.
- Fossil fuel reductions decrease as system evolves to a cleaner, newer system overall.
- Fossil fuel use decreases both from demand management/conservation programs and from the inclusion of new supply options.
- Use of oil6 decreases *more* with RETs+Conservation than with RETs alone.

**Fuel Use Reductions:**
**Reference Demand-Side Management**

Comparison of Impacts for Years 2007 and 2011
Fuel Use Reductions: Double Conservation

Comparison of Impacts for Years 2007 and 2011

Fuel Use Reductions: Triple Conservation

Comparison of Impacts for Years 2007 and 2011
The bottom line
How much does it all cost?

Cost of Electricity

Percent increase in system cost from RETs

<table>
<thead>
<tr>
<th>Technology Mix</th>
<th>Base Fuel Costs</th>
<th>Uncertain NGas Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>0.34%</td>
<td>0.15%</td>
</tr>
<tr>
<td>PV</td>
<td>2.93%</td>
<td>2.73%</td>
</tr>
<tr>
<td>Wind &amp; PV</td>
<td>3.28%</td>
<td>2.90%</td>
</tr>
</tbody>
</table>
Summary: Impacts of Integrating Wind and PVs into the New England Power System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wind Power</th>
<th>Photovoltaics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Capacity</td>
<td>1500 MWP</td>
<td>1500 MWP</td>
</tr>
<tr>
<td>Average Energy Capture (% of 1992 Demand)</td>
<td>3 %</td>
<td>1.5 %</td>
</tr>
<tr>
<td>Average Capacity Credit</td>
<td>350 MW</td>
<td>450 MW</td>
</tr>
<tr>
<td>Average Capacity Factor</td>
<td>24 %</td>
<td>15 %</td>
</tr>
<tr>
<td>* Cost of Energy, 1995 2004</td>
<td>9.8 ¢/kWh</td>
<td>68.4 ¢/kWh</td>
</tr>
<tr>
<td>** % System Cost Increase</td>
<td>0.08 %</td>
<td>0.86 %</td>
</tr>
<tr>
<td>*** % CO2 Decrease</td>
<td>4.2 %</td>
<td>2.3 %</td>
</tr>
<tr>
<td>% SO2 Decrease</td>
<td>3.6 %</td>
<td>1.2 %</td>
</tr>
<tr>
<td>% NOx Decrease</td>
<td>2.9 %</td>
<td>1.6 %</td>
</tr>
<tr>
<td>% GWh from RET</td>
<td>2.7 %</td>
<td>0.9 %</td>
</tr>
<tr>
<td>% GWh from Oil6 Decrease</td>
<td>1.1 %</td>
<td>0.3 %</td>
</tr>
<tr>
<td>% GWh from Coal Decrease</td>
<td>0.3 %</td>
<td>0.1 %</td>
</tr>
</tbody>
</table>

Summary of Long-term Planning

- Modeling RETs and quantifying their stand-alone performance
- Modeling RETs as part of the power system and quantifying impacts in terms of system performance
Distributed Generation and Short Term Operations

- Why does industry resist inclusion of small-scale generation (DG)?
- How would an owner get paid for the benefits provided by installing DG?
- Can DG be part of the competitive markets?

Short Term Operations Overview

- The distributed utility
- The first problem: local instability in the distribution system
- The second problem: schedule mismatches and decentralized response (control) in the transmission system
- Conclusions
Historical Distribution Structure

The Distributed Utility
The System Operations Problem

Daily Scheduled Power Flows

Anticipated Demand

Scheduled Generation
Daily Deviations from Schedule

One Day

Hourly Deviations from Schedule

One Hour
Significance of Deviations

Mismatch = \frac{P_{\text{gen}} - P_{\text{load}}}{P_{\text{gen}}}

- Mismatch is small on transmission system – traditional concern for power system operation.
- Mismatch is relatively larger within the distribution system, with distributed generation.

Distribution System Dynamics

Frequency Instability

![Frequency Instability Graph](image1)

Frequency Stability

![Frequency Stability Graph](image2)
The Two Control Problems

- Distribution system instability
  - *Problem*: Local, fast frequency and voltage deviations can cause instability

- Transmission system and market operation
  - *Problem*: Power mismatch, system frequency drift are historically centrally controlled
  - New, independently owned DG will want to operate independently

Price-Based Control Signal

- Generators’ goal is to operate where marginal cost = marginal revenue (MC = MR)
- Price-based control signal provides feedback between system and individual generators
  - System price represents MR
  - Generators set output so MC = MR
- Response to price signal can be automated
- Generators can operate independent of central control
Power System and Market Dynamics

System Disturbance and Initial Generator Response

DG output and marginal cost response to decentralized price-based control-signal

Summary: Short-term Operations

- RETs and NDTs are part of the distributed utility/distributed generation concept
- Inclusion of DG can impact stability
- A price-based control signal will promote the evolution to a distributed utility by facilitating the full integration of distributed generators into the power system and the competitive markets
Integrating DG into the Power System

- Technical issues for integrating RETs and DG
  - Long term planning
    - Pro: modular, low emissions, small footprint
    - Con: non-dispatchable requires different planning frameworks
  - Short term operations
    - Do not fit into the existing or emerging institutional structures (system operation, market rules)

Integrating DG into the Power System

- Financial issues
  - Which products will DG be paid for?
    - Energy
    - Ancillary services
    - New ‘reliability’ product
  - Will they be penalized for less familiar operating characteristics (location)?
  - How will independent DG be paid (no existing billing mechanism)
Integrating DG into the Power System

Closing Policy Questions

- What is the role of government in technology development?
  - Should there be federal policies to promote the development and use of renewable energy technologies?
  - How should federal R&D money be spent?
    - renewable vs. conventional supply options
    - distributed, small-scale vs. centralized generating plants