Overview

• Stand-alone vs. System performance
  – New Analysis Parameters (definitions & use)

• Integrating intermittent technologies into the power system
  – Capacity credit
  – Capacity displacement

• Distinguish between
  – Deterministic and stochastic phenomena
  – Variability and uncertainty

• Strategies for mitigating variability and uncertainty

What to Take Away from Today…

• Awareness of the differences between
  – Deterministic and stochastic
  – Variability and uncertainty
  – … and the importance of these differences

• Awareness of what the following are, what they are used for (esp. in power systems)
  – Linear optimization (‘programming’)
  – Stochastic optimization
  – Monte Carlo Simulation
  – Dynamic optimization

• Long term system planning:
  – Understand generator and load characteristics, and decide what to build to serve load

• Hourly to monthly decisions: Unit commitment
  – Decide which plants to have warmed up and ready to go
  – Different technologies have different requirements

• Minutes to Hour: Economic dispatch (+ OPF)
  – Decide which plants to use to meet the expected load now
  – 5 minutes to 1 hour

• Cycles to Minutes: Short term system operations and Load Flow Model; Dynamics Models
  – Maintain supply and demand balance moment to moment
  – ~17msec per cycle up to 5 minute control functions
Discussion

• You are working at an ISO and your supervisor is an old-school engineer who does not like the idea of wind/solar power
• Regulators are forcing the system to integrate more intermittent renewables
• There is a long queue of proposed wind (and/or solar) projects for your region

Your Task

• Your task is to make a convincing case for integrating wind, up to 10% of the regional capacity
• How do you go about making the case?
• What analyses do you suggest and why?
• What data is needed? (and why)
• How can you demonstrate the value of wind to the system as
  – An energy resource?
  – A capacity resource?
• What will the results of your analyses be?
• Build upon the analysis tools you have used so far
• Use the performance parameters we have discussed
• Think about the different needs for the different time scales

Modeling Intermittent Resources

• Chronological (time series) data is deterministic
• Wind and solar data are inherently probabilistic ... stochastic
• Understand the distinctions between:
  – deterministic & stochastic
  – variability & uncertainty

Strategies to Mitigate Variability

• Understand the benefits from geographic diversity on the smoothing of variability

Need more electric power technologies that can ramp and respond quickly...

  – Conventional generation ramping
    • Generators ramp quickly up and down in response to RETs ramping down/up
  – Demand response
  – Storage resources
Diurnal (Daily) Ramping

Increasing need for flexible ramping resources with increased wind

System Ramping Needs

Net Load Variability in Midwest ISO

Figure 1. 10-Minute Variability of Net Load, Load, NSI, and Wind Generation

NSI = net scheduled interchange
Determining Capacity Credit

• Is the system capable of meeting a higher peak demand if wind is added to the system?
• LOLP – prob. load will exceed generation
• LOLE – # of hours load will not be met (per year)
• Calculate ELCC (NREL report; Electricity Journal)
  1) Run large model to get desired LOLE (HOMER!)
  2) Add windfarm and find new LOLE
  3) Remove wind and replace with combustion turbine (CT), slowly incrementing capacity of CT until same LOLE is found as when windfarm was included
  4) This capacity (of CT) = ELCC of the windfarm

* Capacity Credit *

• Alternative terms
  – Capacity credit
  – Capacity value
  – Effective load carrying capability
  • This also uses the concept of ‘loss of load probability’ LOLP, and loss of load expectation, LOLE
Methods to Mitigate Uncertainty

- Modeling: Stochastic Optimization
  - Optimal decision making under uncertainty
  - Real world problems have parameters which are unknown at the time a decision should be made.
  - (Deterministic optimization problems have known parameters)
  - Assume that probability distributions governing the data are known or can be estimated.

Stochastic Optimization

- Stochastic optimization is used when decisions are made repeatedly, in essentially the same circumstances.
  - How does this relate to power system operations?
- The objective is to find a decision that will perform well on average.
- Analysis requires defining a finite set of scenarios and underlying probability distributions
  - Load level, wind speed, outages, forecast errors…

Time Series Data with Uncertainty

Day Ahead Forecast Uncertainty

\[ X_i = \alpha + \beta X_{(i-1)} + \varepsilon_i \]
10-Minute Forecast Uncertainty

\[ X_t = \alpha + \beta X_{t-1} + \epsilon_t \]

Distribution of Load Forecast Errors

Generator Forced Outage Rates

- Estimated from a distribution of time to failure (days)
- Reliability of generators is estimated by fuel type, based on information from the Generator Availability Database (GADS)

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>EFOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>410</td>
</tr>
<tr>
<td>Hydro</td>
<td>355</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>336</td>
</tr>
<tr>
<td>Nuclear</td>
<td>103</td>
</tr>
<tr>
<td>Fossil - Oil</td>
<td>287</td>
</tr>
<tr>
<td>Peaker</td>
<td>277</td>
</tr>
</tbody>
</table>
Modeling Uncertainty

- Stochastic optimization (= stochastic programming)
- Monte Carlo analysis

Both aim to capture the underlying probabilistic, or stochastic, nature of the data

Optimization with Uncertainty

- When the parameters are uncertain, but assumed to lie in some given set of possible values, we could solve by substituting each possible parameter value and optimize the given objective function repeatedly

\[
\begin{align*}
\min \ C_T &= \sum C_i(P_{oi}) \\
\text{s.t.} \quad &\Sigma(P_{oi}) = P_L \\
& P_{Gi \ min} \leq P_{oi} \leq P_{Gi \ max}
\end{align*}
\]

- The stochastic formulation would use expected values in place of assumed known values
  - Minimize the expected cost, subject to expected load and expected generation capability

Monte Carlo Simulations

- Example of Monte Carlo simulations showing probability distributions for different cases.
Dynamic Programming:
Multi-stage optimization

Concluding Thoughts

- The power system is inherently stochastic, not deterministic
  - It has historically been viewed as deterministic
  - The introduction of wind and solar energy is forcing a change in operating and planning methods
- Stochastic optimization, Monte Carlo simulation, and dynamic optimization are mature modeling and analysis methods for decision making with uncertainty
  - (stochastic programming, dynamic programming)

Knowledge Building Thought

- “Product” if desired at the end of the semester could be a research proposal
  - Introduction
  - Background of topic and previous research
  - Your new question
    - Why it is of interest and to whom
    - How you would go about answering/solving it
    - What form would your results take
  - Conclusions

System Integration Parameters
Probabilities & Stochastic Behavior

i. Net load duration curve
ii. Capacity credit (capacity value, ELCC)
  - (Effective load carrying capability)
iii. Capacity displacement
iv. Emissions reductions
v. Cost of electricity
  - Net effect on system price (system lambda)
Net Load Duration Curve

![Net Load Duration Curve](image)

Capacity Credit

- Dispatchable capacity rendered unnecessary
- Time series data versus probabilistic representation – different uses & benefits?

LDC Questions

- What if wind displaces 5% of baseload and 5% of intermediate generation, but does not generate at all during system peak load hours? (see next graph)
- Using the LDC
  - Which generators are ‘displaced?’
  - How would you find
    - The change in fossil fuel usage?
    - The change to total system energy demand?
    - The change to system capacity needs?

Capacity Displacement

![Capacity Displacement](image)
Discussion

Emission Reduction
• How can these be analyzed and quantified?
• Deterministic or probabilistic/stochastic?

Cost of Electricity
• How can this be analyzed and quantified?
• Deterministic or probabilistic/stochastic?

Summary

• Parameters for analyzing system integration of renewables
  – Capacity credit (capacity value, ELCC)
  – Capacity displacement
• Deterministic v. stochastic
• Variability v. uncertainty
• Strategies of system operation to mitigate:
  – Variability
  – Uncertainty