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Stochastic Unit Commitment

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Sandia National Laboratories

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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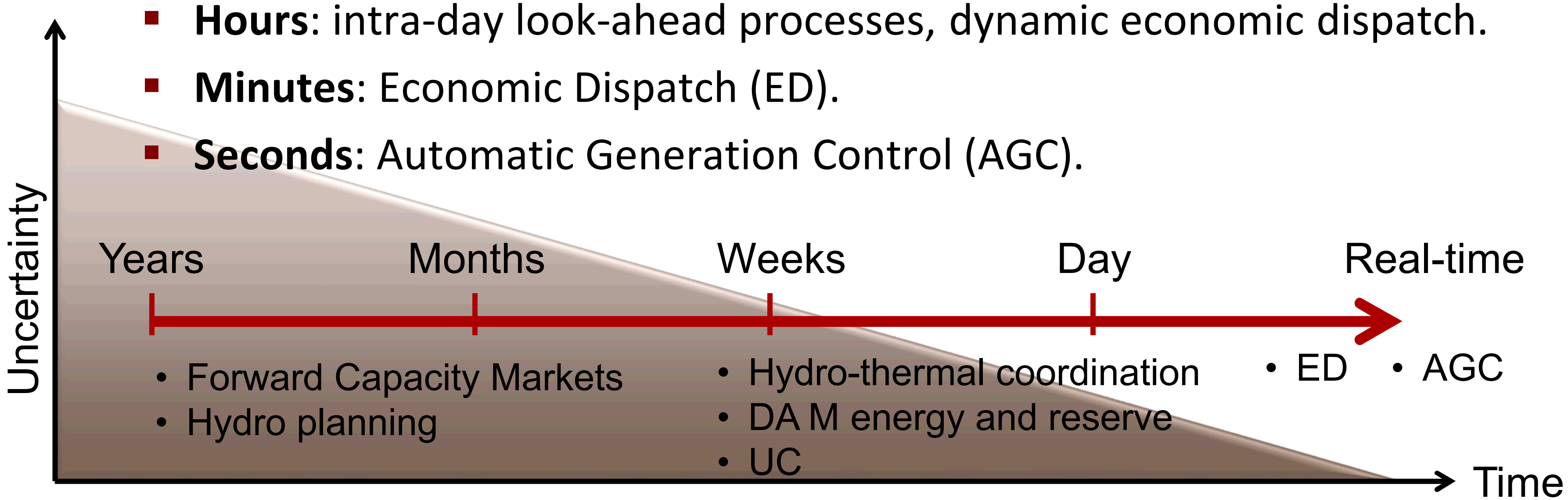
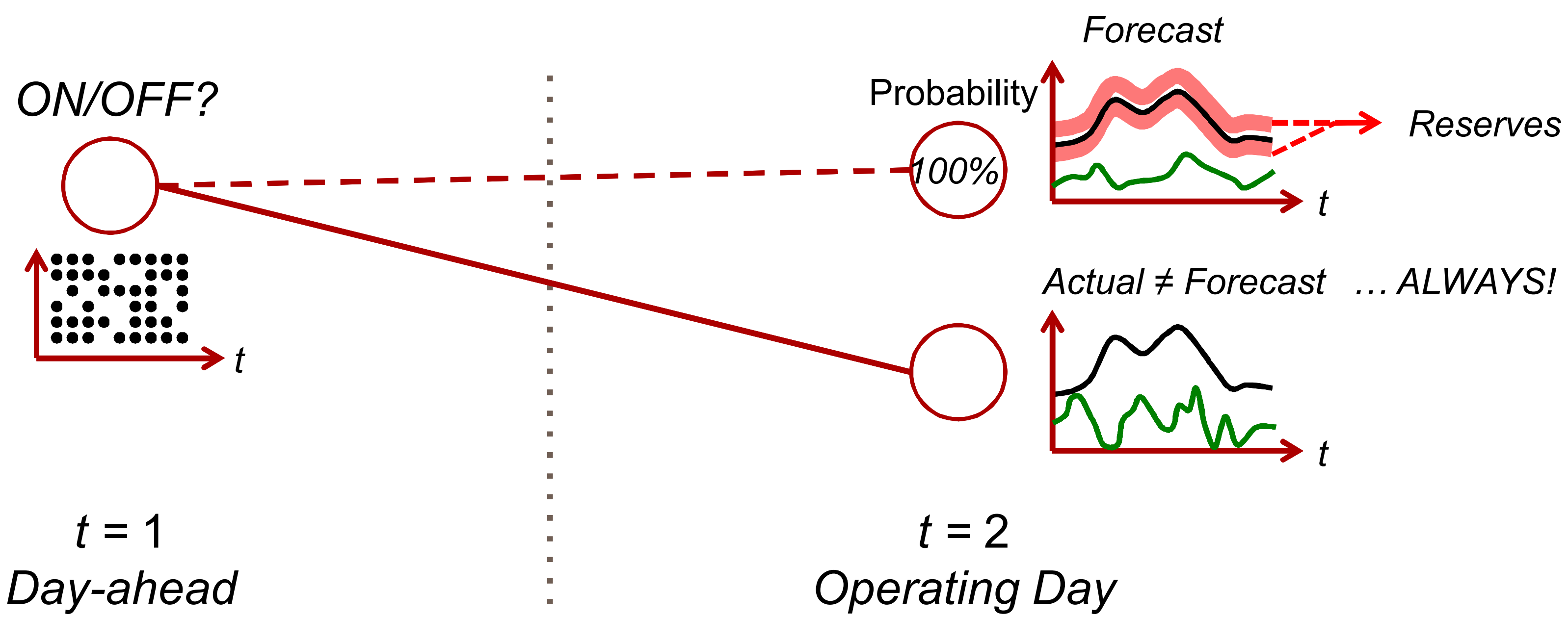
Power System Planning/Operations

- Decision making in power systems looks at processes ranging from very large time constants to near real-time:
  - **Years, Seasons, Months, Weeks**: Resource adequacy, transmission and hydro resource planning.
  - **Days**: Hydro-thermal coordination, day-ahead UC of energy and reserves, intra-day UC.
  - **Hours**: intra-day look-ahead processes, dynamic economic dispatch.
  - **Minutes**: Economic Dispatch (ED).
  - **Seconds**: Automatic Generation Control (AGC).



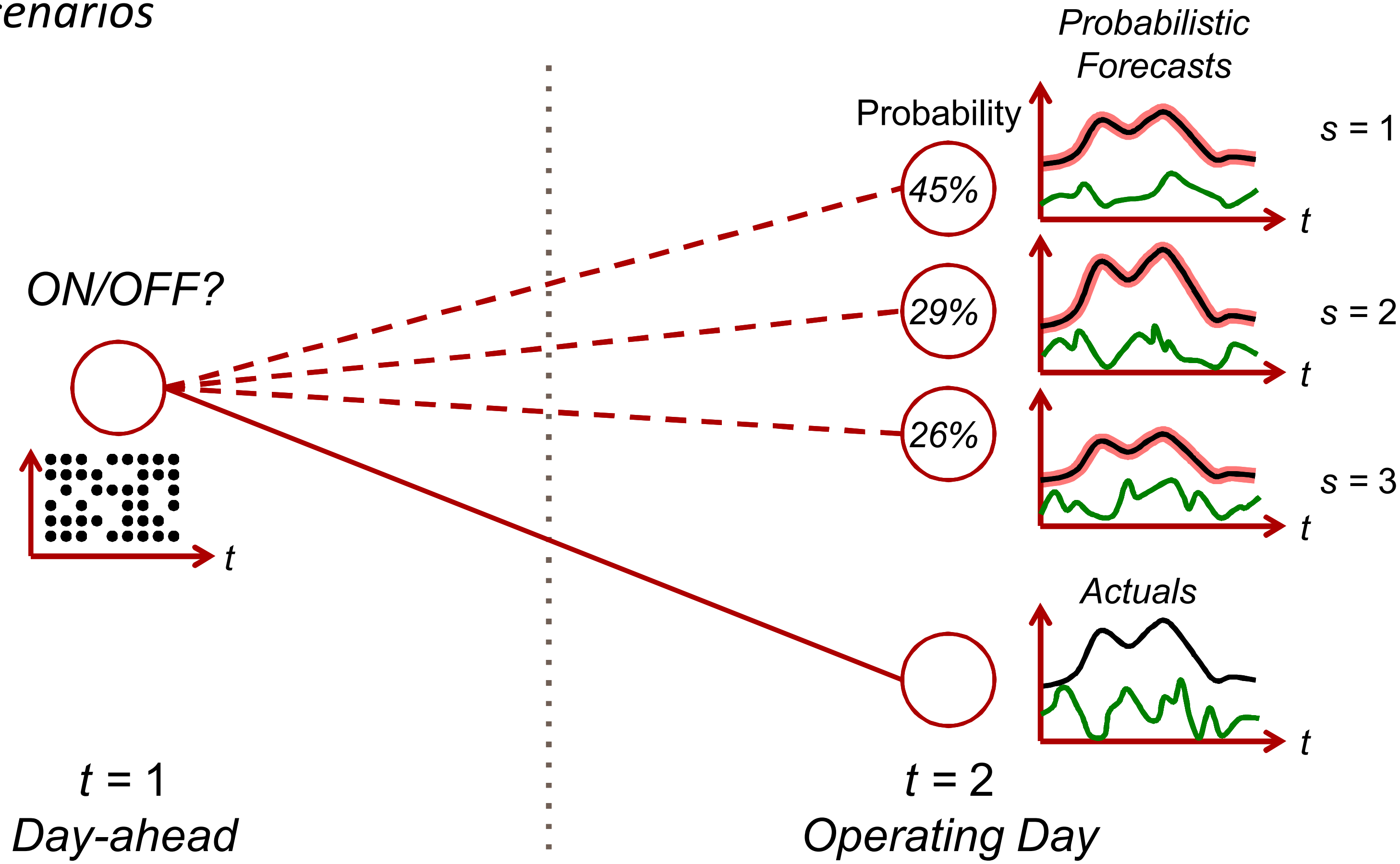
Unit Commitment (UC)

- Schedule generation resources (ON/OFF) such that generation costs are minimized while meeting the (net) load
  - Generation costs: Start-up/Shut-down costs, no load costs, fuel costs.
  - Net load = Load – Non-dispatchable generation (wind, solar)
- Subject to operating and physical constraints (generator min. up/down times, transmission limits, reserve requirements)



Stochastic Unit Commitment

- Schedule generation resources (ON/OFF) such that ***expected*** generation costs are minimized *under several load and renewable generation scenarios*



So Why Isn’t Stochastic Optimization Deployed in Power Systems Contexts?

- Modeling is significantly more complex
  - Stochastic process models, multi-stage decisions
  - Need data and significant expertise in both optimization *and* statistics

- Another reason is that stochastic optimization problems are in general exceptionally difficult to solve
  - Solve times *were* far from those required for operations problems (ARPA-e SNL-led project with UC Davis, ISU, Alstom, ISO-NE)

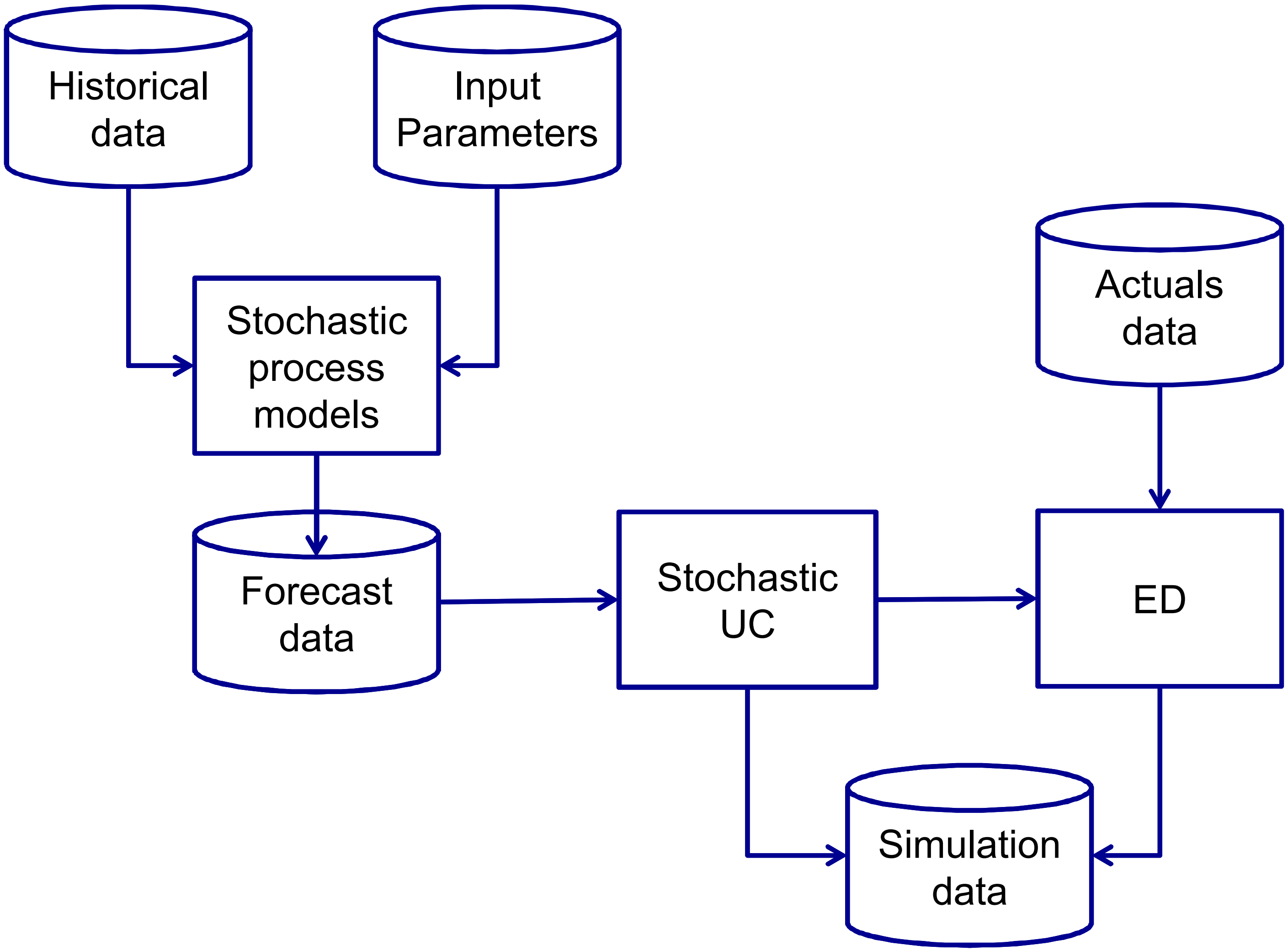
Motivation

- Create a stochastic operations toolkit to promote stochastic UC for systems with high penetration of renewable energy
  - User friendly
    - Overcome adoption barriers such as need for probabilistic forecast and stochastic programming expertise
    - Data (and parametric) driven stochastic models
    - Report important results
- Enable easy-to-implement demonstrations of stochastic operations
- Release of toolkit through SNL website and share report of test case findings with stakeholders

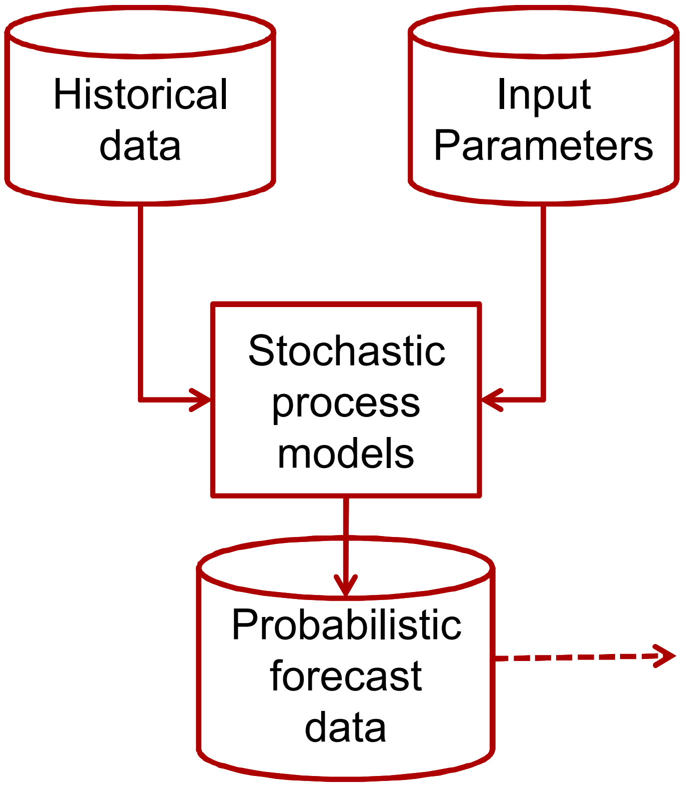
Power System Operations

- Deregulated Regions
  - Day-Ahead Market
  - Reliability Unit Commitment
  - Intra-Day Commitment/Look-Ahead Dispatch
  - Economic Dispatch
- Vertically Integrated Utility
  - Day-Ahead Unit Commitment
  - Intra-Day Commitment/Look-Ahead Dispatch
  - Economic Dispatch

Software Architecture



Stochastic Process Models



- Parametric
  - Plant size, lat/long, altitude, tilt, etc.
  - Calculates clear sky index (using pv_lib* functions)
  - Assumes persistance forecast to calculate forecast error pdf
- Non-parametric
  - Solar power DA forecasts and actuals
  - If forecasts are not available, clear sky index persistance forecasts can be calculated
  - Forecast error pdf are calculated

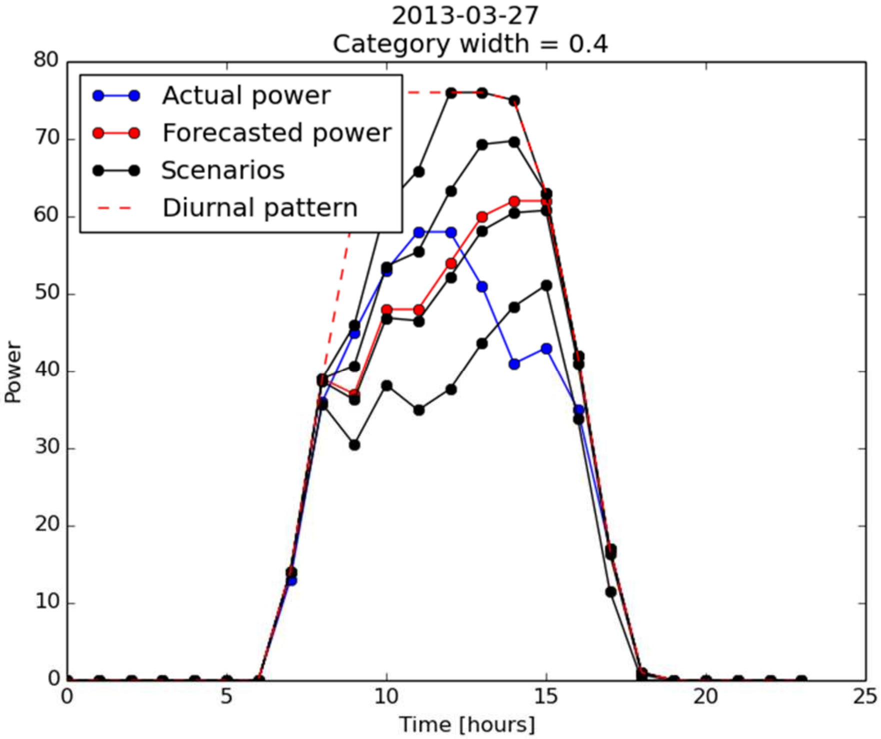
*available at http://pvpmc.org

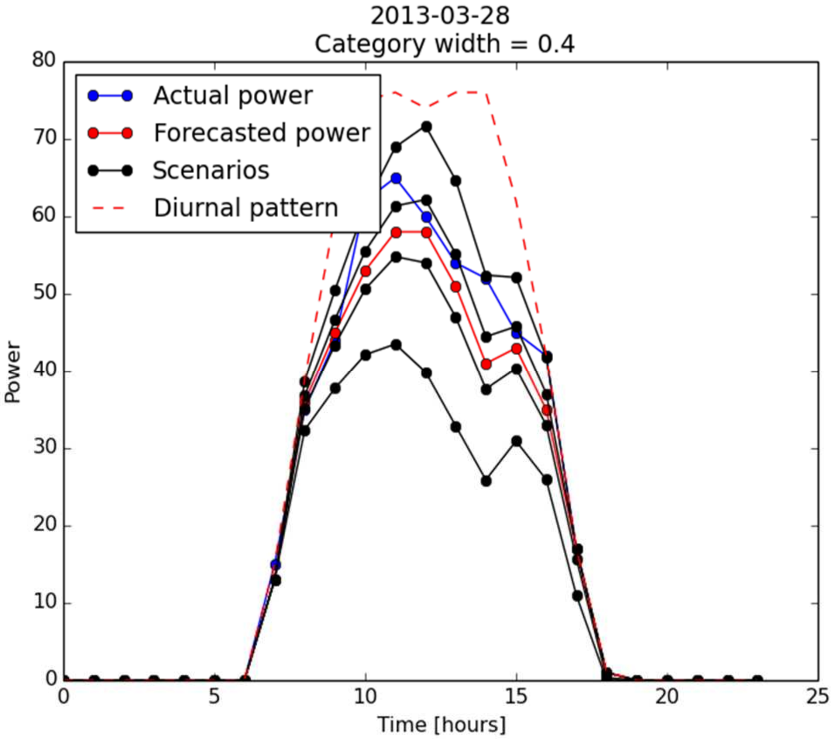
Input Data Format

- CSV file
- Date/Time: Date and time of observed solar power production [MM/DD/YY HH:00]
- Solar Actuals: Observed solar power production [MW] for a period of time at hourly resolution (or better)
- Solar Forecasts: Day-ahead forecasted solar power production [MW] for the same period of time and at the same resolution
- If no solar power production is available, (daily) persistence is assumed.
- Each row follows the following format:
  - MM/DD/YY HH:00,Forecast_value,Actual_value
- Idem for load

Solar forecasts

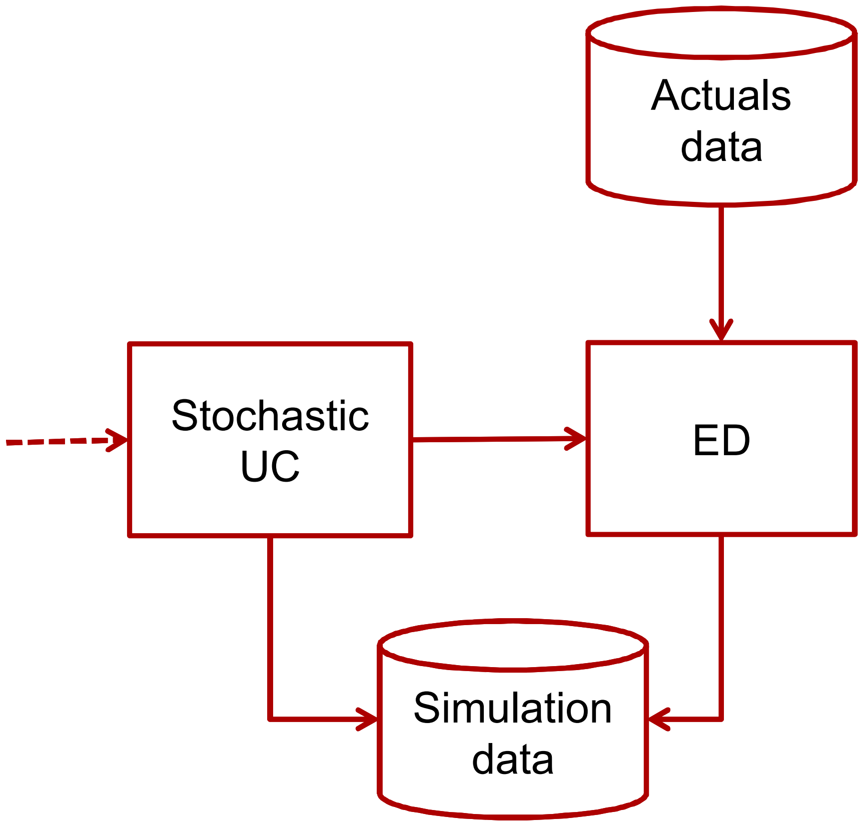
- Exemplar solar production probabilistic forecasts (using persistence)





Stochastic UC

- 2 Stage Stochastic UC
- Minimize commitment (i.e., start-up and no-load) costs and expected dispatch costs to provide sufficient capacity to satisfy *forecasted* net load plus reserve requirements
- Hourly resolution (data-limited)
- Stochastic inputs:
  - Solar power plant output, demand
- Produces:
  - Generator commitments
  - Distribution of dispatch set points
- Solar plant output modeled as:
  - Must take – curtailed only for reliability
  - Dispatchable – curtailed for economics or reliability



Economic Dispatch

- Deterministic
- Minimize cost of serving the net load *actuals* (load and solar power plant output)
- Hourly resolution (data limited)
- Produces:
  - Generator set points
- Uses commitment solution from stochastic UC
- NOTE:
  - Given higher-resolution load and forecast data, we can compute a stochastic economic dispatch in a straightforward manner

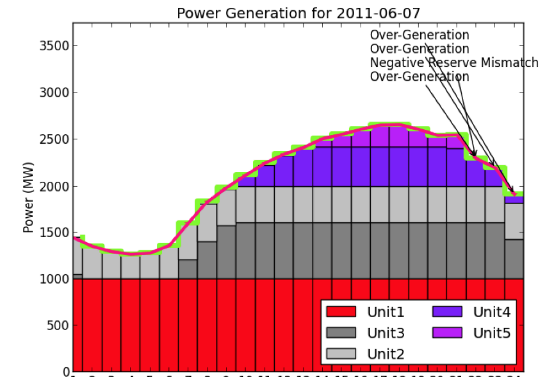
Running Modes

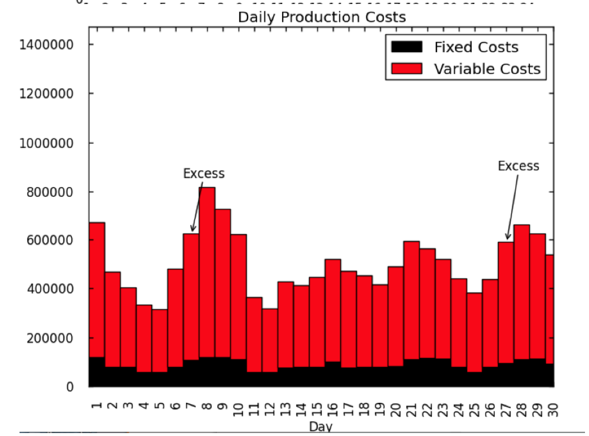
- Multi-day simulation (batch)
  - Simulate operation for long periods of time
  - High data need: operator has access to multiple days of historical data for generator cost/offers, load and forecast of load and solar
  - Better reflects advantages of using stochastic operations

- Single-day operation
  - Run single day operation
  - Lower data need: operator has access to next day's load forecast
  - On any given day, stochastic UC results might produce better/lower operational costs than deterministic… or not

Operations Simulator

- Integral component of the stochastic operations toolkit is the *operations simulator*
- Capabilities include:
  - Full integration of scenario generators
    - Load, forced outages, wind, and solar
  - Deterministic and stochastic commitment and dispatch functionality
  - Out-of-sample simulation for evaluation of potential cost savings
- Intended usage:
  - Compare and contrast commitment and dispatch solutions arising from deterministic and stochastic operations models
  - Computation of cost savings under varying penetration levels





Installation and Release Date

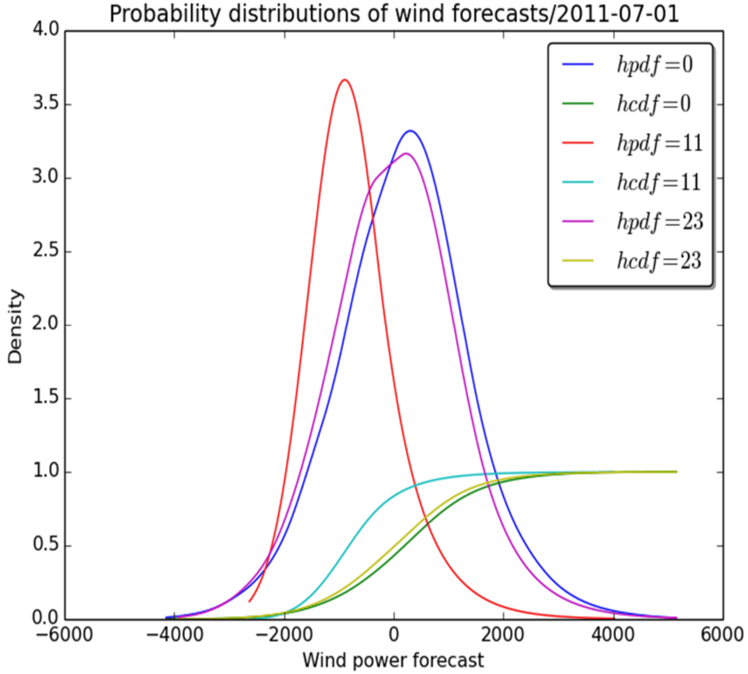
- Install pythonxy or anaconda (python versions)
- Install Pyomo
- Install PRESCIENT (python egg)
- prescient.sandia.gov
- It includes a small illustrative test case
- Continued development

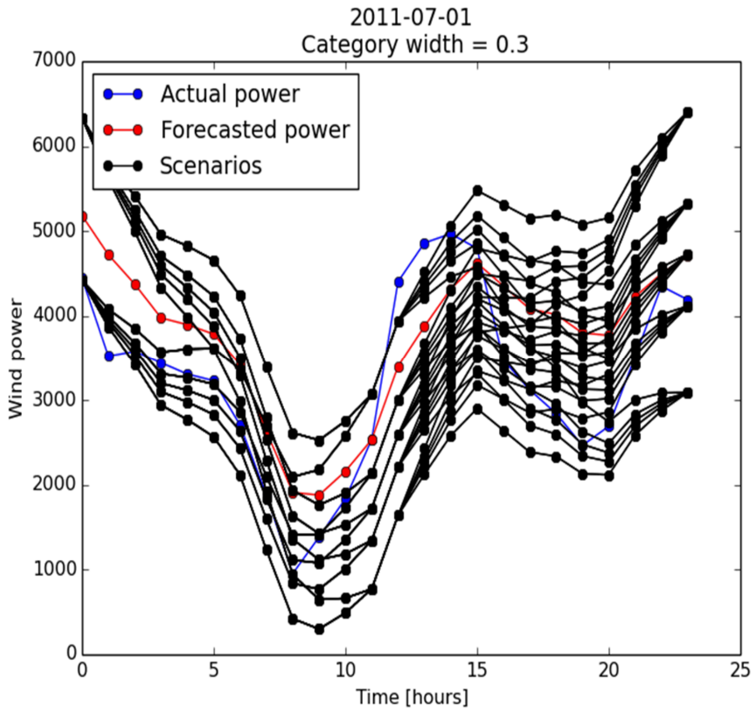
Experimental Methodology

Sandia National Laboratories

- 2011 Day-of actual and day-ahead forecasted load
  - Used to generate expected load scenario
- NREL Eastern Wind data set
  - Assume load and wind uncorrelated – first order approximation
  - 2004 forecasts and actuals
  - Consider all on-shore wind sites in ISO-NE
    - Large daily penetration rates – often near 50%
  - Generate 50 scenarios per day, plus expected wind scenario
- Deterministic UC
  - Maintain 10% reserves to account for load and wind error
- Stochastic UC
  - Maintain 2% reserves to account for load error
  - Accounting for load error through wind scenarios

Illustrative Wind Scenarios



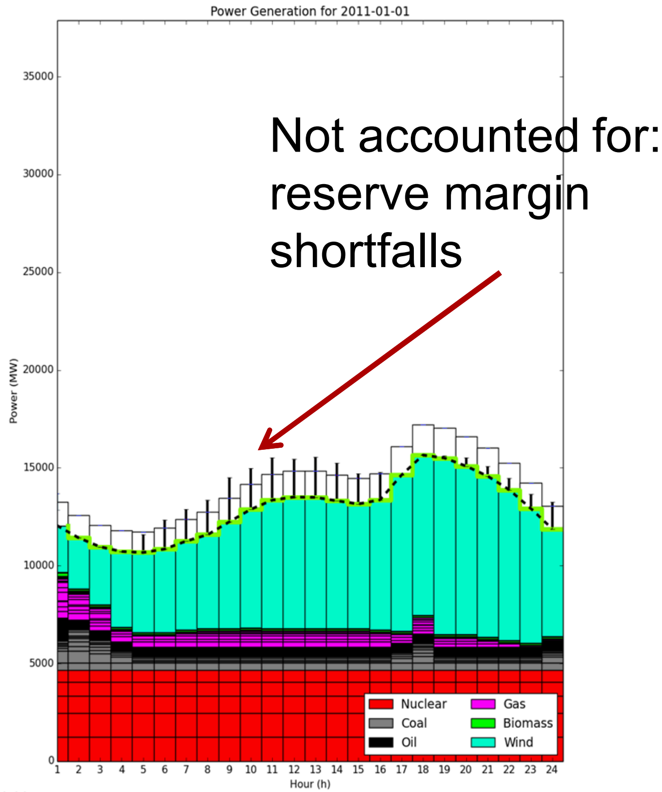


Error distributions at hours 1, 12, and 24

Scenarios constructed via "quantilization" of the error distributions

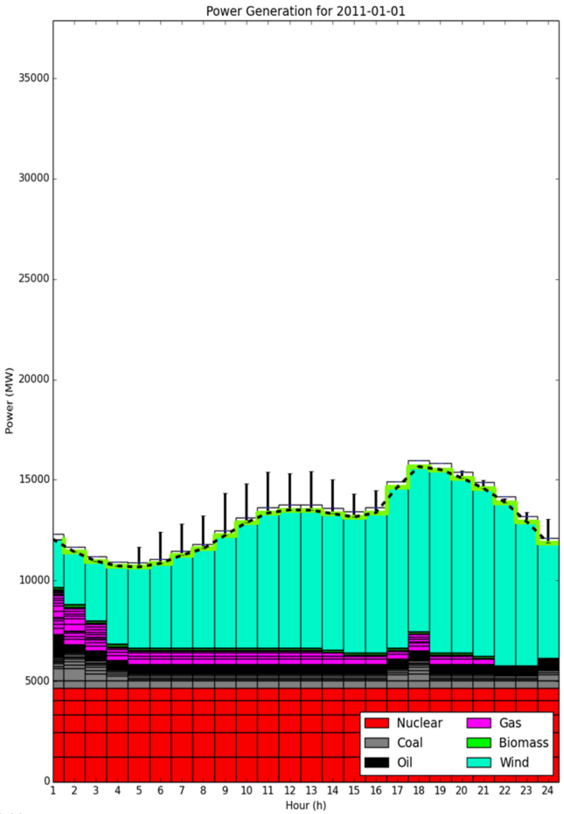
January 1, 2011

Deterministic UC



Variable costs: 3449.11
Fixed costs: 6397.73
Renewables penetration rate: 46.14%

Stochastic UC

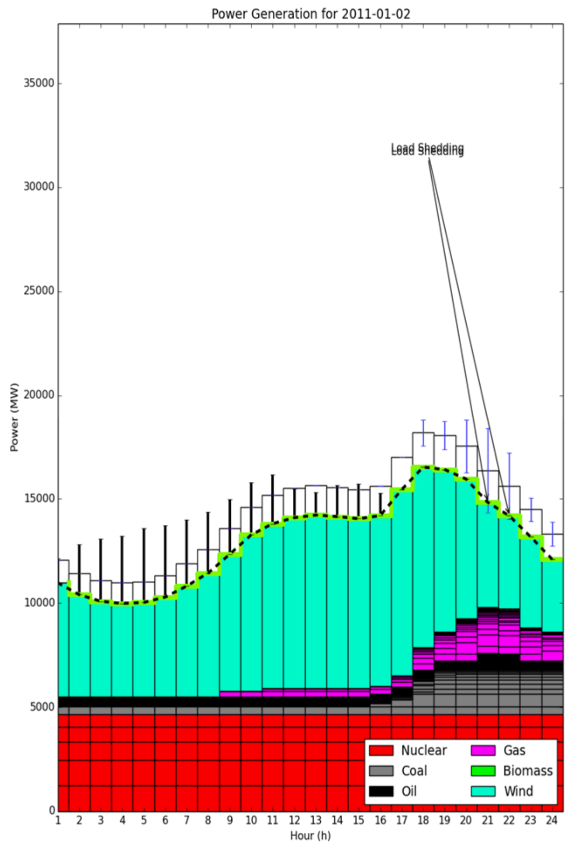


Variable costs: 3343.84
Fixed costs: 6117.36
Renewables penetration rate: 47.06%

Approximately 4% cost savings for stochastic UC…
… savings comes from ~3000MW less of wind curtailment

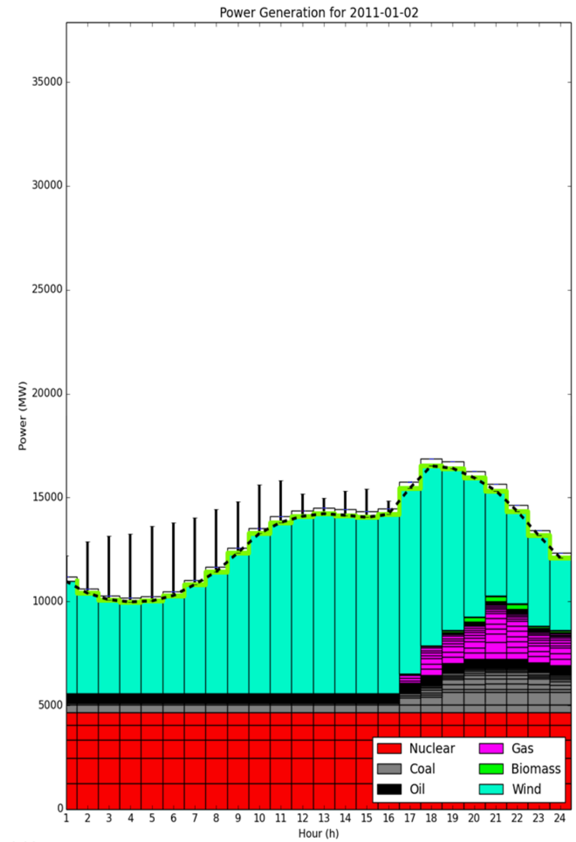
January 2, 2011

Deterministic UC



Variable costs: 3854.76
Fixed costs: 5773.33
Renewables penetration rate: 48.54%

Stochastic UC

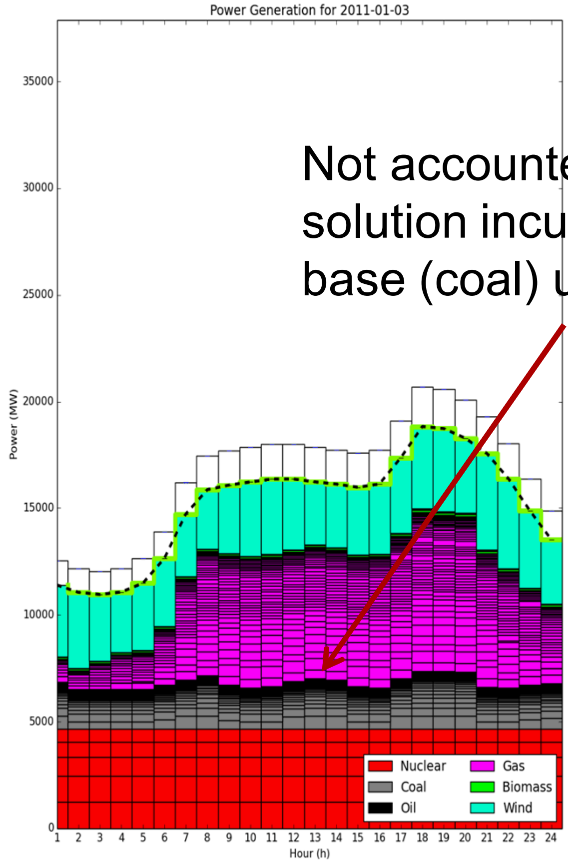


Variable costs: 3426.87
Fixed costs: 6186.06
Renewables penetration rate: 49.18%

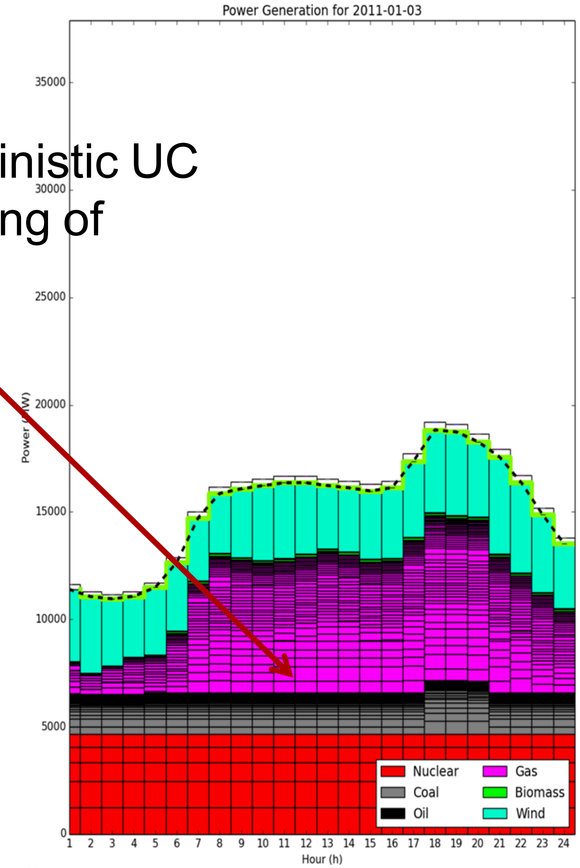
Approximately same costs – but deterministic UC sheds significant load and exhibits significant reserve shortfalls

January 3, 2011

Deterministic UC **Stochastic UC**



Variable costs: 6741.23
Fixed costs: 11342.76
Renewables penetration rate: 22.16%



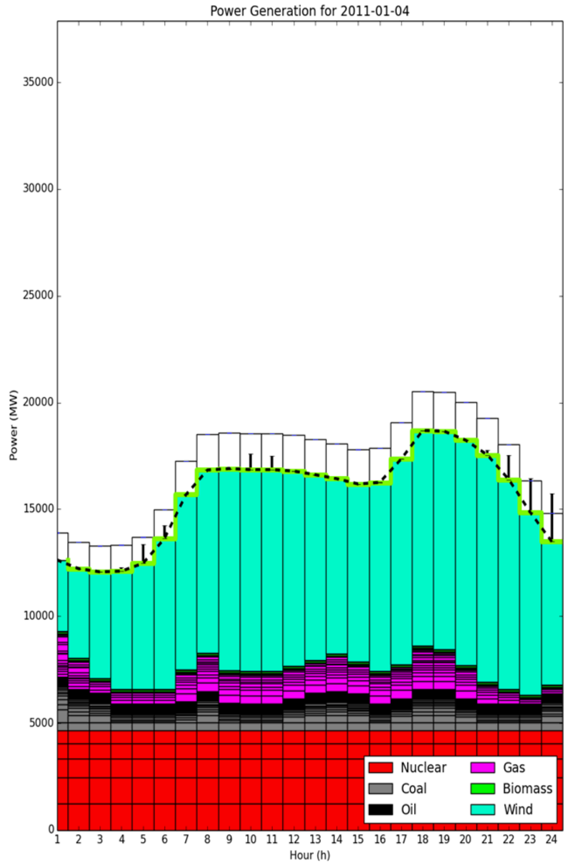
Variable costs: 6808.22
Fixed costs: 12342.75
Renewables penetration rate: 22.16%

Not accounted for: Deterministic UC solution incurs more ramping of base (coal) units

In this case, deterministic UC wins – stochastic UC solution is 5% more expensive

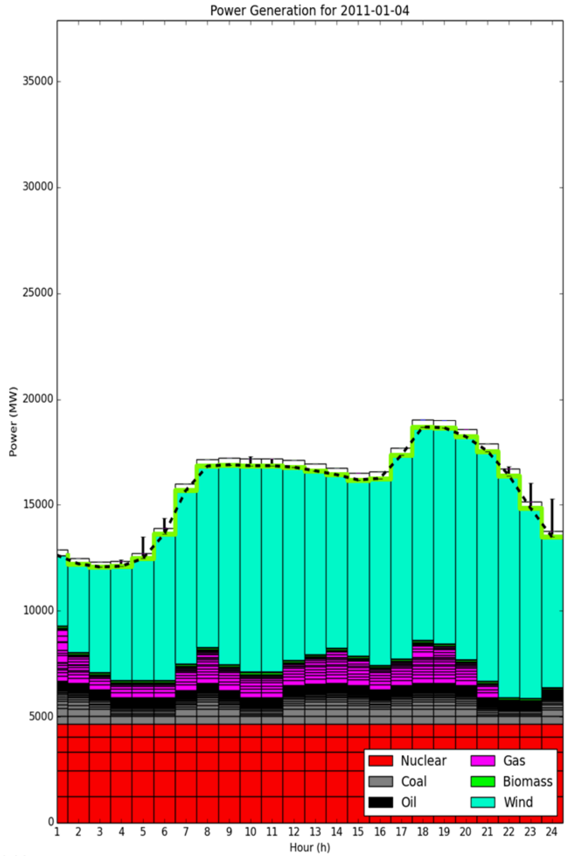
January 4, 2011

Deterministic UC



Variable costs: 3702.32
Fixed costs: 7193.03
Renewables penetration rate: 51.88%

Stochastic UC

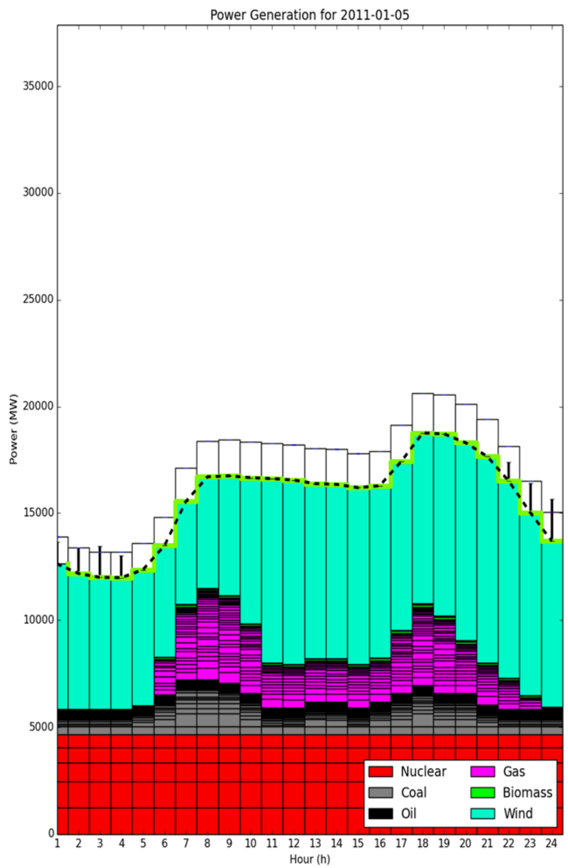


Variable costs: 3600.48
Fixed costs: 6612.01
Renewables penetration rate: 52.42%

Stochastic UC saves 7% relative to deterministic…

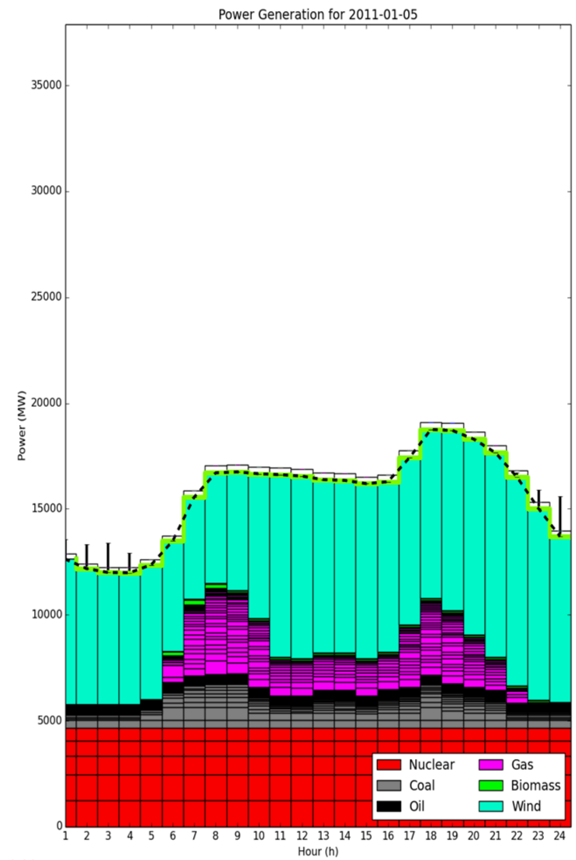
January 5, 2011

Deterministic UC



Variable costs: 4223.16
Fixed costs: 7693.56
Renewables penetration rate: 47.41%

Stochastic UC

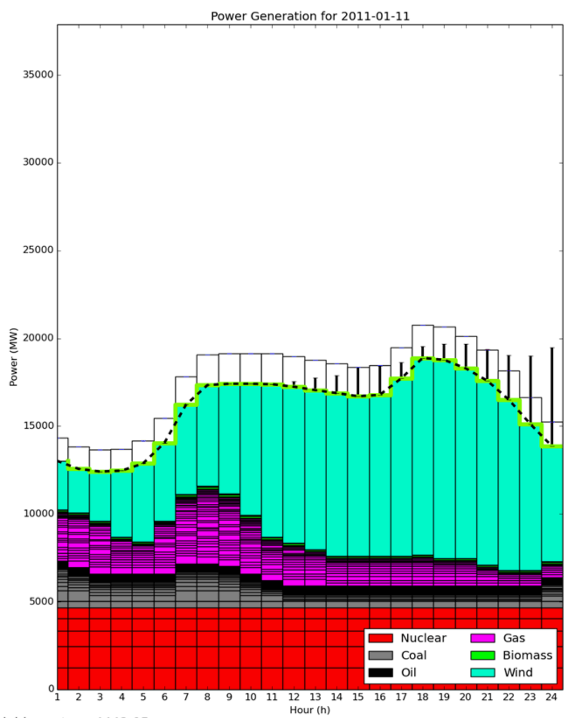


Variable costs: 4209.87
Fixed costs: 6887.33
Renewables penetration rate: 47.83%

Stochastic UC is 7.5% less costly than deterministic UC

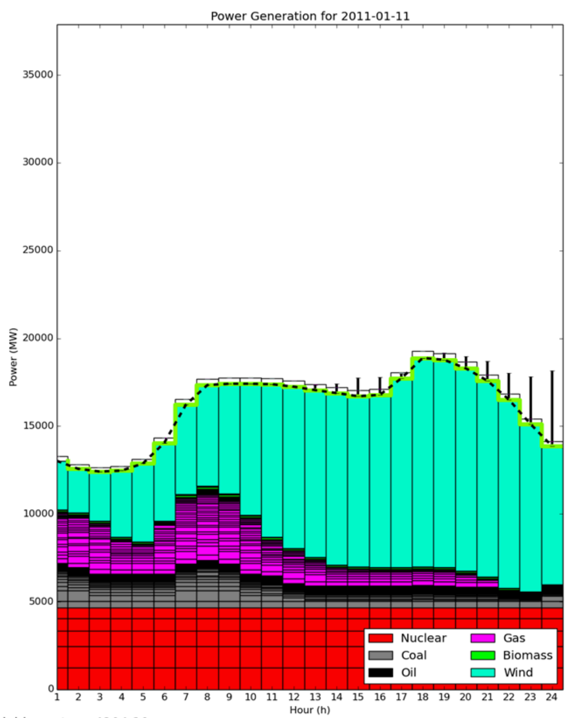
January 11, 2011

Deterministic UC



Variable costs: 4443.85
Fixed costs: 7959.90
Renewables penetration rate: 46.30%

Stochastic UC



Variable costs: 4204.20
Fixed costs: 6621.41
Renewables penetration rate: 48.71%

Stochastic UC is 12% less costly than deterministic UC

Cost Comparison Summary

- Stochastic UC often wins – and can win big
  - Cost savings comes from significant decreases in the amount of curtailed wind
- Deterministic UC can also win
  - But not nearly as often
  - Often more about being lucky than good
- Full-scale ISO-NE analyses were performed
  - Approx. 350 generators
  - Approx. 10 min. to solve a single day stochastic UC
  - 2011
  - 2-4% savings
  - Pessimistic result given the gas price conditions in 2011

QUESTIONS