Advanced Unit Commitment With High Penetrations of Variable Generation

Research at the National Renewable Energy Laboratory

FERC Conference on Unit Commitment Software

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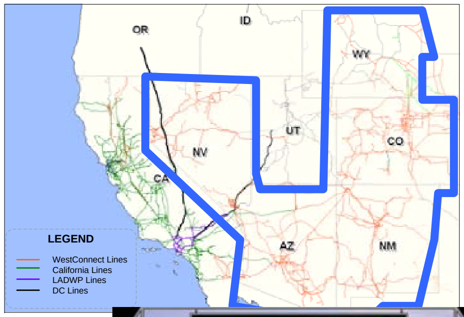
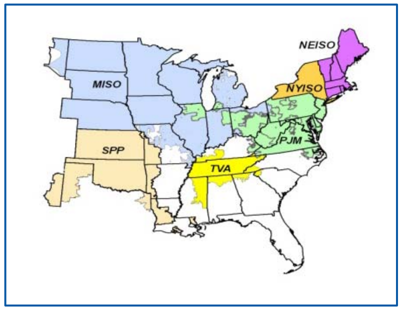
NREL's Transmission & Grid Integration Group

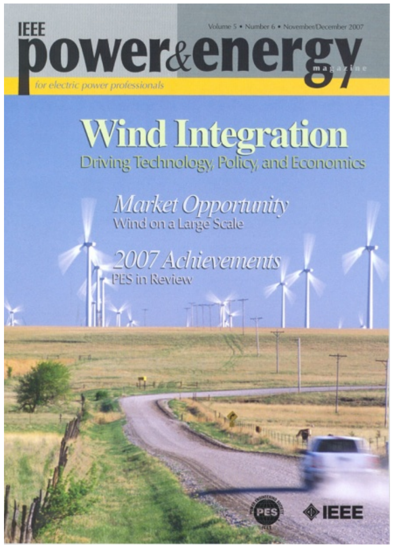
WWSIS

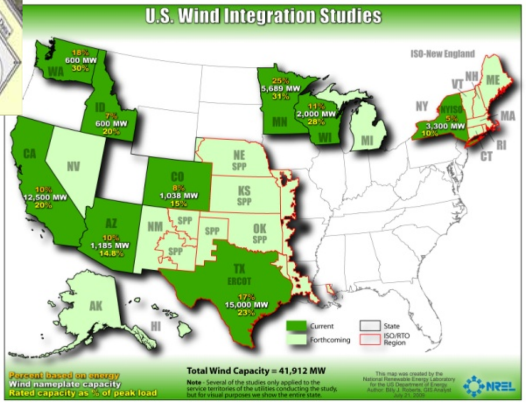


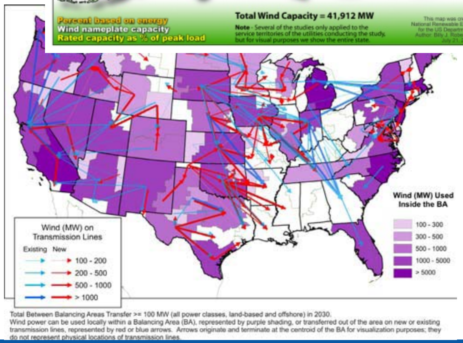
EWITS



- •Work on Integration of renewable "utility-scale" generation on the high-voltage bulk transmission system
- •Research areas
  - Assessing transmission utilization and build-out
  - Managing variability of wind and solar
  - Wind plant data monitoring
  - Wind forecasting topics
  - Market and system operations, scheduling of generation with renewables (SCUC/SCED)
  - Integration studies
  - Generator modeling
  - Outreach and education







Variability and Uncertainty

Variability: Wind and solar generator outputs vary as the intensity of their energy sources (wind and sun)

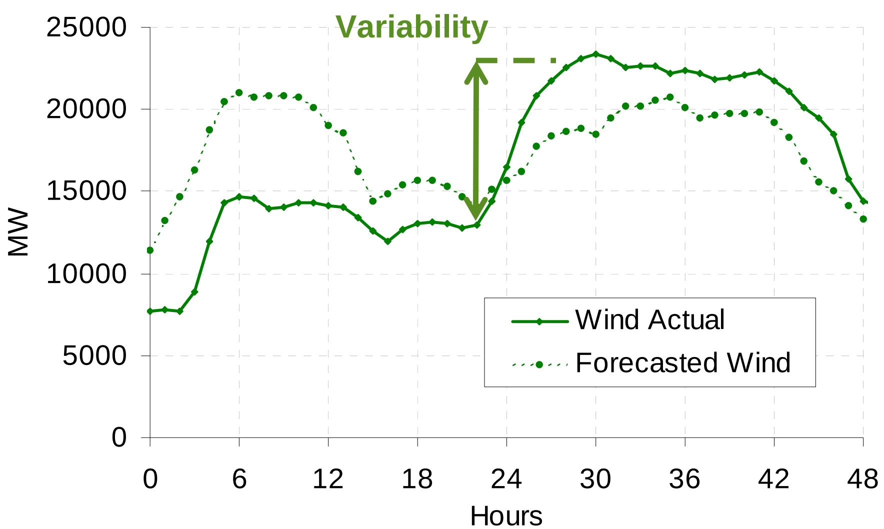
– Several timescales: minute (regulation), hour (ramping), diurnal, seasonal

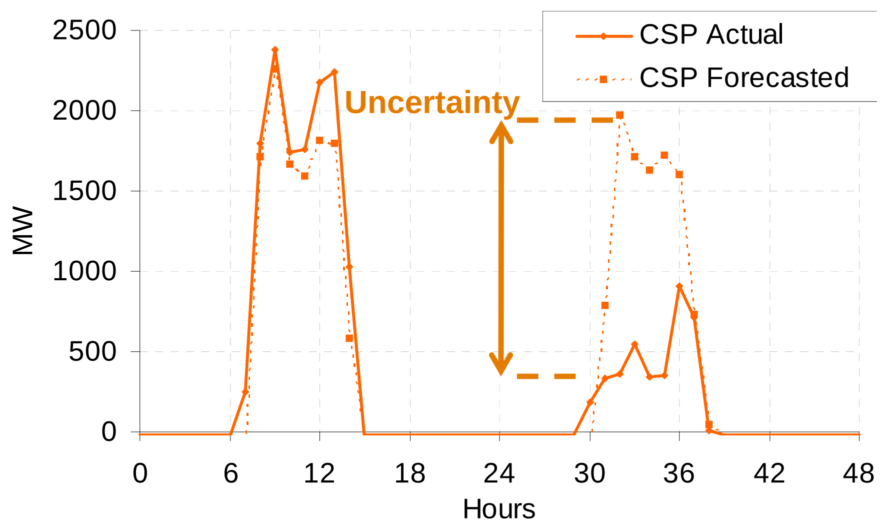
Uncertainty: Wind and solar generation cannot be predicted with perfect accuracy

– Several timescales: dispatch, unit commitment, resource adequacy

– Actual power output is different that forecast output

A perfect forecast eliminates **uncertainty**, but there is still **variability**

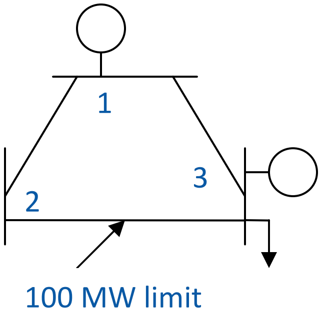




How can the Unit Commitment be changed?

- Ways to enhance unit commitment to incorporate the variability and uncertainty of variable generation (VG)
  - Allow the VG to be part of the UC or ED solution
  - Use of VG power forecasts in the UC
  - Stochastic UC to capture the uncertain behavior and reduce costs
  - Perform multiple UC throughout the day rather than once the morning before
  - Calculate the operating reserve requirements used in the UC based on predicted outcomes not on static rules
- The challenges
  - Computation times of certain models
  - Interaction of UC and the Energy Market
  - Can confidence be placed in VG power forecasts?
  - Many other engineering and economic problems

Wind power not part of solution to the SCUC/SCED

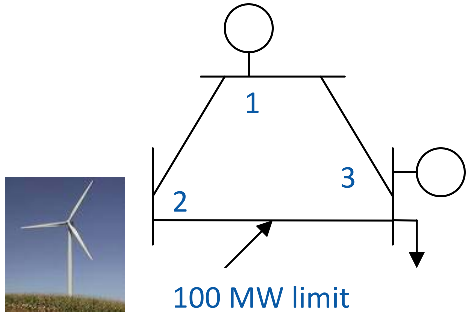


G1: 250 MW
10 $/MWh
Wind: Forecast 100 MW
G3: 100 MW
50 $/MWh

L3: 250 MW
X12 = X13 = X23

Output, Cost, and LMP											
Wind plant fixed											
	Wind Gen MW	**Gen 1 MW**		**Gen 1 Cost**		**Gen 3 MW**		**Gen 3 Cost**		**Total Cost**	**LMP at Bus**
Base Case (250 MW)	100	100	*	$10/ MWh	+	50	*	$50/ MWh	=	$3500	
Add 1 MW to Bus 1	100	101	*	$10/ MWh	+	50	*	$50/ MWh	=	$3510	$10
Add 1 MW to Bus 3	100	100	*	$10/ MWh	+	51	*	$50/ MWh	=	$3550	$50
Add 1 MW to Bus 2	100	102	*	$10/ MWh	+	49	*	$50/ MWh	=	$3470	$-30

Wind power is part of solution to the UC/ED



G1: 250 MW
10 $/MWh
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L3: 250 MW
X12 = X13 = X23

Other Benefits
- Market-based solution that improves market efficiency while maintaining reliability
- Allows curtailment to proceed through scheduling software rather than manual intervention
- Less financial harm to wind and other generators.

Load pays $30 less.

$1500 or over 40% savings in total production costs.

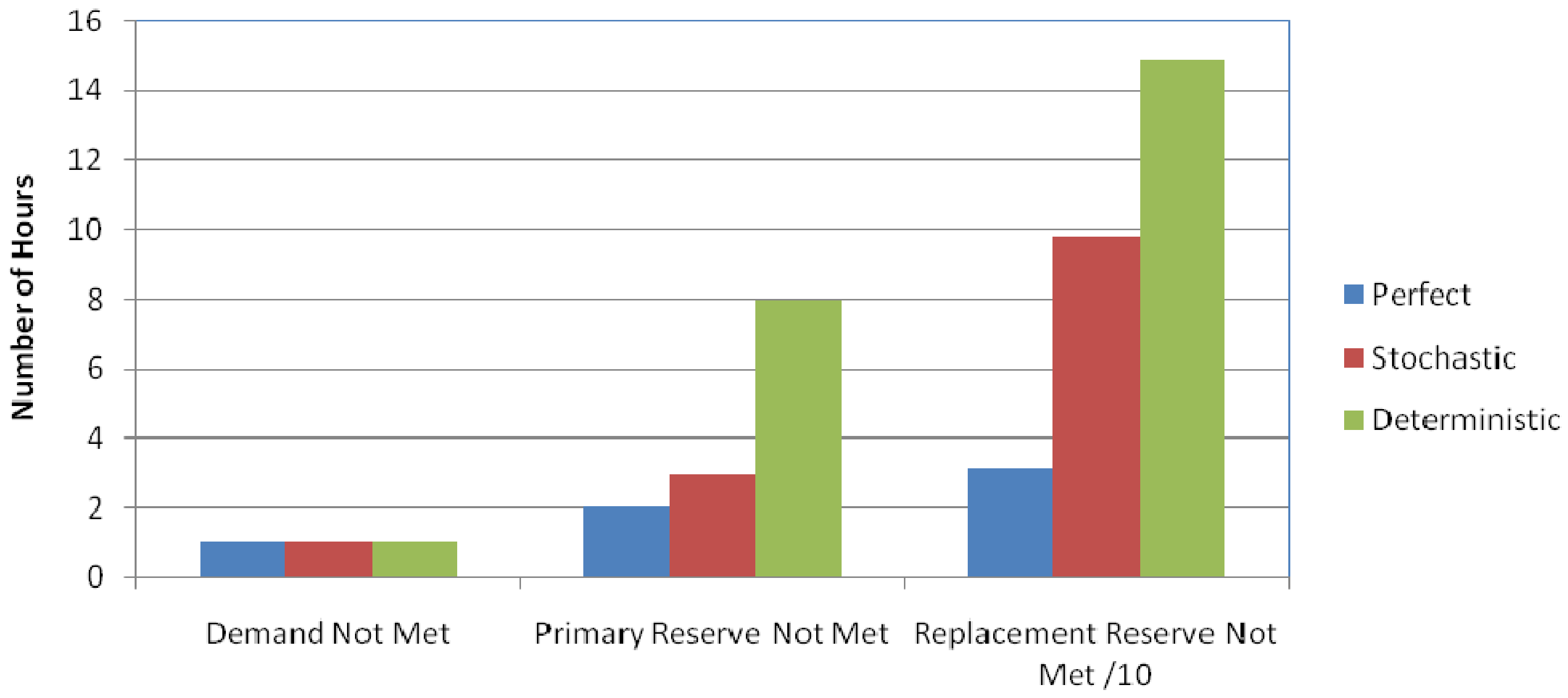
Output, Cost, and LMP Wind plant fixed											
	Wind Gen MW	**Gen 1 MW**		**Gen 1 Cost**		**Gen 3 MW**		**Gen 3 Cost**		**Total Cost**	**LMP at Bus**
Base Case (250 MW)	100	100	*	$10/ MWh	+	50	*	$50/ MWh	=	$3500	
Add 1 MW to Bus 1	100	101	*	$10/ MWh	+	50	*	$50/ MWh	=	$3510	$10
Add 1 MW to Bus 3	100	100	*	$10/ MWh	+	51	*	$50/ MWh	=	$3550	$50
Add 1 MW to Bus 2	100	102	*	$10/ MWh	+	49	*	$50/ MWh	=	$3470	$-30

Output, Cost, and LMP Wind plant dispatched											
	Wind Gen MW	**Gen 1 MW**		**Gen 1 Cost**		**Gen 3 MW**		**Gen 3 Cost**		**Total Cost**	**LMP at Bus**
Base Case (250 MW)	50	200	*	$10/ MWh	+	0	*	$50/ MWh	=	$2000	
Add 1 MW to Bus 1	50	201	*	$10/ MWh	+	0	*	$50/ MWh	=	$2010	$10
Add 1 MW to Bus 3	49	202	*	$10/ MWh	+	0	*	$50/ MWh	=	$2020	$20
Add 1 MW to Bus 2	51	200	*	$10/ MWh	+	0	*	$50/ MWh	=	$2000	$0

Wind generator no longer is financially harmed to produce.

Assessment of Advanced Unit Commitment Techniques on Practical U.S. System

All Island Grid Study (Ireland)
Stochastic UC Performance



Note – Replacement Reserve divided by 10 to be displayed on plot
Not actual reliability (LOLE, etc) but measure over 1 particular year

Advanced Unit Commitment in the EI

International Project Team

- NREL – Project Management, data and modeling for the US
- Risoe DTU – developer of the Scheduling Model
  - Peter Meibom: original developer
- Univ Stuttgart IER – developer of the Scenario Tree Tool
  - Rudiger Barth: original developer
- ECAR – Assistance on analysis and model runs

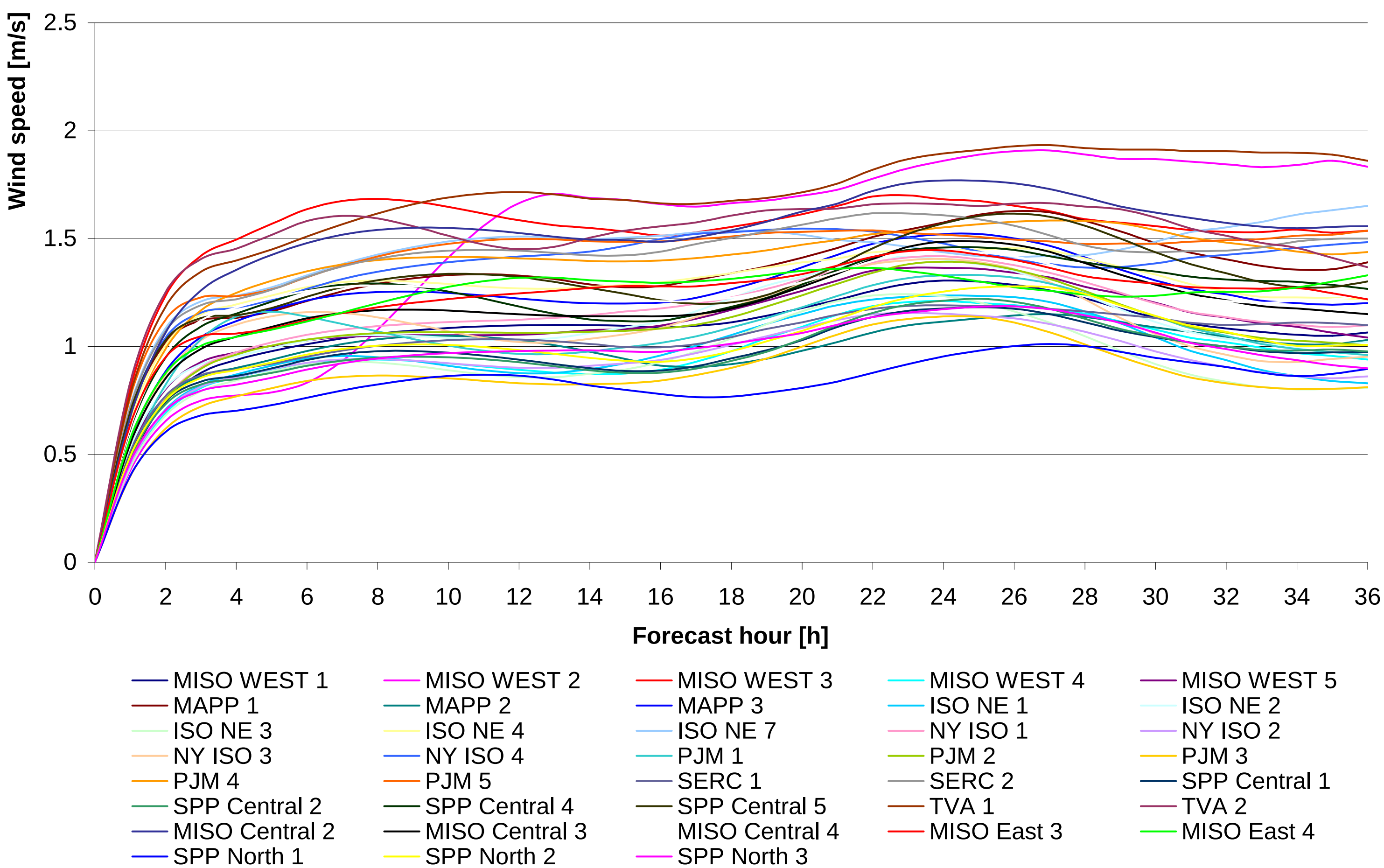
Objectives

- Understand the impacts of forecast error on the Eastern Interconnect
- Understand the impacts and benefits of stochastic planning on the Eastern Interconnect
- Understand the impacts and benefits of rolling UC updates on the Eastern Interconnect

Scope

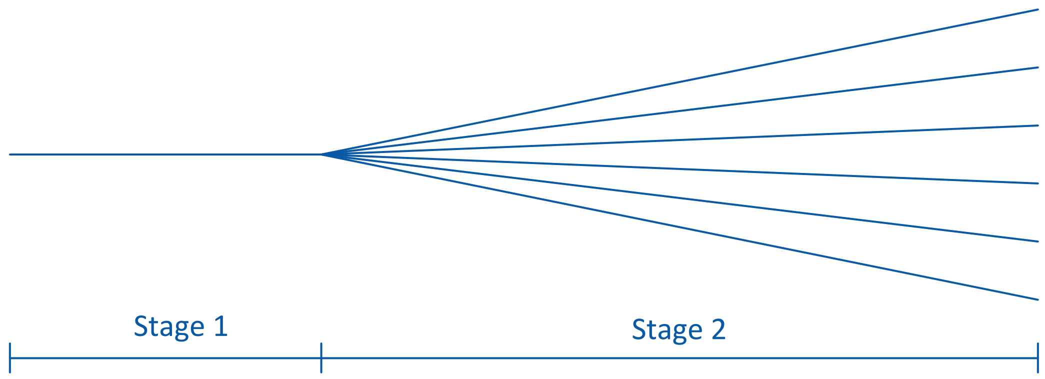
- Uses the WILMAR tool
- Uses EWITS data based on EWITS scenario 2 (hybrid scenario)
- Possible sensitivities when seen as valuable

Representation of Forecast Errors



Generation of forecast scenario trees

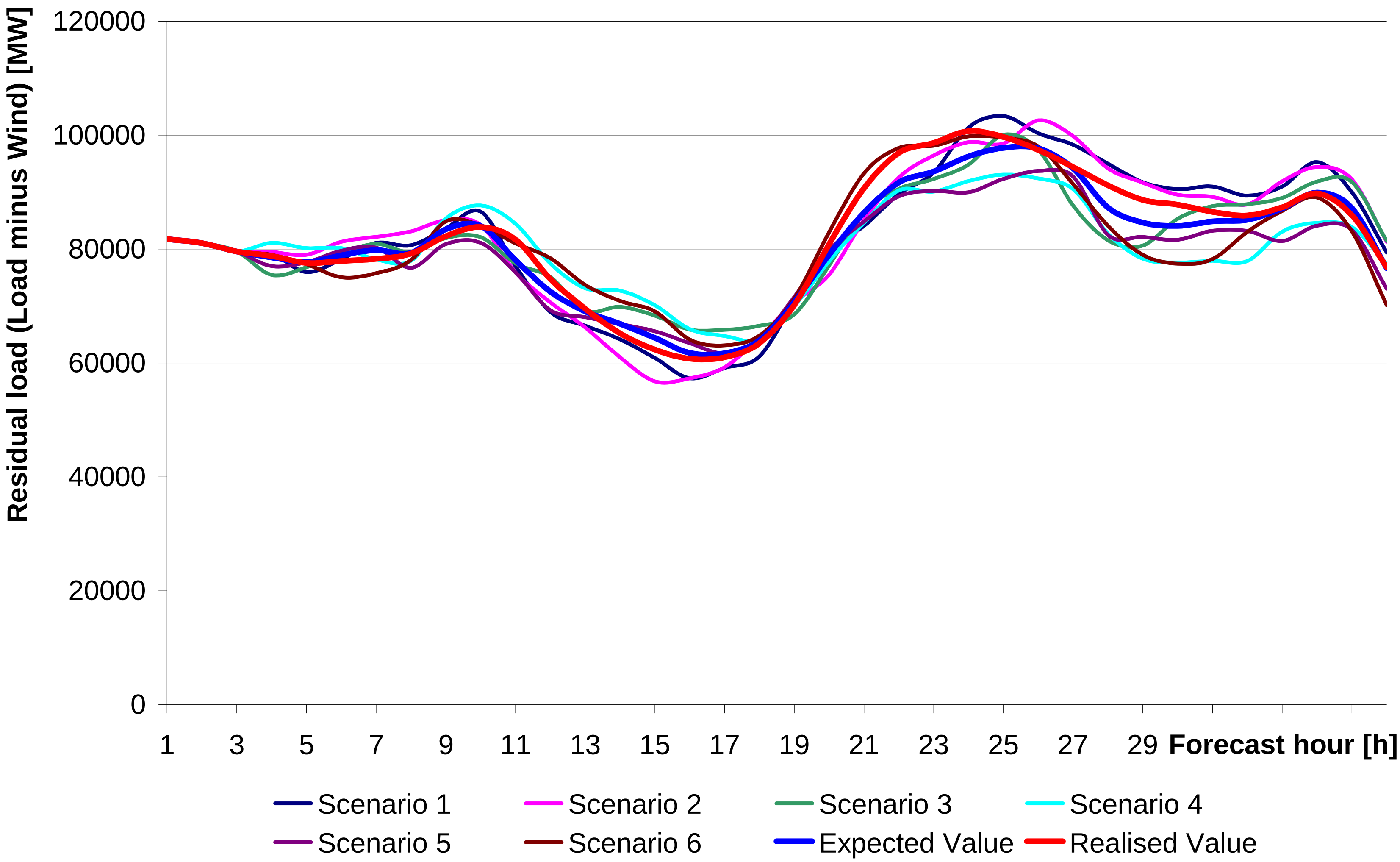
Large number of scenarios generated cannot be treated by Scheduling Model: Reduction of forecast scenarios to a specified number of scenarios and generation of scenario trees with predefined structure



Resulting forecast scenario trees contain:

- Load and wind power forecast scenarios
- Forecasts of demand for replacement reserves
- Probabilities of reaching each node

Example day-ahead scenario tree for PJM



Output from Scheduling model

- In general: levels of each variable and marginals (shadow prices) of each equation.
- Unit commitment of each unit
- Day-ahead production planned for each unit
- Real-time dispatch schedule of each unit
- All schedules in between (every 3 hours for rolling UC)
- Realized distribution of each reserve power category on units
- Hourly power exchange between regions
- Hourly emissions of CO_2 from each unit
- Operational costs: fuel, start-up, variable operation and maintenance

What are we looking for?

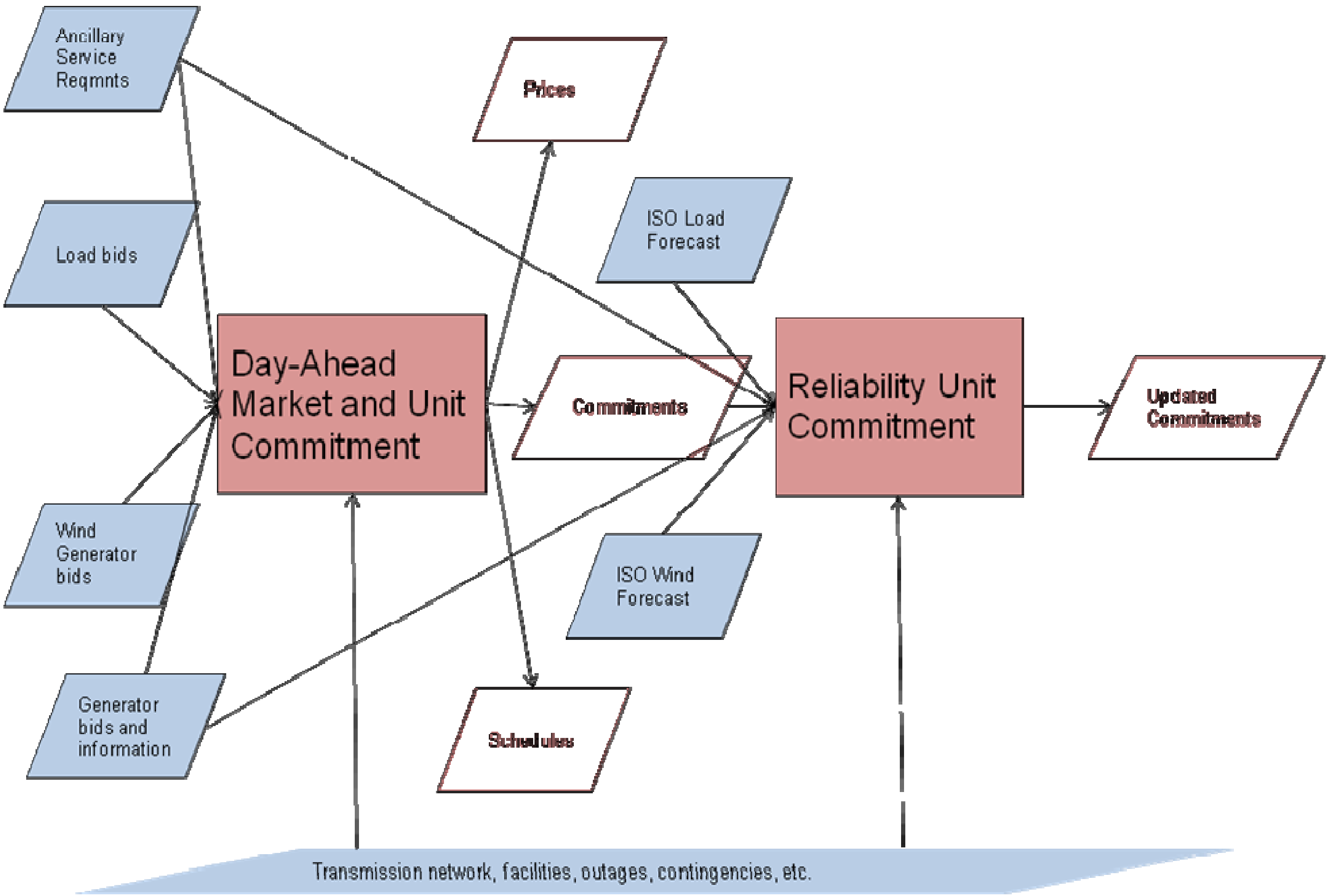
Model runs:

- Stochastic planning using scenario trees with six branches (six forecasts), unit commitment updated every 3 hours (**Stoc**).
- Stochastic planning, unit commitment for units with start times greater than 1 hour, updated once per day in the day-ahead market (**UCDay**)
- Deterministic planning with forecast error, unit commitment updated every three hours (**OTS**). Only one wind power production and load forecast taken into account in each rolling planning period being equal to the expected wind power production and load in the scenario tree used in the stochastic model runs.
- Deterministic planning with perfect foresight (**PFC**) i.e. wind power and load forecasts corresponds to realized wind power and load.

Comparisons of these model runs gives insight into the differences of forecast error, stochastic planning, and rolling UC updates

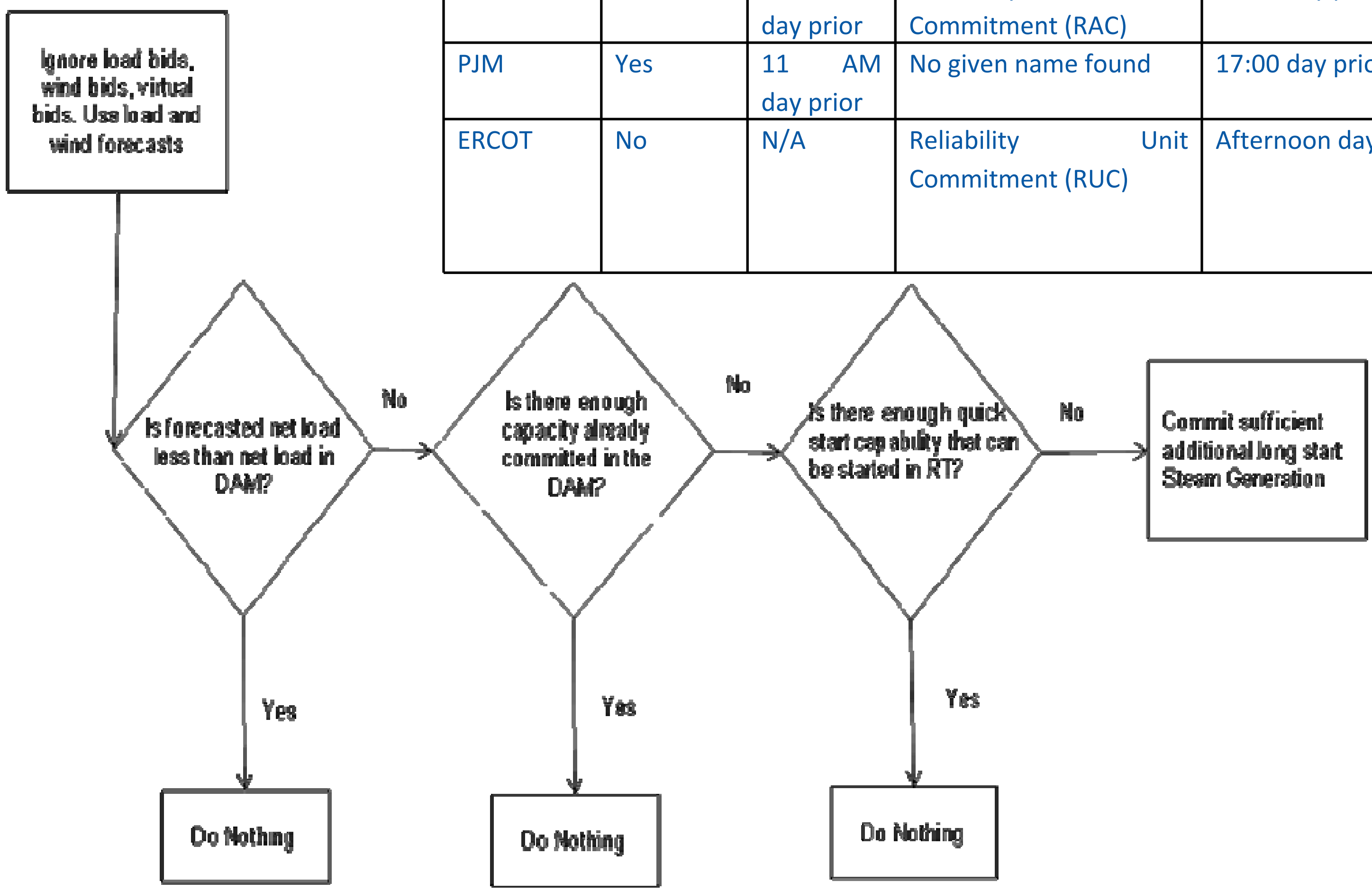
Interaction of Advanced Unit Commitment Strategies with Energy Markets

Full Day-Ahead Procedure



General RSCUC Procedure

ISO Region	DAM	DAM close	RSCUC name	Timing of RSCUC	Wind Forecast
NYISO	Yes	5 AM day prior	Bulk Power System Forecast Load Pass	Simultaneously with DAM	In RSCUC
ISO-NE	Yes	12 Noon day prior	Resource Adequacy Analysis (RAA)	18:00 day prior	None
MISO	Yes	12 Noon day prior	Reliability Assessment Commitment (RAC)	18:00 day prior	In RSCUC
PJM	Yes	11 AM day prior	No given name found	17:00 day prior	In RSCUC
ERCOT	No	N/A	Reliability Unit Commitment (RUC)	Afternoon day prior	80% exceedance in RSCUC



Example of inefficiency using RSCUC

<u>System</u>
Steam: 10x200MW
CT: 5x50MW
Wind:500MW NP
Ignoring Reserve

<u>Scenario 1</u>	<u>Scenario 2</u>
Load Forecast: 2100MW Wind Forecast: 200MW Load Bid: 2000MW Wind Bid: 200MW	Load Forecast: 2100MW Wind Forecast: 400MW Load Bid: 2000MW Wind Bid: 50MW
<u>Market Results</u> Steam: 9 commitments 1800MW CT: 0 Wind: 200MW	<u>Market Results</u> Steam: 10 commitments 1950MW CT: 0 Wind: 50MW
<u>Reliability Results</u> Need 100 MW of generation 2 CTs can be turned on in RT No need for last Steam	<u>Reliability Results</u> Need 100 MW of generation Have 350MW more wind *Steam unit was committed by market but not needed in RT*

Inefficiencies only based on large errors

Virtual Trading Allowance Key!

Otherwise discrepancies could cause large inefficiencies

Production Costs

	Base Case Wind Cost	RSCUC process Cost (no wind bid in DAM)	RSCUC process Cost (wind bid full capacity in DAM)	RSCUC process Cost (virtual traders rep wind with between -10 and +10% errors)
August 1,2006	$1,268,862	$1,310,255	$1,312,401	$1,273,262
April 1, 2006	$346,402	$451,504	N/A	$346,681

Wind Curtailments

	Base Case Wind Curtailment	RSCUC process Wind Curtailment (no wind bid in DAM)	RSCUC process Wind Curtailment (wind bid full capacity in DAM)	RSCUC process Wind Curtailment (virtual traders rep wind with between -10 and +10% errors)
August 1,2006	145 MWh (0.4%)	1,405 MWh (4.0%)	145 MWh (0.4%)	145 MWh (0.4%)
April 1, 2006	6,183 MWh (12.8%)	10,179 MWh (21%)	N/A	6,174 MWh (12.8%)

Stochastic UC Options

All scenarios in obj fcn

$\min \sum\pi_s\sum\sum\{P_{s,g,t}*F_{g,t} + LS_{s,t}*\gamma\ldots\}$

s.t.

$u = u_s$

For all s

$G_s<b_s$

$G_{eq,s}= b_{eq,s}$ -> $\sum P_g + LS = D$

Option 1

Value of Loss Load (VOLL) becomes important. Unlikely situations may be chosen to be violated because of costs. Solve time would be much higher because there is many more variables in the objective.

Only expected value in obj fcn

$\min \sum\sum\{P_{s_0,g,t}*F_{g,t} + \ldots\}$

s.t.

$u = u_s$

For all s

$G_s<b_s$

$G_{eq,s}= b_{eq,s}$

Option 2

In order to stay efficient, must make all scenarios equally likely. Very similar to how contingencies are modeled in SCUC. Might not make as much cost-efficient solutions. Load Shedding should not be an option.

What is the price of energy paid?

- A stochastic SCUC will have *n* LMPs for every *n* scenarios
- What does a generator get paid?
    - Run Deterministic SCED following the Stochastic SCUC to get a single LMP for each bus
    - Take the LMP and Generation schedule from a base scenario (median or most likely) of the stochastic SCUC to determine LMP
    - Probability Weighted LMP pricing

Probability Weighted LMP

$$Payment_i^{DA} = \sum_{s=1}^{NS} \pi_s * \left(Pg_{i,s}^{DA} * [K_{i,n}] * LMP_{n,s}^{DA} + \sum_{r=1}^{R} RS_{i,r,s}^{DA} * RCP_{r,s}^{DA} \right)$$

- Better reflect the objective
- Better reflects the real-time outcome (price and schedule)
- Incentivizes reliable operation
- Incentivizes flexibility

Probability Weighted LMP

Unit-hours with negative profits

	Probability Weighted Pricing	Using single base scenario
Energy only	87 hours	165 hours
Energy with reserves	63 hours	161 hours

Sum of negative profits

	Probability Weighted Pricing	Using single base scenario
Energy only	-$12,352.54	-$27,224.90
Energy with reserves	-$10,291.64	-$25,450.69

DOE/NREL REF study

- Study evaluating 80% renewables in the year 2050
  - About 50-55% VG
- Simple operational analysis using hourly SCUC model to evaluate generation behavior and transmission flow results
- NREL researchers and ABB developers working closely on enhancements to correctly model unique resources in ABB's GridView
  - Concentrating Solar Plant with Thermal Energy Storage Model
  - Plug-in Electric Vehicle Model
  - Compressed Air Energy Storage Model
- GridView is a SCUC/SCED multi-day planning model
  - These enhancements can easily be integrated into RTO Day-ahead SCUC models and real-time SCUC/SCED models for better capturing these unique resources behavior

Further Research and Questions

- Full review of operating reserves in the SCUC
    - F(x) = operating reserve requirement
    - What is x? What is F?
- Can wind ramps be modeled in the SCUC in phase and magnitude similar to network contingencies
    - Can prepare for big GW wind events (e.g. ERCOT Feb 2007/2008) in the SCUC and make sure resources are ready given high probability
- Is stochastic SCUC the right way to go or can a modified deterministic SCUC get the benefits without the cost?
- Are we best utilizing storage resources in the SCUC?
- What is the appropriate lead time and frequency of intra-day SCUC if needed?
- . . .

Questions

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www.nrel.gov/wind/systemsintegration

www.uwig.org