NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Scheduling and Pricing under Variable and Uncertain Power Systems

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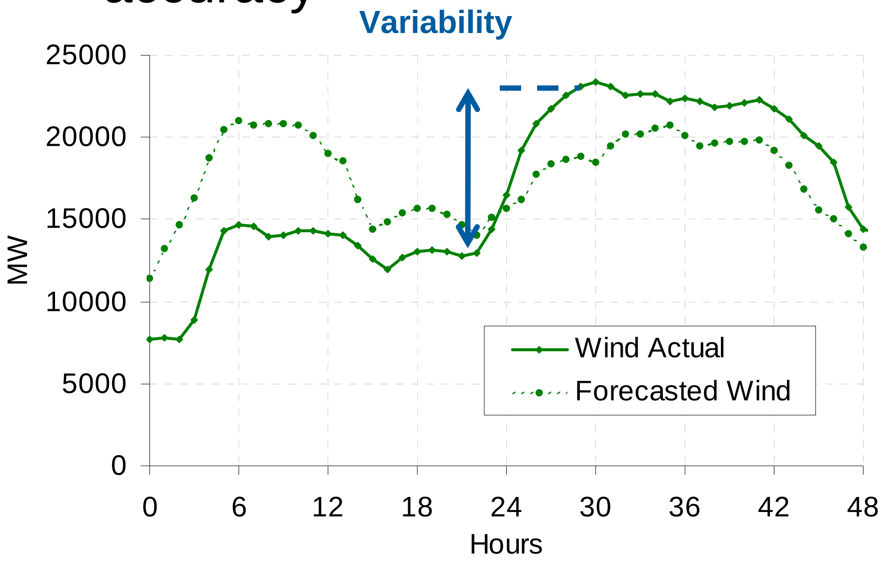
Variability and Uncertainty

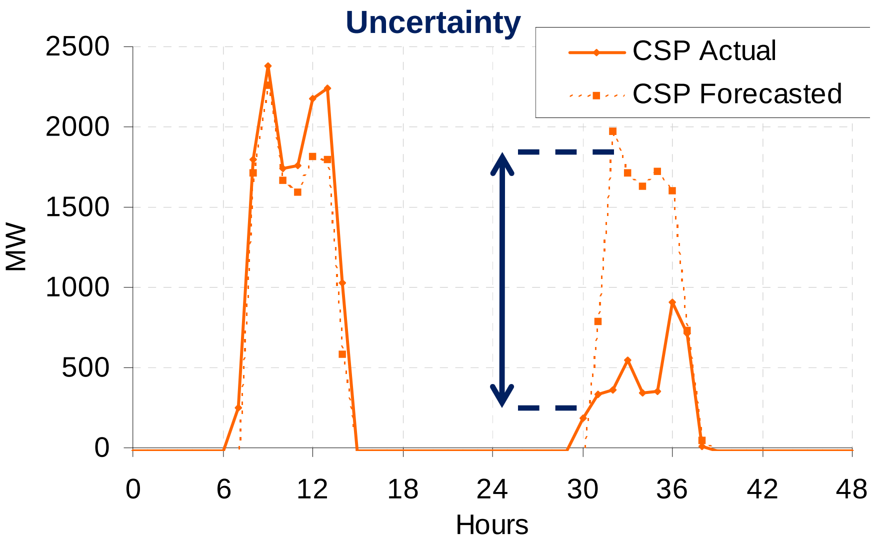
- Variability: issues can occur at time resolutions the system is not prepared for.
  - The scheduling model is not prepared for it. For example, a 5-minute dispatch cannot correct 1-minute variability
  - The system resources are not prepared for it. For example, resources ramp rates and start-up times are too low to handle 5-minute variability even if it is known to occur.
- Uncertainty: issues can occur that were not explicitly anticipated.
  - When scheduling toward one realization and another realization occurs.

Variability and Uncertainty

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

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





Variability: load varies throughout the day, conventional generation can often stray from schedules

Uncertainty: Contingencies are unexpected, load forecast errors are unexpected

Variability and Uncertainty

Sources of V and U

System demand (**V and U**)
Variable generation (**V and U**)
Conv. gen behavior (**V**)
Conv. gen outages (**U**)
Transmission outages (**U**)
Fuel prices (**V and U**)

Impacts of V and U

Active power imbalance
- Frequency excursions
- Area control error

Line flow exceedance

Reactive Power Imbalance
- Voltage violations

Angle instability

Changes in production costs
Changes in generator cycling
Changes in software solution times

Variability and Uncertainty

- Understanding of variability and uncertainty impacts requires more than characteristics of variable and uncertain variables, it requires understanding of the mitigation strategies being used to accommodate these impacts.
- Ex: A system with very large uncertainty, can have zero uncertainty reliability impacts as dispatch resolution -> 0, minimum capacities and start-up times -> 0 , and ramp rates -> ∞

Mitigation Strategies

Variability	Uncertainty
Faster Ramp Rates	Faster Ramp Rates
Faster Start-up times (shut-down times)	Faster Start-up times (shut-down times)
Greater power output ranges	Fewer Commitment Constraints (min on, off, etc.)
	Better Forecasting

How to model variability and uncertainty ?

Type of Model	Mathematical	Explicit Secure	Full Optimal
Uncertainty	Operating reserve	Security constrained	Stochastic optimization
Variability	Operating reserve	Maximum movement ramp constrained	Faster interval resolution

} Longer Horizons

Computation Time and complexity

Improved Efficiency and Reliability?

Current Strategies

V/U	Issue	Cause	Modeling Mitigation Strategy
Uncertainty	Imbalance	Conventional Trip	Contingency Reserve
Uncertainty	Imbalance	VG Forecast error	Reserve (other)
Uncertainty	Imbalance	Load Forecast error	Reserve (other)
Uncertainty	Power flow	Conventional Trip	Locational reserve requirements
Uncertainty	Power flow	VG Forecast error	Nothing
Uncertainty	Power flow	Branch failure	Security-constrained
Variability	Imbalance	VG/load variability (slow)	5-min dispatch
Variability	Imbalance	VG/load variability (fast)	Reserve (AGC)

Incentives

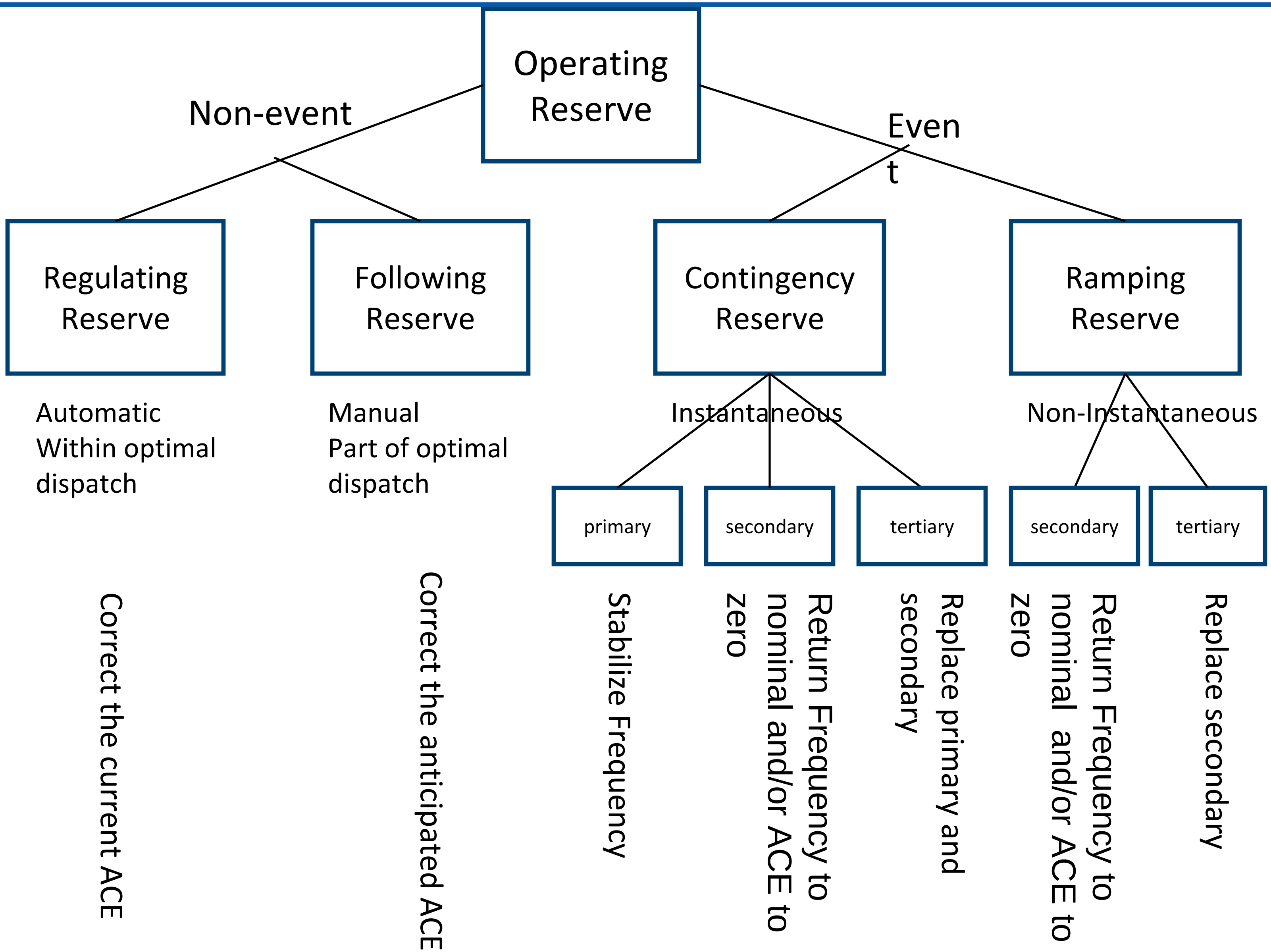
- Issue #1: With increasing amounts of variability and uncertainty on the system, we need to find a way to incentivize the resources that accommodate this variability and uncertainty.
- Issue #2: With different modeling strategies to mitigate the variability and uncertainty, we have to ensure there are no adverse ways in which the incentive programs are structured.

Incentives Today

- Various operating reserves are paid today to providers of capacity of those services.
- Prices are the marginal cost to provide capacity.
- Reserves are co-optimized with energy.
- Price of reserve reflect the lost opportunity cost to provide energy or other reserve.
- Prices of reserve reflect pricing hierarchy so higher valued services contain the lower valued services price.
- Some mechanisms include utilization payments.
  - FERC Order 755 for Regulating Reserve

Pricing for operating reserve, the main mechanism for accommodating variability and uncertainty seems to work OK. But what about moving to other strategies???

Operating Reserve Categorization



Ela, Milligan, and Kirby “Operating Reserves and Variable Generation” NREL/TP-550-51928, August 2011.

Dynamic Operating Reserves

- The need for operating reserves will likely change with time and horizon.
- Operating reserve demands, and therefore prices, will not be known in advance and market participants will need to forecast.
- Virtual trading of ancillary services may be helpful in convergence between day-ahead and real-time markets.

Ela, Kirby, Navid, and Smith, “Effective Ancillary Service Market Designs on High Wind Power Penetration Systems,” IEEE PES GM, 2012

Scheduling Strategies to Improve Variability

Faster Dispatch interval

- Faster clearing of energy markets and economic dispatch can help reduce the impact of variability.
- Faster clearing will reduce the need of requiring expensive regulating reserve capacity.
- This may eliminate the premiums given to units that follow the ACE while still requiring them to move fast and follow the ACE.
- Will this reduce the incentive for resources to offer capacity as flexible in the real-time energy market?

Fast Dispatch

- Using FESTIV Model
- Perfect forecasts in all time frames, hourly day-ahead SCUC, 30-min real-time SCUC, 20% wind penetration, 6-second AGC, 24 hour simulation.

	Dispatch at 5-minute intervals	Dispatch at 1-minute intervals
Regulation Reserve	Regulation reserve at 1% load	No regulation reserve
Abs ACE (MWH)	94	59
Cost ($)	$909,852	$909,878
Revenue ($)	$1.636M	$1.396M

- Improved reliability, same costs, but significantly less payments. Missing money?

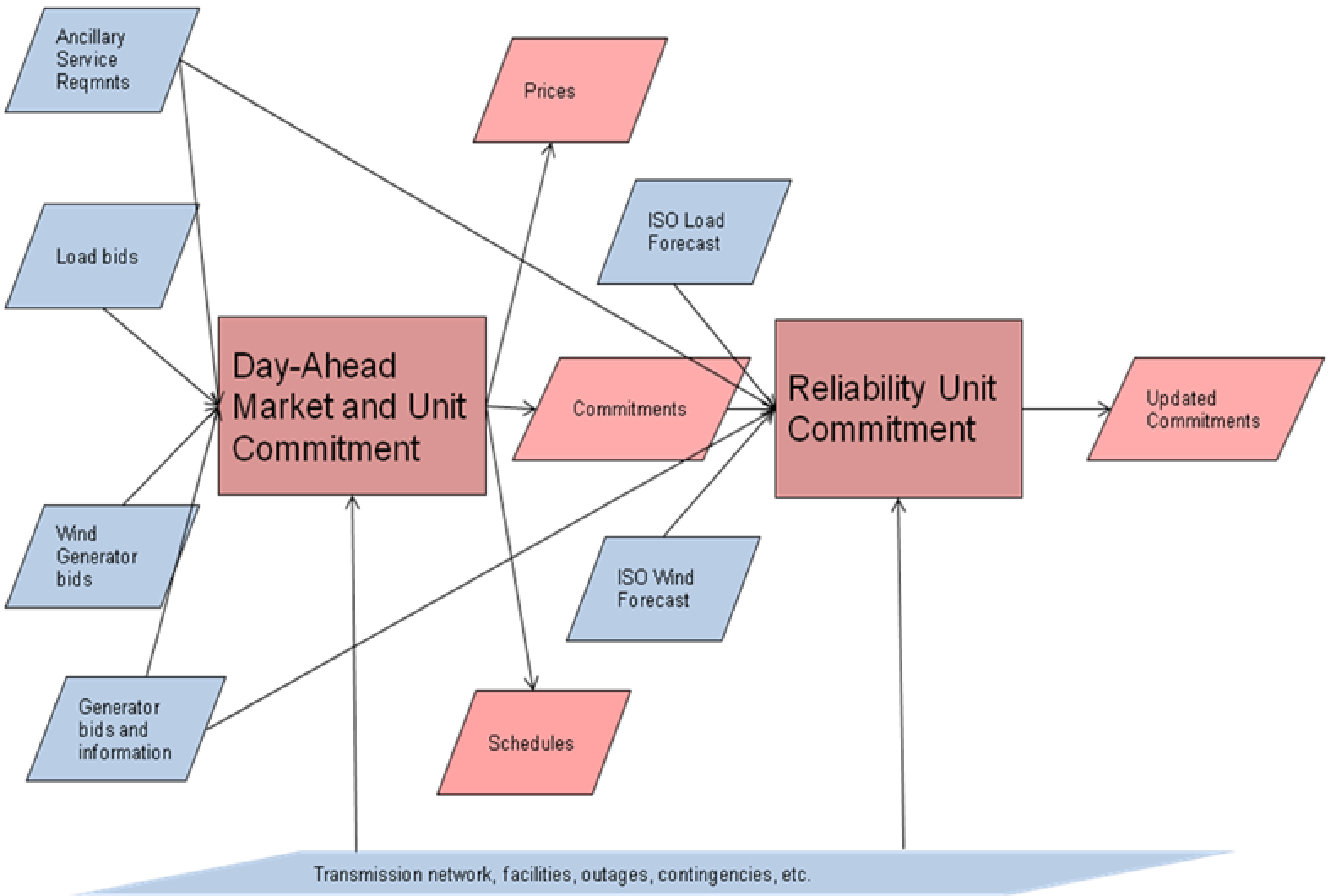
FESTIV Model:
Ela, O'Malley, "Studying the variability and uncertainty of variable generation at multiple timescales," IEEEE Trans. Power Syst., 2012

Scheduling Strategies to Improve Uncertainty

Day-Ahead Markets and RSCUC

- Most ISOs in the US will run two SCUC programs with two different purposes
  - **DAM** – purely financial, used for price certainty, hedging against volatile real-time market, insurance of side payment guarantees
  - **RSCUC** – The ISO uses this to ensure a reliable system with sufficient capacity available for the day-ahead time frame
- Different inputs
- Different objective functions

Full Day-Ahead Procedure



Stochastic Unit Commitment

- Higher penetrations of uncertainty result from larger penetrations of variable generation, e.g., wind
- Higher quantity of reserve or new methods of scheduling may be required.

- Stochastic Security Constrained Unit Commitment (STSCUC):
  - Minimization of expected costs with respect to meeting a multitude of potential scenarios reliably
  - Wu et al 2007, Bouffard et al 2008, Ruiz et al 2009, Meibom et al 2011
  - Proof of reduced costs, limited proof of improved reliability
- 1st-stage variables fixed for all scenarios (start-up and unit status of long-start units)

Stochastic Unit Commitment

- Computationally intensive (main disadvantage)
- Scenario representation complex
- Linkage with market design not straightforward
- Can be used in RSCUC or DAM
  - RSCUC usage somewhat straightforward
  - Benefit of usage in RSCUC may not be full
- This work focuses on usage of STSCUC in DAM and linkage between the two

Issues

- For a STSCUC modeling *n* scenarios, there will be *n* LMP for every bus and time period
- A unit turned on for a high net-load scenario will likely cost more than the prices that are based on the median scenario
- A price based on median scenario may not truly reflect the schedules given
- A price based on median scenario may not incentivize resources to provide the flexibility to provide different dispatch depending on scenario
- **The units that used to get paid for providing reserve are still providing reserve, without the reserve payment.**

Payments and Costs

Payment with Deterministic Pricing

$$Payment_{i,h} = Pg_{i,h}^{DA} * [K_{i,n}] * LMP_{n,h}^{DA} + (Pg_{i,h}^{RT} - Pg_{i,h}^{DA}) * [K_{i,n}] * LMP_{n,h}^{RT} + \sum_{r=1}^{R} RS_{i,h,r}^{DA} * RCP_{h,r}^{DA} + (RS_{i,h,r}^{RT} - RS_{i,h,r}^{DA}) * RCP_{h,r}^{RT}$$

Payment with Probability-Weighted Pricing

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

Cost

$$Cost_{i,h} = SUC_i * z_{i,h} + NLC_i * u_{i,h} + \left\{\sum_{k \in K_i} IC_{i,k} * Pg_{i,k,h}^{RT}\right\} + \sum_{r=1}^{R} RC_{i,,rh} * RS_{i,h,r}$$

Ela, O'Malley, "A probability-weighted lmp and rcp for day-ahead energy markets using stochastic security-constrained unit commitment," PMAPS 2012.

Results

Using FESTIV model, 2-stage STSCUC

	Unit-hours with negative profit		Total $ of negative profit	
	LMP based on single scenario	Probability weighted LMP	LMP based on single scenario	Probability weighted LMP/RCP
August	77	43	-$9,252	-$4,180
April	73	42	-$6,357	-$4,724

Summary

- There are new ways to accommodate the increasing variability and uncertainty that is being introduced especially by variable generation
  - Resource flexibility
  - Enhanced modeling strategies
- The resources that provide this flexibility must be incentivized to do so regardless of modeling strategy
- New innovative methods of modeling may be introduced, and new incentive structures may have to be introduced alongside

Questions

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www.nrel.gov/wind/systemsintegration