Flexibility Auctions: A Framework for Managing Imbalance Risk

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Introduction

Flexibility auction

Numerical example

Conclusions

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An Electric Sector in Transition

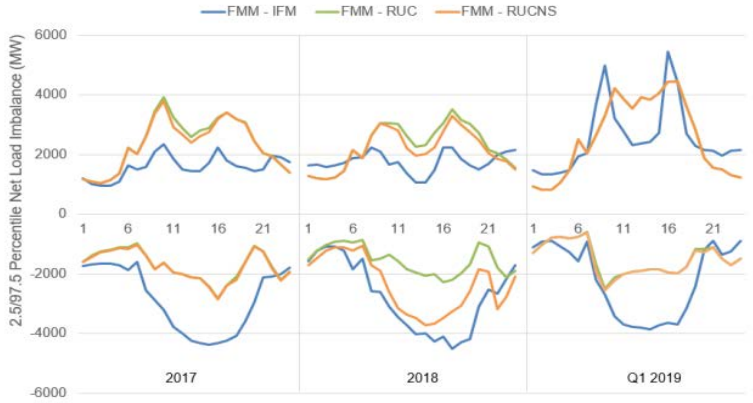
- Wind and solar photovoltaics are anticipated to contribute >50% of future electricity
- System operators ***and flexible resources*** must manage challenging imbalances

Key milestones in the pathway to net zero

By 2050, almost 70% of electricity generation globally from solar PV and wind

Source: International Energy Agency, 2021. "Net Zero by 2050 A Roadmap for the Global Energy Sector."

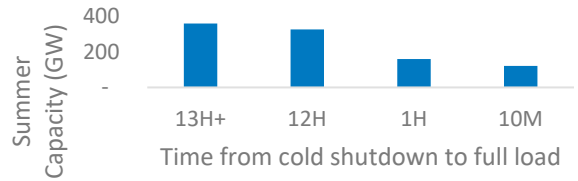
Net load imbalances at California ISO



Source: CAISO., 2020. Day-Ahead Market Enhancements: (Revised Straw Proposal),. Folsom, CA. http://www.caiso.com/InitiativeDocuments/RevisedStrawProposal-Day-AheadMarketEnhancements.pdf

Operators and participants *could hedge system supply-demand and own imbalance risk.*

One aspect of operational flexibility

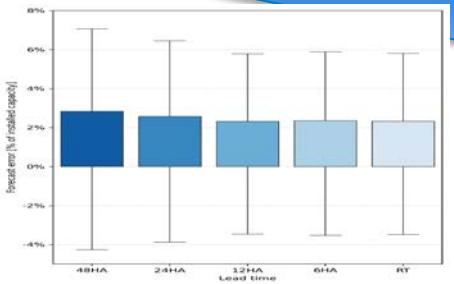


Data for generators included in EIA-860A/860B 2019 and have data for time from cold shutdown to full load.

Supply curves for operational flexibility become steeper as lead time reduces …

Day-ahead | Hour-ahead | Minutes-ahead | Real-time operations

… While uncertainty with respect to generation decreases as lead time reduces



Source: EPRI

Graph adapted from ADVANCED RESEARCH PROJECTS AGENCY – ENERGY (ARPA-E) U.S. DEPARTMENT OF ENERGY PERFORMANCE-BASED ENERGY RESOURCE FEEDBACK, OPTIMIZATION, AND RISK MANAGEMENT (PERFORM) Funding Opportunity No. DE-FOA-0002171 CFDA Number 81.135

Designing a Framework for Imbalance Risk

"Easy to do badly and difficult to do well."

Source: P. L. Joskow, 2006. "Designing Wholesale Electricity Markets", https://economics.mit.edu/files/1185.

Two Settlement System

- Day-ahead market considering imbalance risk
- Real-time market

Marginal Pricing

- Imbalance risk pricing
- Co-optimization of products traded (opportunity costs)

Independent System Operator

Cost-effective and reliable outcomes *considering imbalance risk*

Bid-Based Market

- Supply bids for flexibility
- Demand bids for flexibility

Four quadrants adapted from W. W. Hogan, 1998. "Competitive Electricity Market Design: A Wholesale Primer", http://www.science.smith.edu/~jcardell/Readings/uGrid/Electricity%20Markets/Hogan%20ElecMktPrimer.pdf

Agenda

Introduction

Flexibility auction

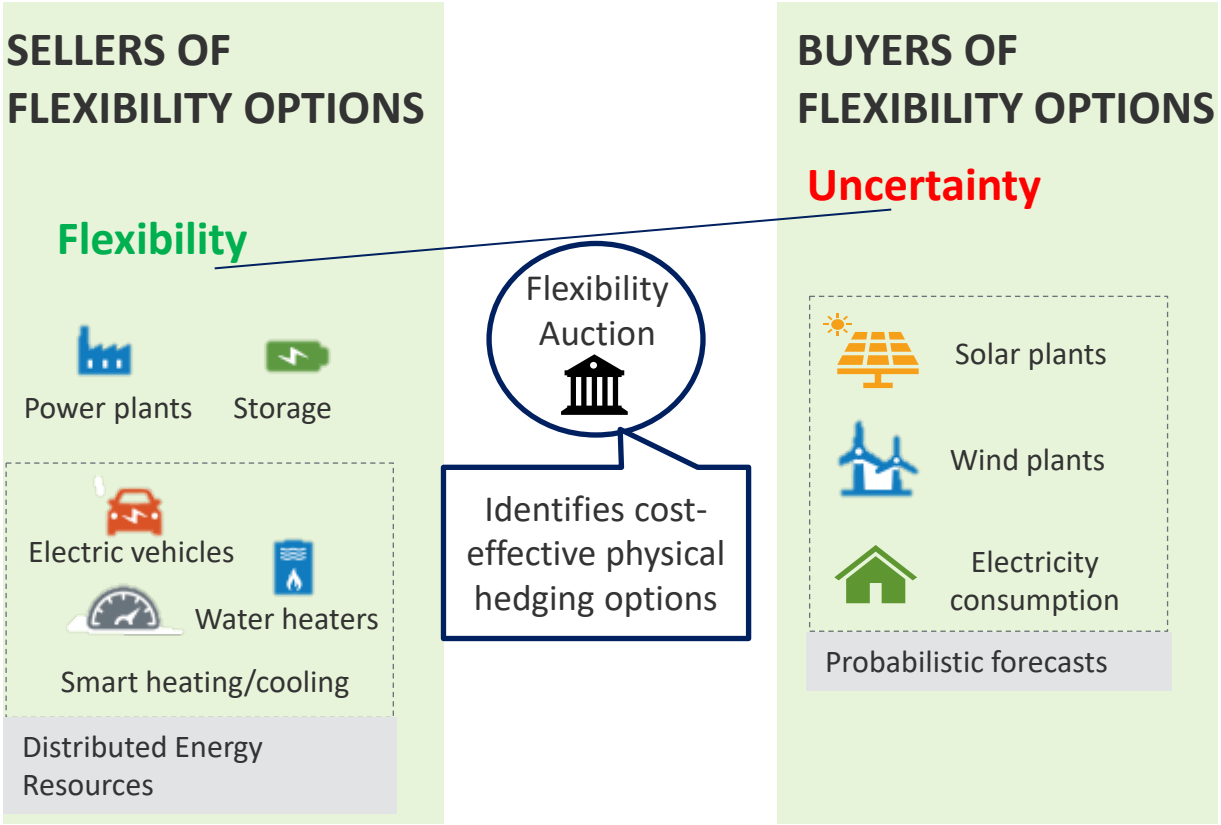
- **Who?**
- **What?**
- **How?**

Numerical example

Conclusions

FLEXIBILITY AUCTION: Participants

- Initial focus on participants with physical assets
- Extension: financial participants



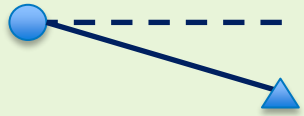
FLEXIBILITY AUCTION: *Preliminary* Product Definition

A contract issuing rights to its purchaser to buy or sell energy *imbalances* during a market interval at a strike price.

Day-ahead energy award

Real-time physical availability

Negative imbalance



Positive imbalance

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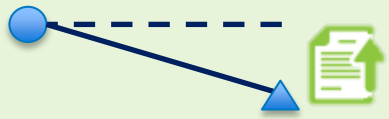
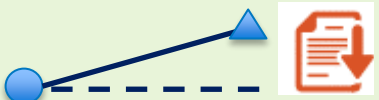


Upward option

- ✓ "Call" option to purchase up to *x* MW at strike price.
- ✓ Can be exercised only when imbalance is negative.

Positive imbalance



Downward option

- ✓ "Put" option to sell up to x MW at strike price.
- ✓ Can be exercised only when imbalance is positive.

FLEXIBILITY AUCTION: *Preliminary* Product Definition

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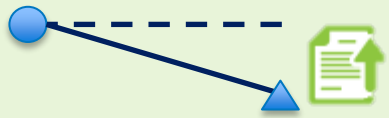

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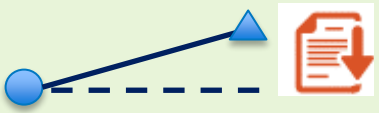

Downward option

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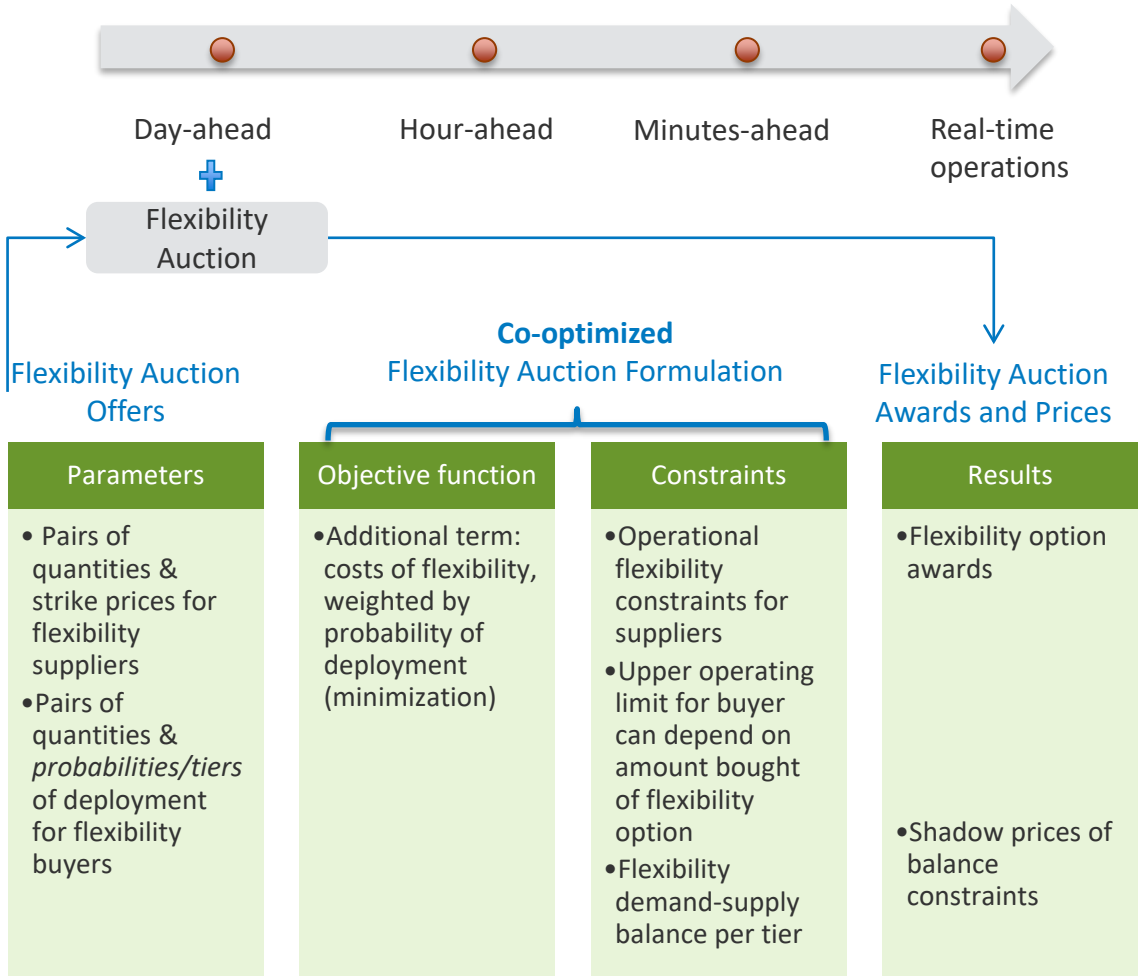
Option "tier" indicates the frequency at which the option can be exercised.

FLEXIBILITY AUCTION: Trading and Pricing



FLEXIBILITY AUCTION: Settlements

Two-settlement system:

A. Option pricing in day-ahead
B. Option pay-off in real-time

SIMPLIFIED FORMULATION FOR FLEXIBILITY UP
MW = flexibility option award = imbalance
Flexibility up supplier = supplier in real-time market

Buyer

A

−{ "flex up price"
−prob-weighted avg‡ strike price}× MW

B

− RT energy price × MW
+max(0,{RT energy price
− avg‡ strike price}) × MW

Seller

A

+{ "flex up price"
−prob-weighted strike price} × MW

B

− Max(0,{RT energy price− Strike price})× MW
+RT energy price ×MW

‡Megawatt-weighted average over all suppliers

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Simple Example for One Interval

Flexibility buyers

Scenario	Probability	Renewable 1	Renewable 2	Aggregate
S1	20%	67	64	131
S2	20%	74	67	141
S3	20%	83	72	155
S4	20%	90	75	165
S5	20%	95	77	172
Correlation of R1 & R2		~1		

Flexibility suppliers

	Variable cost ($/MWh)	Max capacity (MW)
ST 1	20	50
CT 2	35	10
CT 3	50	10
CT 4	60	10

Strike price = Variable Cost
Ramp Rate = Capacity

Energy-only participants

Load: 200 MW

DISCLAIMER: Simple example:

1) excludes “surprises” (assumes uncertainty perfectly quantified & revealed by flexibility buyers);
2) assumes perfectly correlated uncertainties among flexibility buyers.

Observation 1: Price signals for imbalance risk

Endogenous consideration of imbalance costs for renewable energy [1]

MW Schedule	DA Energy	$T1$ $FLEX$ ↑	$T2$ $FLEX$ ↑	$T3$ $FLEX$ ↑	$T4$ $FLEX$ ↑	$T1$ $FLEX$ ↓	$T2$ $FLEX$ ↓	$T3$ $FLEX$ ↓	$T4$ $FLEX$ ↓
RE 1	83	-7	-9					-7	-5
RE 2	67	-3					-5	-3	-2
ST 1	50						5	10	7
CT 2	0	1	9						
CT 3	0	9							
CT 4	0								
Shadow price, $/MWh	29	10	17	21	25	-19	-12	-8	-4

DA energy price = Expected RT energy price

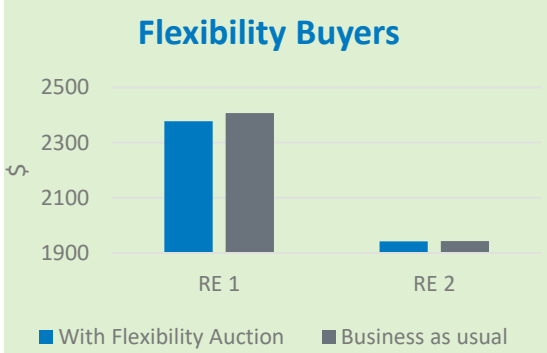
[1]

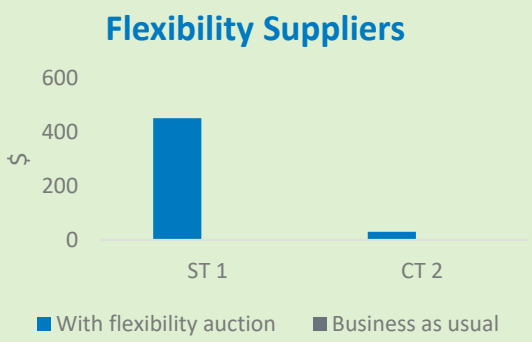
If no flexiblity auction, degeneracy for DA energy price in [20,35]. Assuming ε MW of virtual supply at 29$/MWh, same DA energy price ($29/MWh).

Observation 2: Mutually beneficial imbalance risk sharing

- Overall E(profits) remain the same
- Win-win: Both suppliers and buyers experience lower profit variability after trading flexibility options

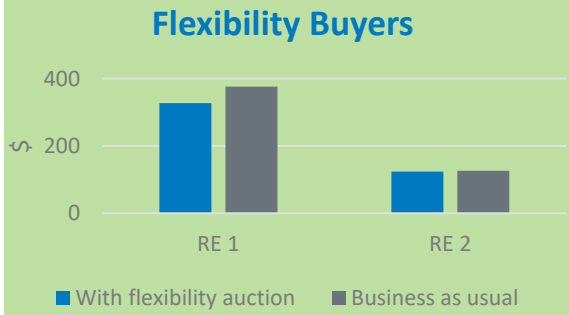
Estimated day-ahead profits

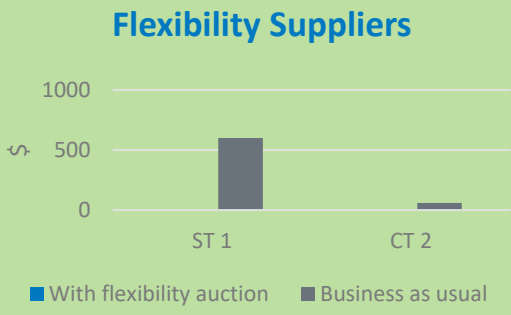




Expected day-ahead and real-time profits same between two cases: RE1 (2260). RE2 (2005), ST1 (450), CT2 (30)

Standard deviation of day-ahead and real-time profits





Simple Example [Modified: Unit Commitment]

Flexibility buyers

Scenario	Probability	Renewable 1	Renewable 2	Aggregate
S1	20%	67	64	131
S2	20%	74	67	141
S3	20%	83	72	155
S4	20%	90	75	165
S5	20%	95	77	172
Correlation of R1 to R2		~1		

Flexibility suppliers

	Min capacity	Variable cost ($/MWh)	Max capacity (MW)
ST1 (DA start)	44	20	50
ST2 (DA start)	25	22	50
CT 2	0	35	10
CT 3	0	50	10
CT 4	0	60	10

Strike price = Variable Cost
Ramp Rate = Capacity

Energy-only participants

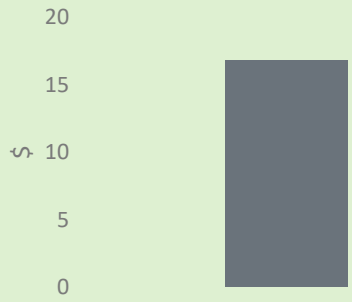
Load: 200 MW

- Business as usual case would have committed ST1 unaware of flexibility needs.
- With flexibility auction, ST2 should be committed.

Observation 3: Cost-effective power system operations

Introducing a flexibility auction might reduce perfect forecast gap (extent is system-dependent)

Perfect forecast gap



Elimination of perfect forecast gap due to simple example assumptions – not generalizable result!

0

Production cost per scenario and expectation

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Conclusions

- Preliminary design of flexibility auction proposed
- Simple examples show price signals for imbalance risk
- Simple examples show improved hedging for suppliers & buyers of flexibility options
- Simple examples show increased market surplus

Ongoing Work

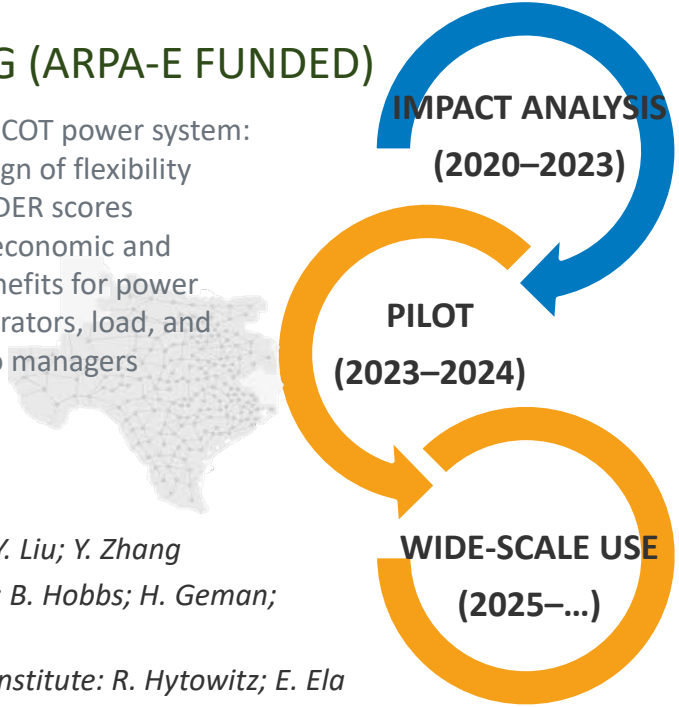
- Comparison with other hedging instruments
- Implementation in FESTIV*
- Simulations with ARPA-E PERFORM Texas system to analyze value of the auction

*Flexible Energy Scheduling Tool for Integrating Variable Generation. https://www.nrel.gov/grid/festiv-model.html

1 ONGOING (ARPA-E FUNDED)

Simulate Texas ERCOT power system:

- To verify design of flexibility auction and DER scores
- To estimate economic and reliability benefits for power system, generators, load, and DER portfolio managers



2 PARTNERS NEEDED

Pilot framework for delivery risk

3 FUTURE PLANS

- Facilitate use of DER scores at national scale
- Assist energy markets to implement flexibility auctions

- *NREL: E. Spyrou; M. Cai; Y. Liu; Y. Zhang*
- *Johns Hopkins University: B. Hobbs; H. Geman; M. AlAshery; Y. Ma*
- *Electric Power Research Institute: R. Hytowitz; E. Ela*
- *Packetized Energy: P. Hines; M. Almassalkhi*
- *kWh Analytics: J. Kaminsky*

Three-year Project

- Detailed formulation with additional considerations— such as network constraints, multi- interval markets, and market monitoring functions etc. —will be released along with results on value analysis.
- Additional focus on flexibility by DERs.

Thank you

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