Flexibility Options: A Proposed ISO Product for Managing Energy Imbalance Risk

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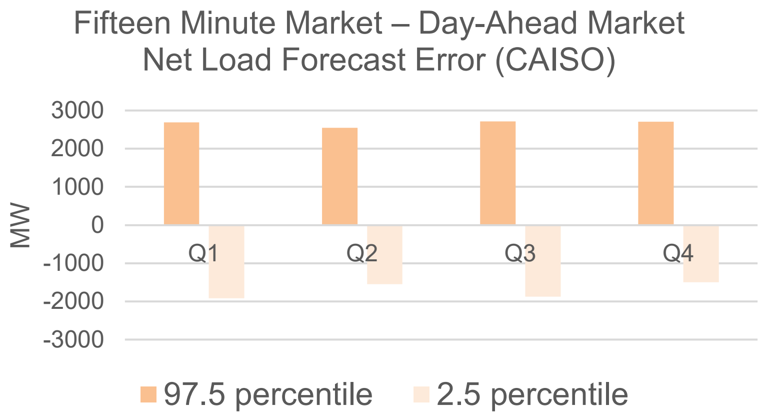
Outline

- Context
- Flexibility Options
- Key Observations and Next Steps

An Electric Sector in Transition

System operators and flexible resources must manage challenging energy imbalances.

By 2050, almost 70% of electricity generation globally will come from solar photovoltaics and wind.



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

Dataset: January 2017 to March 2019

Graph Adapted from M. Poage and D. Tretheway. 2019. "Day-Ahead Market Enhancements Stakeholder Working Group Meeting," August 13, 2019. CAISO.

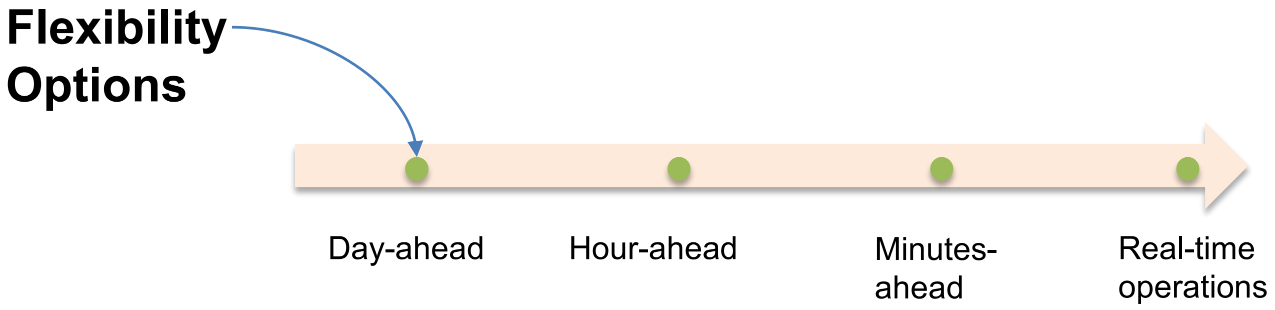
Operational Flexibility for Managing Energy Imbalances

As lead time reduces, …

- ✓ uncertainty with respect to energy imbalance decreases
- ✓ supply curves for Real-Time operational flexibility become steeper

Research Question

How will introducing a new *flexibility option* product in day-ahead ISO auction contribute to market efficiency and power system reliability?



Endogenously consider cost of operational flexibility to manage imbalances

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- Context
- Flexibility Options
  - Participants (Who?)
  - Product Definition (What?)
  - Formulation and Settlements (How?)
- Key Observations and Next Steps

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BUYERS OF FLEXIBILITY OPTIONS

Uncertainty

Solar plants

Wind plants

Load-serving entities

ISO Day-Ahead Markets

Identify cost-effective hedging of energy imbalances with ***flexibility options***.

SELLERS OF FLEXIBILITY OPTIONS

Flexibility

Power plants

Storage

Electric vehicles

Water heaters

Smart heating/cooling

Distributed energy resource aggregators

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Identify cost-effective hedging of energy imbalances with ***flexibility options***.

Set of percentiles (Ω_S)

Probability of shortfall ($\Pi_{s,t}$)

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Load-serving entities

- $P_{i,s,t}$: Generation or consumption
- $CAP^{\uparrow}_{i,r,t}$: Willingness to pay for hedging generation shortfalls.

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Identify cost-effective hedging of energy imbalances with ***flexibility options***.

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SELLERS OF FLEXIBILITY OPTIONS

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Distributed energy resource aggregators

- $C^{\uparrow}_{i,r,t}$: strike price at which they would supply Real-Time energy.
- $C^{\downarrow}_{i,r,t}$: strike price at which they would buy Real-Time energy.

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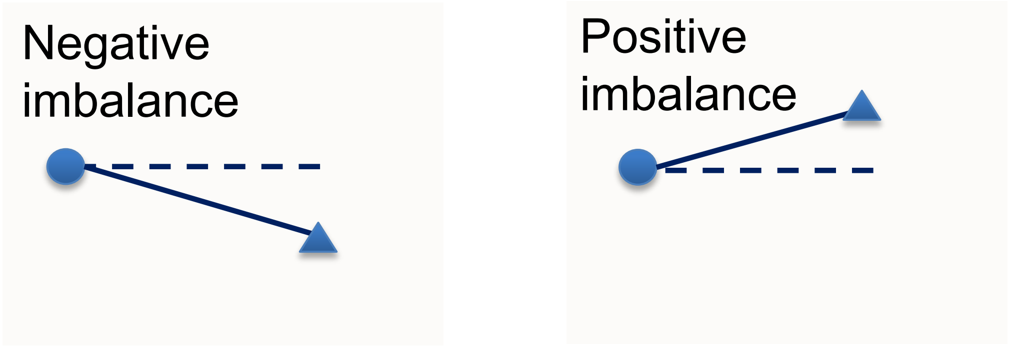
● Day-ahead energy award

▲ Real-time physical availability



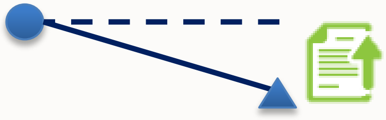
A contract issuing rights to its purchaser to buy or sell energy *imbalances* during a market interval at a strike price.

● Day-ahead energy award

▲ Real-time physical availability

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

Negative imbalance



Upward option

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

Positive imbalance

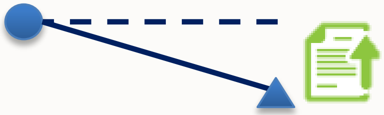
Downward option

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

- Day-ahead energy award
- Real-time physical availability

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

Negative imbalance



Upward option

- ✓ "Call" option to purchase up to x MW at strike price.
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Positive imbalance

Downward option

- ✓ "Put" option to sell up to x MW at strike price.
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Option "tier" indicates the frequency at which the option can be exercised.

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Co-optimized within DA markets Formulation

Preliminary and non-exhaustive

Existing terms in objective function such as energy cost

Expected cost for flexibility deployment

$$\min_{\Xi} \sum_{i\in\Omega_G, t\in\Omega_T} \mathrm{C}_{i,t}\cdot \mathrm{p}_{i,t}\cdot \mathrm{I_m} + \cdots + \sum_{\mathrm{i}\in\Omega_G'', \mathbf{t}\in\boldsymbol{\Omega}_\mathbf{T}} \mathbf{I_m}\cdot\left(\sum_{\mathbf{r}\in\boldsymbol{\Omega}_{\mathbf{R},\mathbf{t}}}\left({}^{\uparrow}\boldsymbol{\Pi}_{\mathbf{r},\mathbf{t}}\cdot \boldsymbol{C}_{i,t}^{\uparrow}\cdot {}^{\uparrow}\mathbf{hs}_{\mathbf{i},\mathbf{r},\mathbf{t}}\right) - \sum_{\mathbf{r}\in\boldsymbol{\Omega}_{\mathbf{R},\mathbf{t}}}\left({}^{\downarrow}\boldsymbol{\Pi}_{\mathbf{r},\mathbf{t}}\cdot \boldsymbol{C}_{i,t}^{\downarrow}\cdot {}^{\downarrow}\mathbf{hs}_{\mathbf{i},\mathbf{r},\mathbf{t}}\right)\right)$$

$$+\sum_{i,s,t} y_{i,s,t}\cdot\gamma + \sum_{\mathrm{i}\in\Omega_G'', \mathrm{t}\in\Omega_\mathrm{T}} \mathrm{I_m}\cdot\left(\sum_{\mathrm{r}\in\Omega_{\mathrm{R},\mathrm{t}}}\left({}^{\uparrow}CAP_{i,r,t}\cdot {}^{\uparrow}\mathrm{s\_fa}_{\mathrm{i,r,t}}\right)\right) + \cdots$$

Expected costs for fast start units

Expected “cost” of flexibility deficits

Co-optimized within DA markets Formulation

Preliminary and non-exhaustive

Existing terms in objective function such as energy cost

Expected cost for flexibility deployment

$$\min_{\Xi} \sum_{i\in\Omega_G, t\in\Omega_T} C_{i,t} \cdot p_{i,t} \cdot I_m + \cdots + \sum_{i\in\Omega''_G, t\in\Omega_T} I_m \cdot \left(\sum_{r\in\Omega_{R,t}} \left({}^{\uparrow}\Pi_{r,t} \cdot C^{\uparrow}_{i,t} \cdot {}^{\uparrow}hs_{i,r,t}\right) - \sum_{r\in\Omega_{R,t}} \left({}^{\downarrow}\Pi_{r,t} \cdot C^{\downarrow}_{i,t} \cdot {}^{\downarrow}hs_{i,r,t}\right)\right)$$

$$+ \sum_{i,s,t} y_{i,s,t} \cdot \gamma + \sum_{i\in\Omega''_G, t\in\Omega_T} I_m \cdot \left(\sum_{r\in\Omega_{R,t}} \left({}^{\uparrow}CAP_{i,r,t} \cdot {}^{\uparrow}s\_fa_{i,r,t}\right)\right) +$$

Expected costs for fast start units

Expected "cost" of flexibility deficits

Constraints related to the co-optimized flexibility auction

System

$$\sum_{i\in\Omega''_G} {}^{\uparrow}hs_{i,r,t} = \sum_{i\in\Omega'_G} {}^{\uparrow}hd_{i,r,t} \ (\lambda^{FLEX\uparrow}_{r,t})$$

$$\sum_{i\in\Omega''_G} {}^{\downarrow}hs_{i,r,t} = \sum_{i\in\Omega'_G} {}^{\downarrow}hd_{i,r,t} \ (\lambda^{FLEX\downarrow}_{r,t})$$

Flexibility demand

$$\sum_{\substack{r=\{1,\dots,s-1\}\\ s\neq 1}} {}^{\downarrow}hd_{i,r,t} + \sum_{\substack{r=\{s,\dots,|\Omega_{S,t}|-1\}\\ s\neq|\Omega_{S,t}|}} {}^{\uparrow}hd_{i,r,t} \le y_{i,s,t}$$

$$\sum_{\substack{r=\{s,\dots,|\Omega_{S,t}|-1\}\\ s\neq|\Omega_{S,t}|}} {}^{\uparrow}hd_{i,r,t} + {}^{\uparrow}s\_fa_{i,r,t} \ge p_{i,t} - P_{i,s,t}$$

$$y_{i,s,t} \ge |p_{i,t} - P_{i,s,t}|$$

Flexibility supply

$$p_{i,t} + \sum_{r\in\Omega_{R,t}} {}^{\uparrow}hs_{i,r,t} \le P^{max}_{i,t} \cdot u_{i,t} + min(P^{max}_{i,t}, RR_i) \cdot uf_{i,r=1,t}$$

$$p_{i,t} - \sum_{r\in\Omega_{R,t}} {}^{\downarrow}hs_{i,r,t} \ge P^{min}_{i,t} \cdot u_{i,t}$$

+ramping constraints

Two-Settlement System

Option pricing in Day-Ahead

Option pay-off in Real-Time

Preliminary and non-exhaustive

Two-Settlement System

Example for Upward Option

Option pricing in Day-Ahead

Option pay-off in Real-Time

Buyer of upward flexibility option:

$$-(\lambda_{r,t}^{FLEX\uparrow} - {}^{\uparrow}\Pi_{r,t} \cdot strike\ price^{*}) \cdot {}^{\uparrow}hd_{i,r,t}$$

Seller of upward flexibility option:

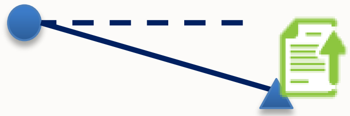
$$(\lambda_{r,t}^{FLEX\uparrow} - {}^{\uparrow}\Pi_{r,t} \cdot C_{i,r,t}^{\uparrow}) \cdot {}^{\uparrow}hs_{i,r,t}$$

* Strike price is MW-weighted average of $C_{i,r,t}^{\uparrow}$

Preliminary and non-exhaustive

Two-Settlement System

Example for Upward Option



● Day-ahead energy award (p_i)

▲ Real-time physical availability (RTP)

	Option pricing in Day-Ahead	**Option pay-off in Real-Time**
Buyer of upward flexibility option:	$-(\lambda_{r,t}^{FLEX\uparrow} - {}^{\uparrow}\Pi_{\mathrm{r,t}} \cdot strike\ price^{*}) \cdot {}^{\uparrow}hd_{i,r,t}$	$\max(0, \lambda_t^{RT-EN} - strike\ price^{*}) \cdot \max(0, \min(P_{i,r-1,t} + {}^{\uparrow}hd_{i,r,t}, p_i) - \max(RTP, P_{i,r-1,t}))$
Seller of upward flexibility option:	$(\lambda_{r,t}^{FLEX\uparrow} - {}^{\uparrow}\Pi_{\mathrm{r,t}} \cdot C_{i,r,t}^{\uparrow}) \cdot {}^{\uparrow}\mathrm{hs}_{\mathrm{i,r,t}}$	$-\max(0, \lambda_t^{RT-EN} - C_{i,r,t}^{\uparrow}) \cdot {}^{\uparrow}hs_{i,r,t}$

* Strike price is MW-weighted average of $C_{i,r,t}^{\uparrow}$

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Simple Example

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

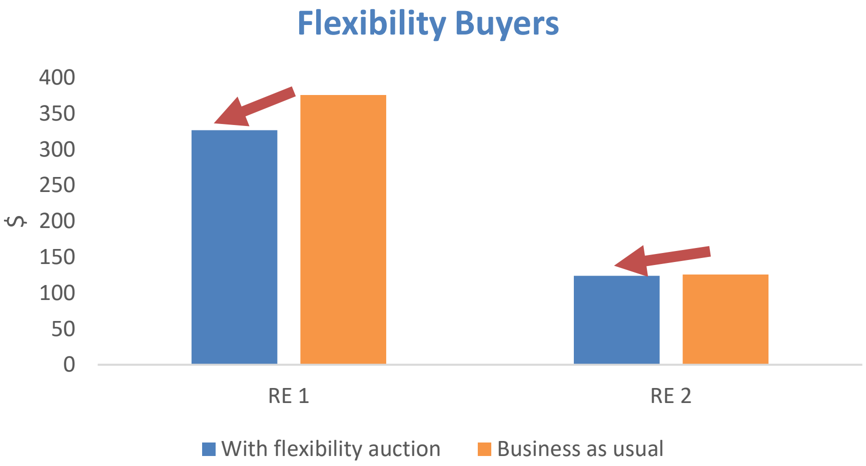
Energy-only participants

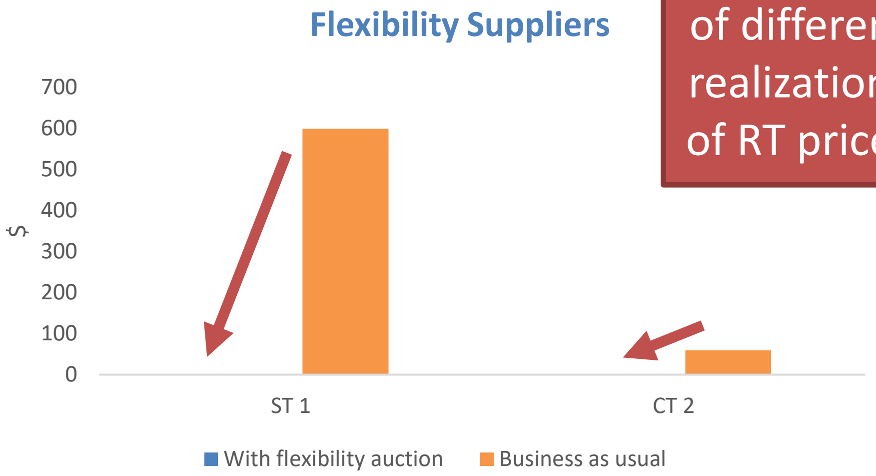
Load: 200 MW

SIMPLE EXAMPLE presented at https://cms.ferc.gov/media/w3-spyrou

Standard deviation of day-ahead and real-time profits *expected* to decrease

$\lambda_{r,t}^{FLEX}$ embeds expectation of different realizations of RT prices





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Simple Example [Modified: Unit Commitment]

Flexibility buyers

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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

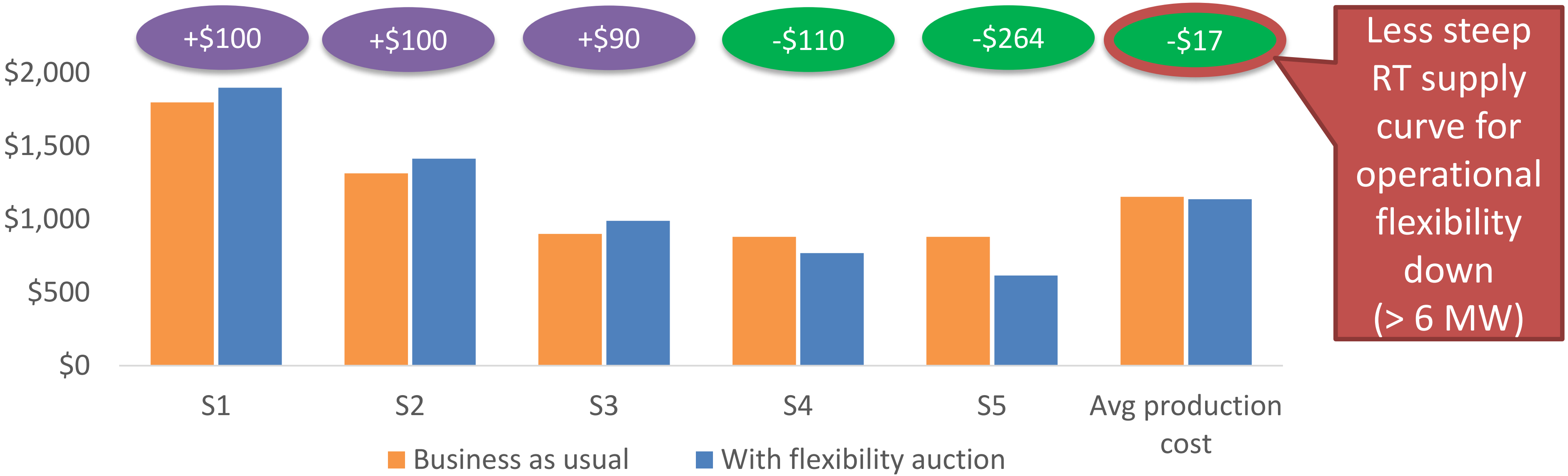
Strike price = Variable Cost
Ramp Rate = Capacity

Energy-only participants

Load: 200 MW

SIMPLE EXAMPLE presented at https://cms.ferc.gov/media/w3-spyrou

Expected production cost and perfect forecast gap *expected* to decrease



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Next Steps

Simulations with ARPA-E PERFORM Texas system in FESTIV* to analyze the value of the introduction of flexibility options

- Comparison with other hedging instruments
- Analysis on risks for all parties involved

Performance analysis for distributed energy resource aggregators acting as flexibility suppliers

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

Thank you!

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