An Integrated Paradigm for the Management of Delivery Risk in Electricity Markets

From Batteries to Insurance and Beyond

2021 Project Status Update

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Abstract

In wholesale electricity markets today, flexibility from a limited number of distributed energy resources (DERs) is offered daily, and the value of flexibility is not yet recognized for economic hedging of delivery risk. Under a three-year project funded by the ARPA-E PERFORM program, a collaborative team is working towards developing an integrated risk management framework that will leverage flexibility from distributed and bulk resources to cost-effectively and reliably manage delivery risk of intermittent resources. Two concepts are at the core of the proposed integrated risk management framework:

(A) flexibility options, which are a novel type of options and enable wholesale electricity market participants to hedge uncertainty by buying flexibility.

(B) DER flexibility scores, which provide a way for utilities or aggregators to classify assets in groups with different likelihood of delivering contracted flexibility.

This report presentation will focus on the proposed ISO-product “flexibility options,” which is complementary to ramp and other products being introduced by ISOs/RTOs to manage net load uncertainties. Participating resources with imbalance risk can buy flexibility options to hedge their production, whereas grid-connected resources that can provide physical flexibility can offer flexibility options. We will present basics of the formulation for a day-ahead ISO market that matches buyers and sellers of this hedge in coordination with existing capabilities to schedule energy and ancillary services, and outline how their settlements mitigate the impact of imbalance risk.

Keywords

Electricity Markets, Imbalance Risk, Distributed Energy Resources, Flexibility, ISO, RTO, Hedging Options

Outline

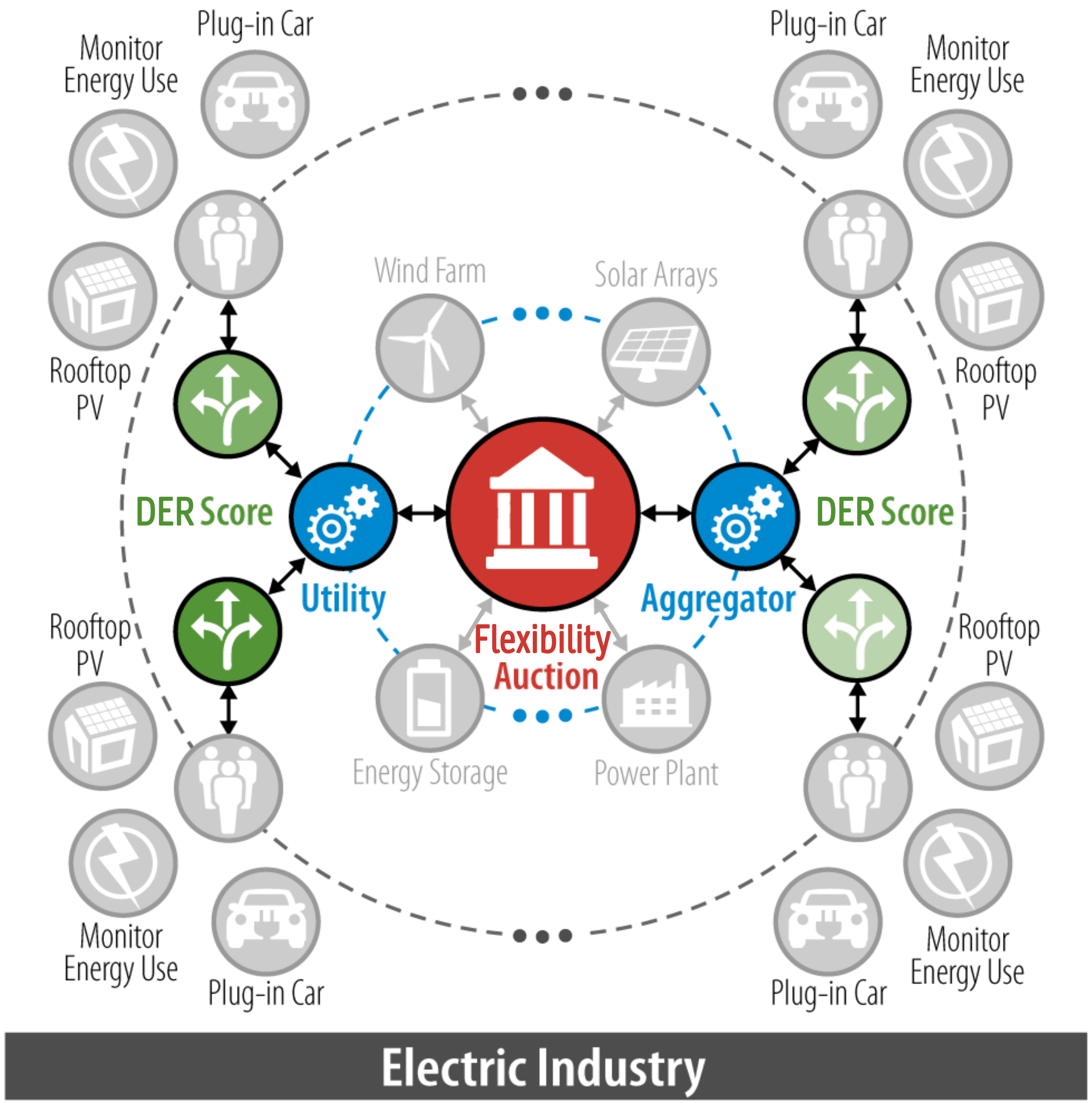
- PERFORM Project Overview
- NREL Team Project Overview
- Motivation for Flexibility Auction
- Flexibility Auction Details: Who, What, When
- Simulation Description and Initial Results
- Future Work for Years 2 and 3

ARPA-E PERFORM Program Overview

- Performance-based Energy Resource Feedback, Optimization, and Risk Management (PERFORM) is a program funded through the Department of Energy's Advanced Research Projects Agency-Energy
  - 12 teams have been awarded projects of various sizes beginning in 2020
  - EPRI is a sub-awardee of the National Renewable Energy Laboratory team
  - The program objective: "PERFORM seeks to develop innovative management systems that represent the relative delivery risk of each asset and balance the collective risk of all assets across the grid. A risk-driven paradigm allows operators to: (i) fully understand the true likelihood of maintaining a supply-demand balance and system reliability, (ii) optimally manage the system, and (iii) assess the true value of essential reliability services. This paradigm shift is critical for all power systems and is essential for grids with high levels of stochastic resources. Projects will propose methods to quantify and manage risk at the asset level and at the system level." Source: PERFORM site listed below
- Sources of general information
  - PERFORM site: https://arpa-e.energy.gov/technologies/programs/perform
  - NREL PERFORM site: https://arpa-e.energy.gov/technologies/projects/integrated-paradigm-management-delivery-risk-electricity-markets-batteries

NREL Project Overview

- We aim to develop an operating paradigm that leverages flexibility from distributed and bulk resources to cost-effectively manage imbalance risk of intermittent resources and load.
- Aim achieved through two main tasks
  1. **DER scores** will characterize flexibility from DERs by magnitude and probability of delivery
  2. **Auction for physical flexibility** accessible by all market participants for economic hedging of their uncertain output. The proposed auction will create a demand for flexibility that extends beyond reliability and will strike a balance between procuring flexibility and mitigating the need for it.



Project Team Overview

PI: Elina Spyrou

DER scores

Flexibility Auction

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NREL Transforming ENERGY
Yajing Liu & Elina Spyrou
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NREL Transforming ENERGY
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(Modeling of participants)

kWh analytics
Jason Kaminsky
(Assessment of hedging options)

Flexibility Auction Overview

WHY management of imbalance risk in electricity markets is necessary?

WHAT are the core concepts under the proposed paradigm?

HOW are we planning to estimate the value of the proposed paradigm?

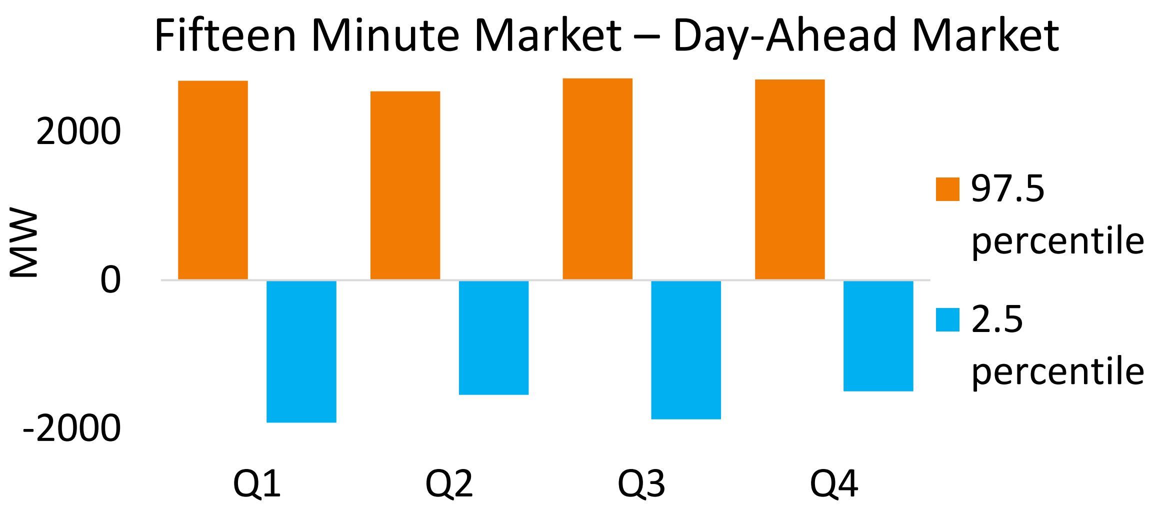
WHY

WHAT

HOW

System operators ***and flexible resources*** must manage challenging imbalances

Net load imbalances at California ISO



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.

- As an example of imbalances, the figure shows net load imbalance between CAISO's fifteen-minute real-time market and the day-ahead market
  - Imbalances in the 97.5% and the 2.5% can exceed 2000 MW
  - This could be equivalent to the loss of a large nuclear unit or the entire load in Sacramento Municipal Utility District

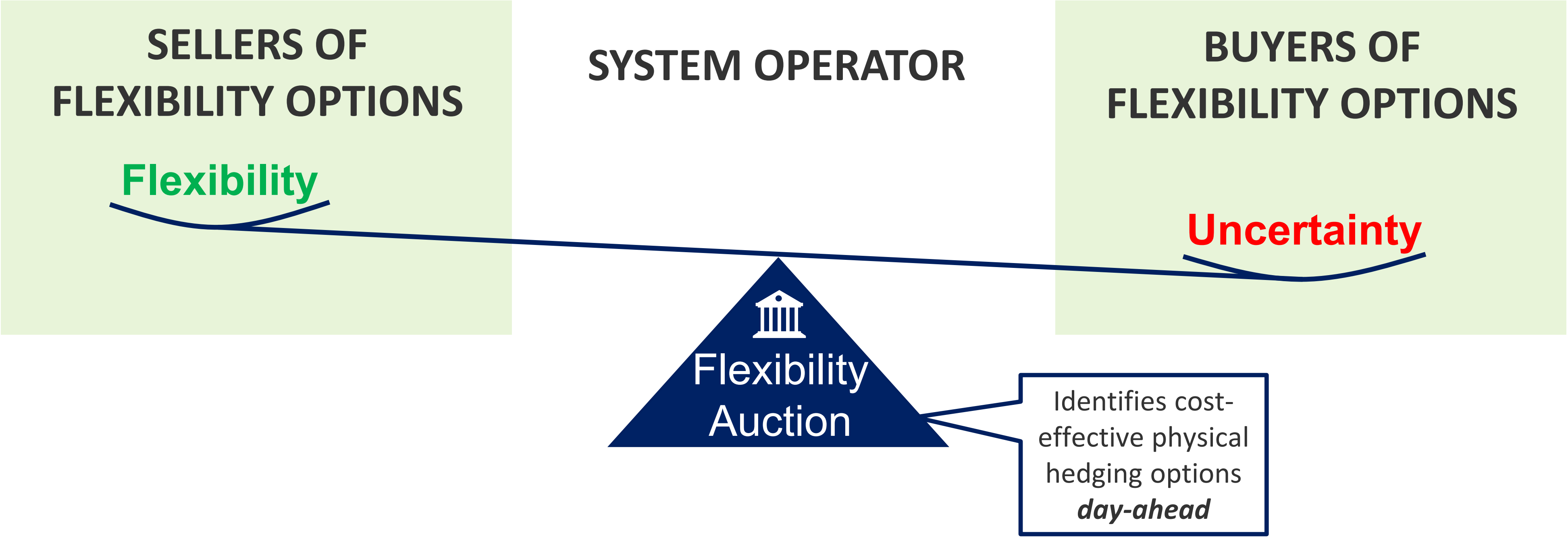
Operational flexibility is needed

Electric generators → **Steeper** supply curves as lead time reduces

Electricity consumers → Usually **overlooked** because of perceived low dependability

- If imbalances are not hedged
  - High prices or possibly load shedding in real-time when not enough flexibility to counter imbalance
  - Over-procurement and increased commitment costs when more flexibility is procured than needed

To manage imbalance risk, we propose a "flexibility auction" run by the system operator composed of sellers who have flexibility and buyers who have uncertain output



WHY — **WHAT** — HOW

SELLERS OF FLEXIBILITY OPTIONS

Flexibility

Power plants

Storage

Electric vehicles

Water heaters

Smart heating/cooling

Distributed Energy Resources Aggregation informed by ***DER scoring***

SYSTEM OPERATOR

Flexibility Auction

Identifies cost-effective physical hedging options ***day-ahead***

BUYERS OF FLEXIBILITY OPTIONS

Uncertainty

Solar plants

Wind plants

Electricity consumption

Probabilistic forecasts

WHY

WHAT

HOW

The operator's perspective

Day-ahead electricity market

Hour-ahead

Minutes-ahead

Real-time operations

Co-optimized

Day-ahead electricity market + Flexibility Auction

Settlements of flexibility options

Inputs

- Need for flexibility and willingness to pay [buyers]
- Cost of flexibility and capabilities [suppliers]

Flexibility Auction Formulation

Operational flexibility conditional on day-ahead schedule

Outputs

- Flexibility option awards
- Flexibility prices

WHY

WHAT

HOW

Formulation

DA obj. function (existing)

Expected cost for flexibility deployment

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

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

Willingness to pay when deficit

Contact Robin (rhytowitz@epri.com) for more information and full formulation

Flexibility supply

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

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

+ramping constraints
+ constraints for fast-start flexibility up and down

Flexibility demand $(3\cdot N_i\cdot N_s\cdot N_T$ constraints)

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

Need for flexibility

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

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

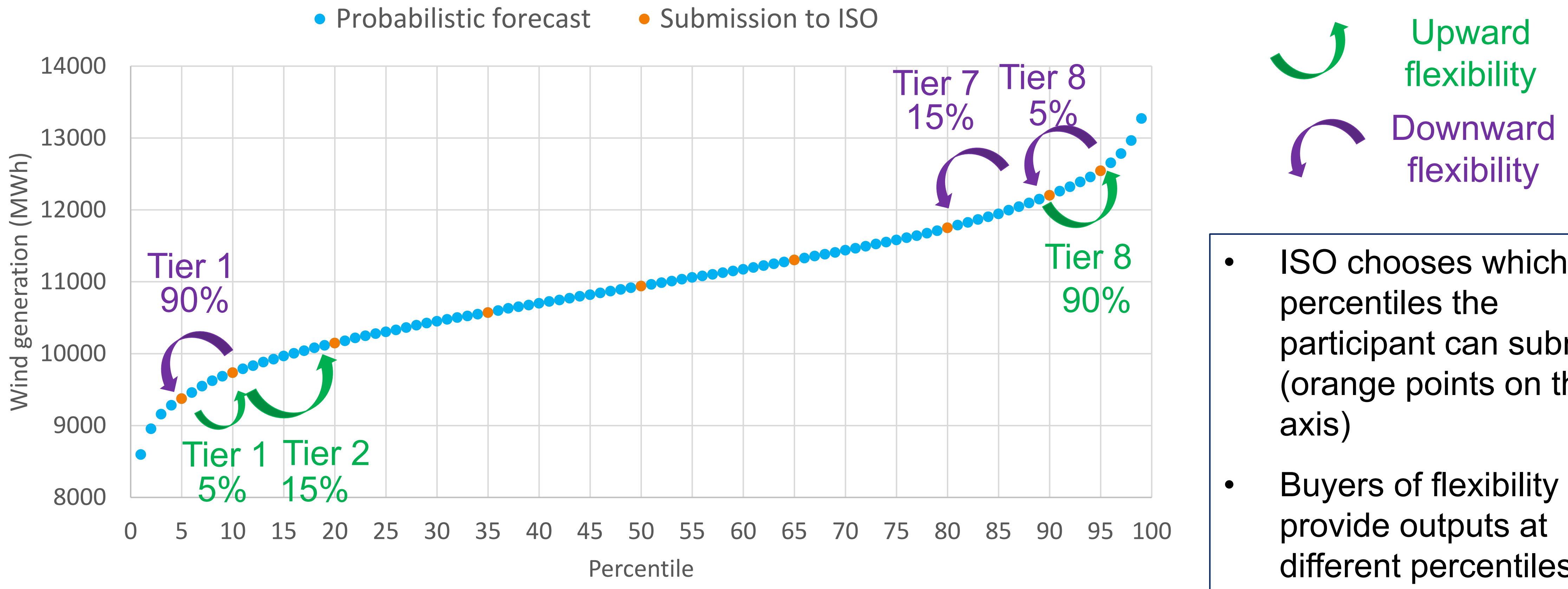
Limit on flexibility contracts

WHY

WHAT

HOW

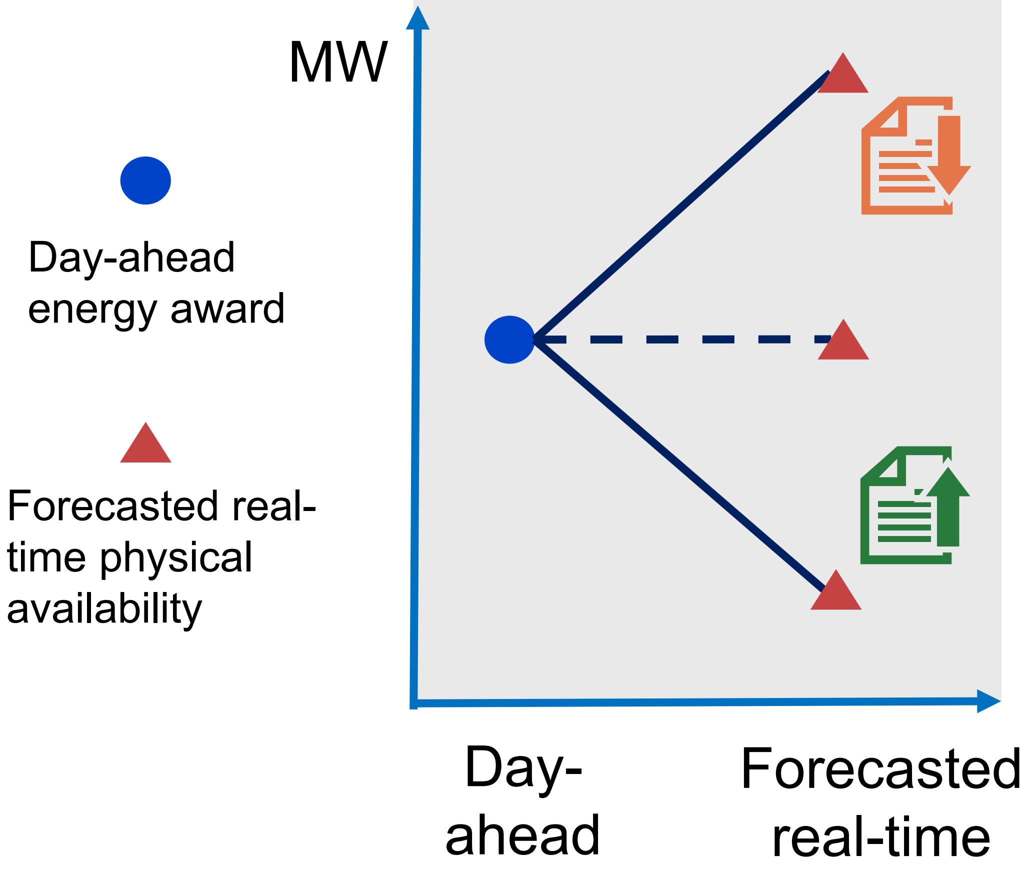
The buyer's perspective: Offers



- ISO chooses which percentiles the participant can submit (orange points on the x-axis)
- Buyers of flexibility provide outputs at different percentiles and willingness to pay.

WHY WHAT HOW

The buyer's perspective: Day-Ahead



Pay for the "downward" option to sell

$$\max(0, \min(\text{Downward option}, \text{RT available} - \text{DA award})$$

At $\max(\text{RT price}, \text{strike price})$

Get paid for day-ahead energy

Pay for the "upward" option to buy

$$\max(0, \min(\text{DA award} - \text{RT available}, \text{Upward option}))$$

At $\min(\text{RT price}, \text{strike price})$

WHY

WHAT

HOW

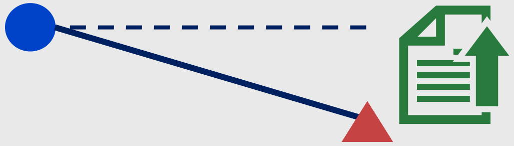
The buyer’s perspective: Real-Time

Day-ahead energy award

Forecasted real-time physical availability

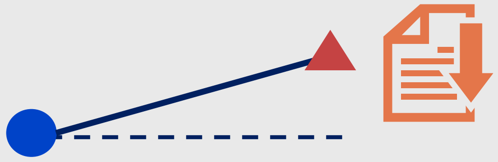
Which option can the buyer exercise?

Negative imbalance



Upward option

Positive imbalance



Downward option

No imbalance

None

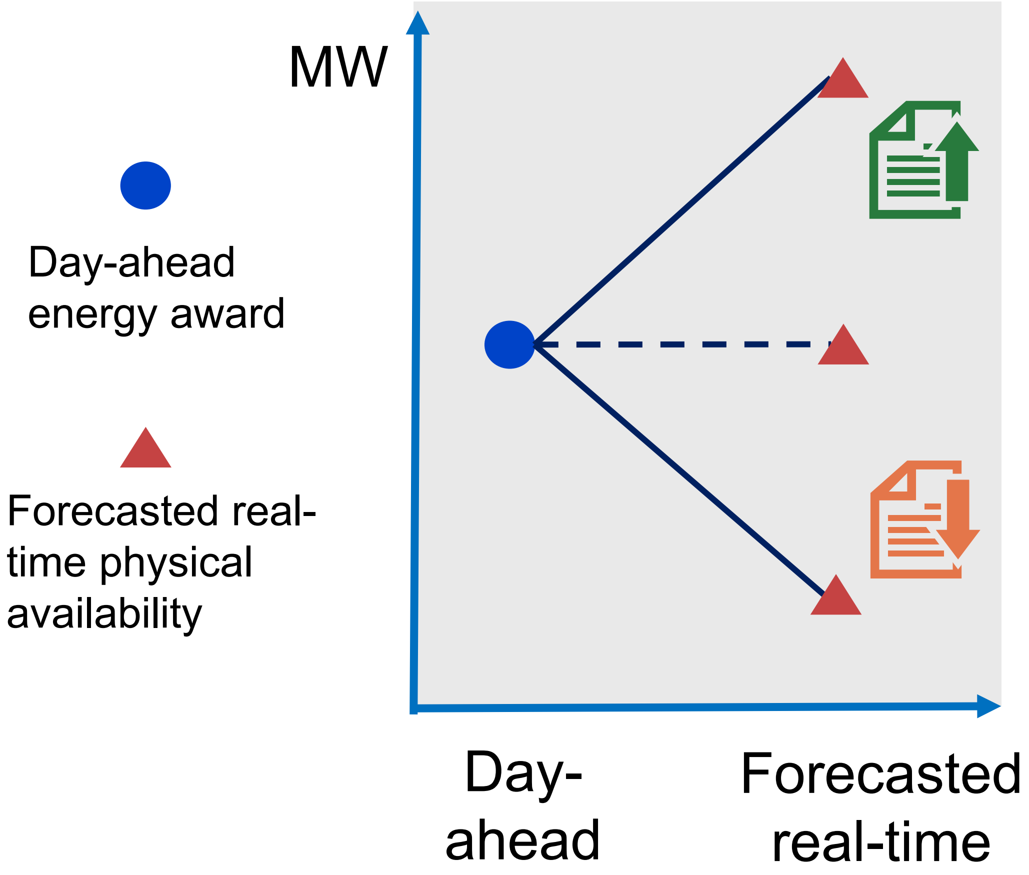
Which price spread the buyer receives?

$\max(0, \text{RT price} - \text{strike price})$

$\max(0, \text{strike price} - \text{RT price})$

N/A

The seller's perspective: Day-Ahead



Get paid the expected real-time foregone profit margin to increase production at *own* strike price

Get paid for day-ahead energy

Get paid the expected real-time foregone profit margin to reduce production at *own* strike price

WHY

WHAT

HOW

The seller’s perspective: Real-Time

Day-ahead energy award

Which suppliers are called?	System-wide negative imbalance	System-wide positive imbalance	No imbalance or imbalance not caused by flexibility buyers
	Upward option	Downward option	None
Supplier pays price spread	$\max(0, \text{RT price} - \text{own strike price})$	$\max(0, \text{own strike price} - \text{RT price})$	N/A

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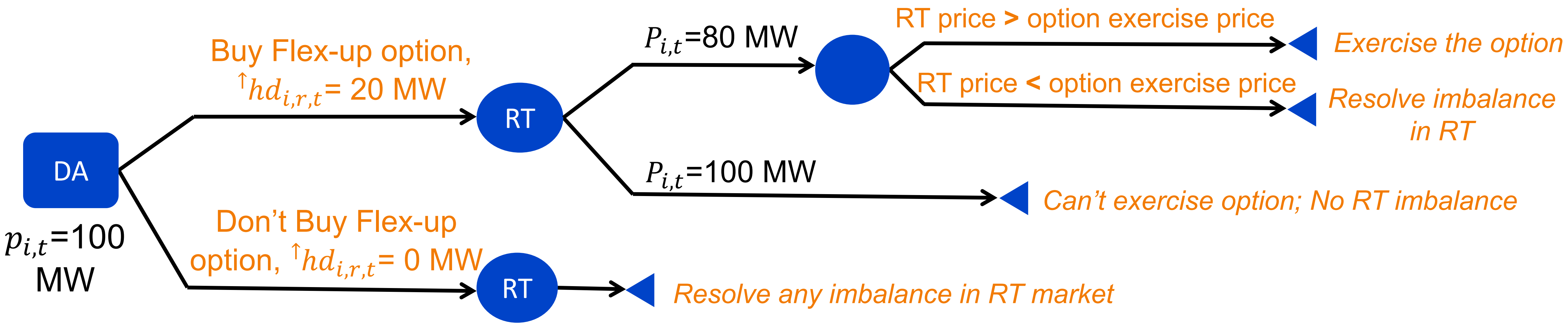
Example for flex-buyer's decision tree: Flex-*up* (case of two scenarios/one tier)

- Two generation scenarios, with equal probabilities 80 MW or 100 MW
- DA clearing results in: $p_{i,t}$=100 MW; $^{\uparrow}hd_{i,r,t}$= 20 MW (Flex-up option)
- Decision tree representation: decision node DA; chance node RT; RT outcome



How does the Flexibility Auction compare to:

Flexible ramping product

(CAISO, MISO, proposed elsewhere)

- Does not consider day-ahead to real-time uncertainty

Attempts to price flexibility

Virtual bidding

(All ISOs/RTOs)

- Does not provide physical hedge

Day-ahead to real-time hedging

Imbalance reserve product

(CAISO, proposed)

- Cost allocation under discussion
- Requirement set by ISO

Explicitly considers net load uncertainty between day-ahead and real-time

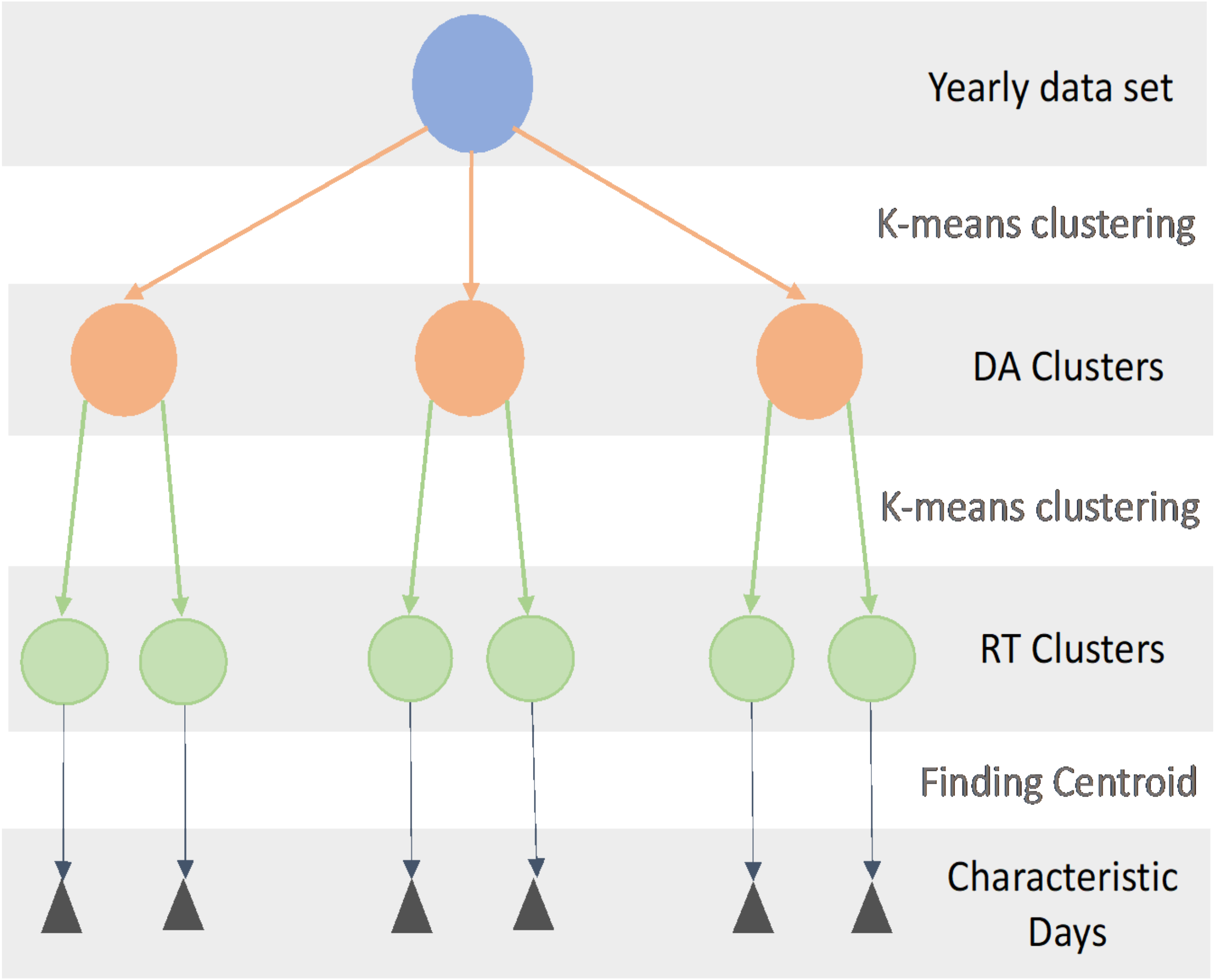
Flexibility auction

- Buyers of flexibility options determine flexibility needs through submission of probabilistic forecasts
- Costs for additional flexibility incurred by only those who buy options
- Sellers receive upfront payments

Experimental Simulation Setup

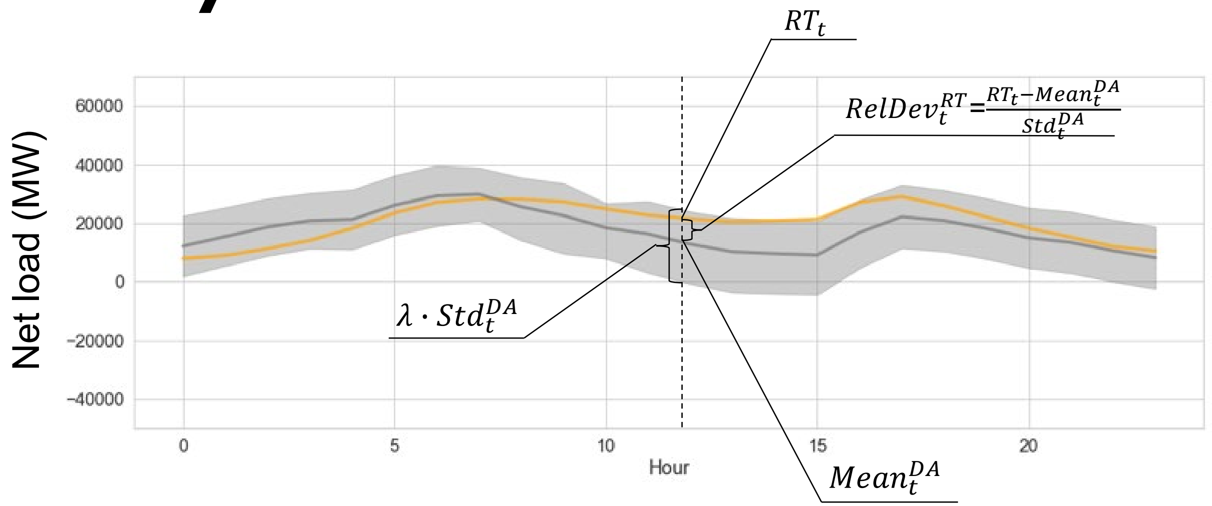
- Simulations using market modeling tool FESTIV (see next slide)
  - Synthetic network of ERCOT (7k buses) provided by PERFORM Data Teams: Texas A&M and U. Wisconsin Madison
    - https://electricgrids.engr.tamu.edu/electric-grid-test-cases/datasets-for-arpa-e-perform-program/
  - Generator data based on EIA and ERCOT published data (700+ generators) provided by PERFORM Data Teams above with additional verification from project team
  - Renewable and load forecasts and actuals provided by NREL data team
    - For the first year of the project, characteristic days are chosen
    - https://github.com/PERFORM-Forecasts/documentation

Characteristic Day Selection Methodology



- Two-step procedure:
  - DA-clustering concerns the procurement of flexibility options day ahead. It purely relies on features associated with the day-ahead probabilistic forecast.
  - RT clustering concerns the activation of flexibility options in real-time. It relies on features capturing the relative position of real-time realization with respect to the day-ahead probabilistic forecast.
- K-means clustering:
  - In both steps, K-means clustering is performed where the features selected in each step are standardized by removing the mean and scaling based on the maximum value the features take over the entire year.
- Locating characteristic days:
  - Characteristic days are selected by identifying days closest to the cluster centroid of each cluster.

Characteristic Day Feature Selection



Key time series relevant to the PERFROM DA probabilistic forecast & RT realization dataset

Set of characteristic days needed because simulations are computationally expensive

- First year of the project: six days chosen using criteria of previous slides and also shown here (right)
- Coming years: thirty-six and seventy-two days using additional criteria

DA features

$$Mean_{ave}^{DA} = \frac{\sum_{t=1}^{24} Mean_t^{DA}}{24}$$

Expectation of the energy demand

$$Std_{ave}^{DA} = \frac{\sum_{t=1}^{24} Std_t^{DA}}{24}$$

Proxy for the expectation of the flexibility needs

RT features

$$RelDev_{ave}^{RT} = \frac{\sum_{t=1}^{24} RelDev_t^{RT}}{24}$$

Averaged deviation

$$RelDev_{std}^{RT} = \sqrt[2]{\frac{\sum_{t=1}^{24} (RelDev_t^{RT} - RelDev_{ave}^{RT})^2}{24}}$$

Intra-day variation of the deviations

$$(RelDev_t^{RT} = \frac{RT_t - Mean_t^{DA}}{Std_t^{DA}})$$

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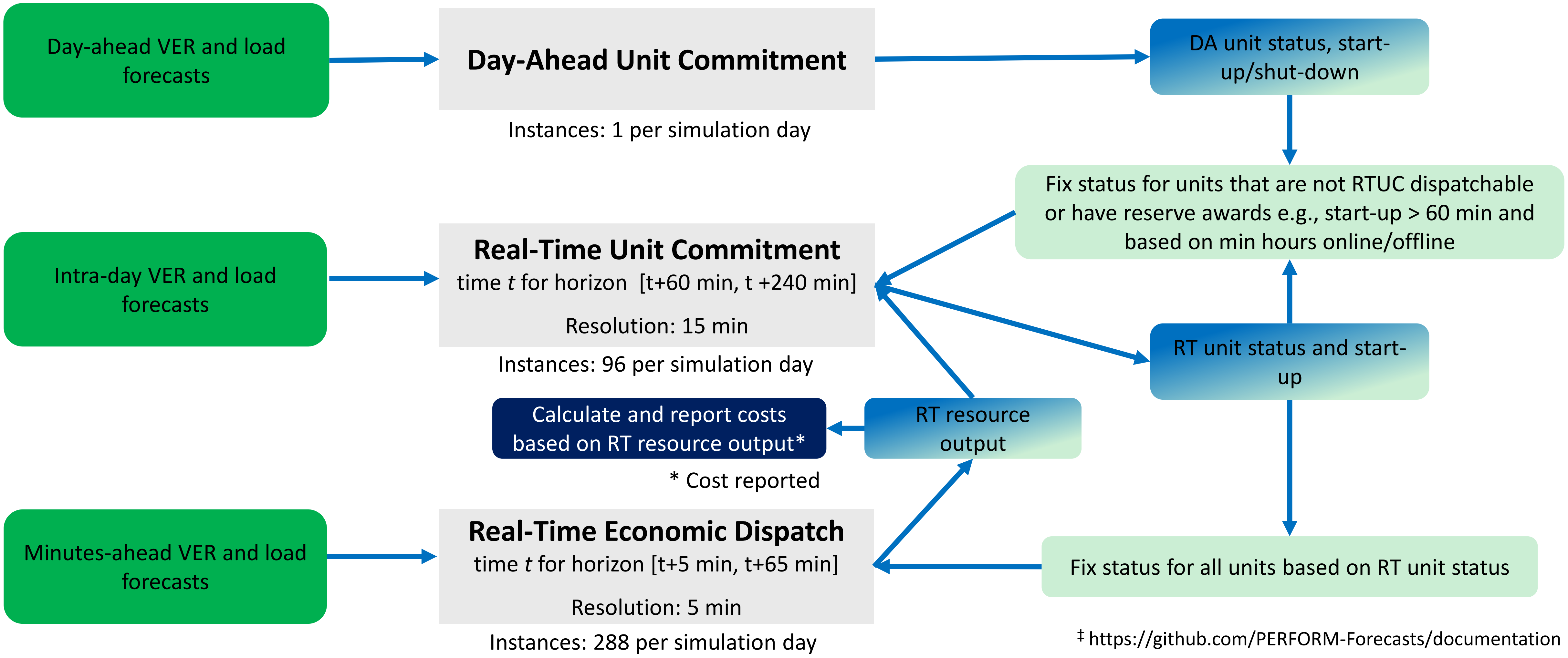
FESTIV flow diagram

HOW

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

Input Data ‡
GAMS optimization modules
Reported metrics
GAMS Outputs/Subsequent Inputs
MATLAB routines for rules



‡ https://github.com/PERFORM-Forecasts/documentation

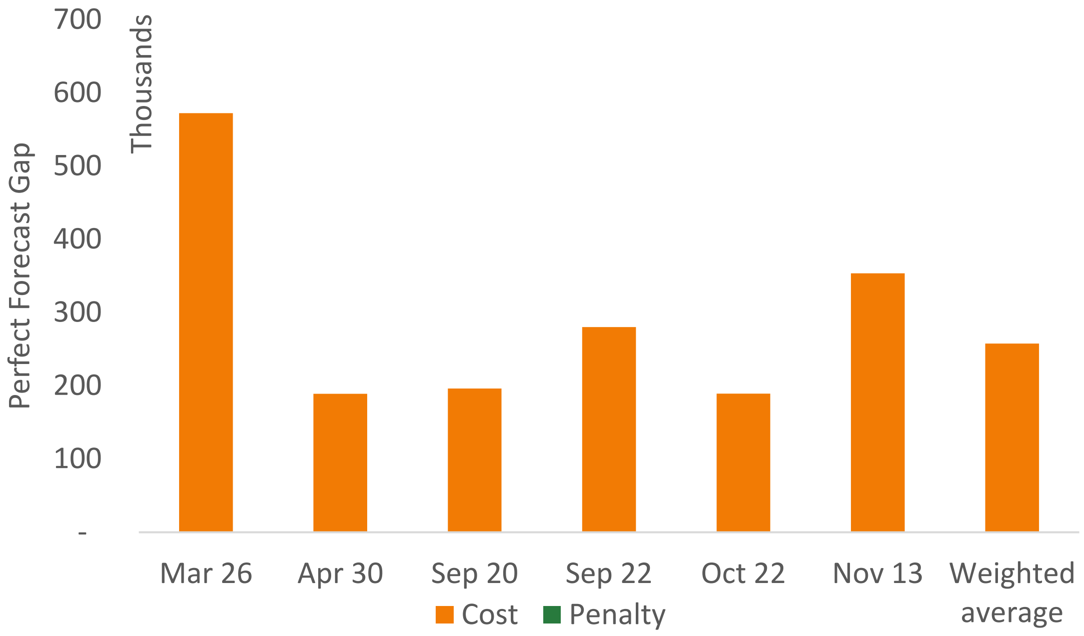
WHY

WHAT

HOW

- **Flexibility Auction compared against other cases / counterfactuals**
  - Perfect forecast
  - Imperfect forecast (current business as usual)
  - Additional reserve product (CAISO's imbalance reserve proposal)
- **Comparison of prefect forecast case and imperfect forecast case showed**
  - Perfect forecast gap is 1.03%
  - Low gap possible due to increased flexibility for input data
  - No load shedding

Preliminary Results



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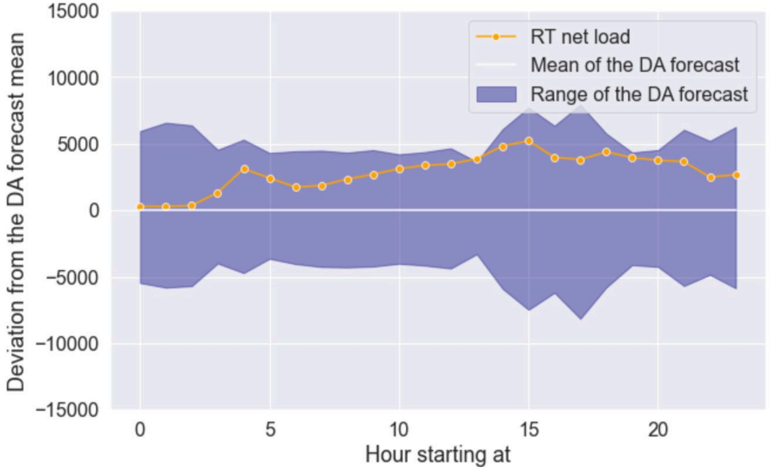
WHY WHAT **HOW**

- **Simulation results are initial, intended to show proof of modeling implementation**
  - Generator data is being updated
  - Refinement and expansion of choice of characteristic days
- **Initial Flexibility Auction results show:**
  - Days with wide sustained forecast error are more challenging
  - The further the realization from the median in the upward direction, the higher the benefits from the FA
  - Down direction leads to additional questions, e.g., should unit decommitment count towards flexibility down?

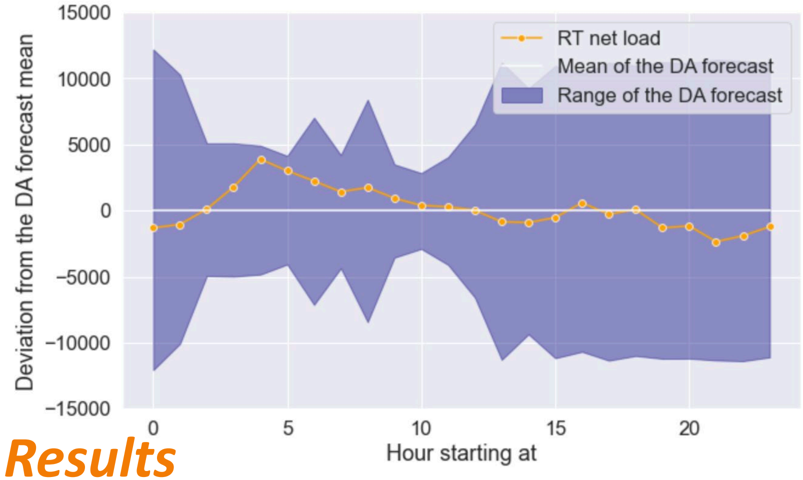
2018-03-26

RT Operating Costs for BAU case are **higher** than FA



2018-10-22

RT Operating Costs for BAU case are **lower** than FA



Preliminary Results

Next steps

- Project completed the first of three years
- Inclusion of further updated and realistic data
- Continued refinement of formulation and design
  - Discussion of aggregation procedures & risk diversification
  - Incentive compatibility and market power mitigation
  - RT commitment costs of flexible units

Please feel free to reach out with feedback or to get involved!

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