ESR Participation Model

An Optimization Approach for Day-Ahead Cost Offers

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Executive Summary

Purpose of the Presentation	Provide an overview of a potential optimization-based methodology for determining cost offers for ESRs in the day-ahead market
Background and Rationale	• The design mechanisms need to balance providing flexibility to ESR market participants to accurately represent the costs and risk preferences while preventing exercise of market power via physical or economic withholding • For efficient and reliable dispatch of ESRs, it is essential to consider the forward opportunity costs in cost-based offers • Over-mitigation of energy storage resources comes at real reliability and monetary cost as it can lead to pre-mature dispatch, which leaves ESRs unavailable during times of tight system conditions
Key Takeaway	PJM is exploring the option of using the output of the unit commitment run in which opportunity costs are endogenously determined through co-optimization over a 24-hour horizon and including these costs in the cost-based offers to be used in the dispatch and pricing run

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Why Do We Need to Account for Opportunity Cost?

- **Opportunity cost is a real cost for energy limited resources.**
  - **Limited State of Charge:** ESRs have SOC limits; actions that deplete SOC in one interval make it unavailable in a later interval.
  - **Short-Run Decisions vs. Long-Run Optimal Dispatch:** PJM's economic dispatch optimizes over the short run (on an hourly basis sequentially in DA and on a 5-minute basis in RT). Energy-limited ESRs will not be dispatched optimally over the long run unless they are allowed to reflect the opportunity cost of their short run actions in their offers.
- **Opportunity cost cannot be reflected today.**
  - When running economically, an ESR can manage its anticipated opportunity cost using the price offer. However, because its cost offer cannot include opportunity cost today[1], the ESR loses the ability to optimally manage SOC when it is mitigated and placed on its cost offer.

This is both a reliability and a market efficiency issue.

If PJM is relying on a large battery fleet for resource adequacy, cost offers that do not recognize opportunity cost may result in misalignment between myopic market-based ESR dispatch and the reliability needs of the grid, leaving the RTO with fewer MWh in tight system/market conditions.

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Day-Ahead Cost Offer: Existing Solution Option

- PJM had proposed a **uniform cost offer cap of $1,000/MWh in the Day-Ahead Market**, corresponding to the price-based soft offer cap.[1]
  - This proposal goes hand-in-hand with the proposed energy must offer requirement, which seeks to prevent physical withholding by requiring ESRs to offer their full operating range across all hours of the day.
  - Because of the strict energy must offer requirement, PJM believes that it is sensible to grant ESRs the flexibility to bid competitively across the full range of expected opportunity costs.
  - Finally, such a cap could fully realize the reliability and market efficiency benefits of ESRs.
- PJM acknowledges that the proposal has raised concerns around market power.
  - Although PJM believes that market power concerns are minimized due to virtual activity, as well as the use-limited nature of this resource, discussion of an alternate approach is warranted.

1. https://www.pjm.com/-/media/DotCom/committees-groups/committees/mic/2026/20260909/20260909-item-08-1---pjm-energy-storage-resource-model-enhancements---esr-cost-offer---presentation.pdf

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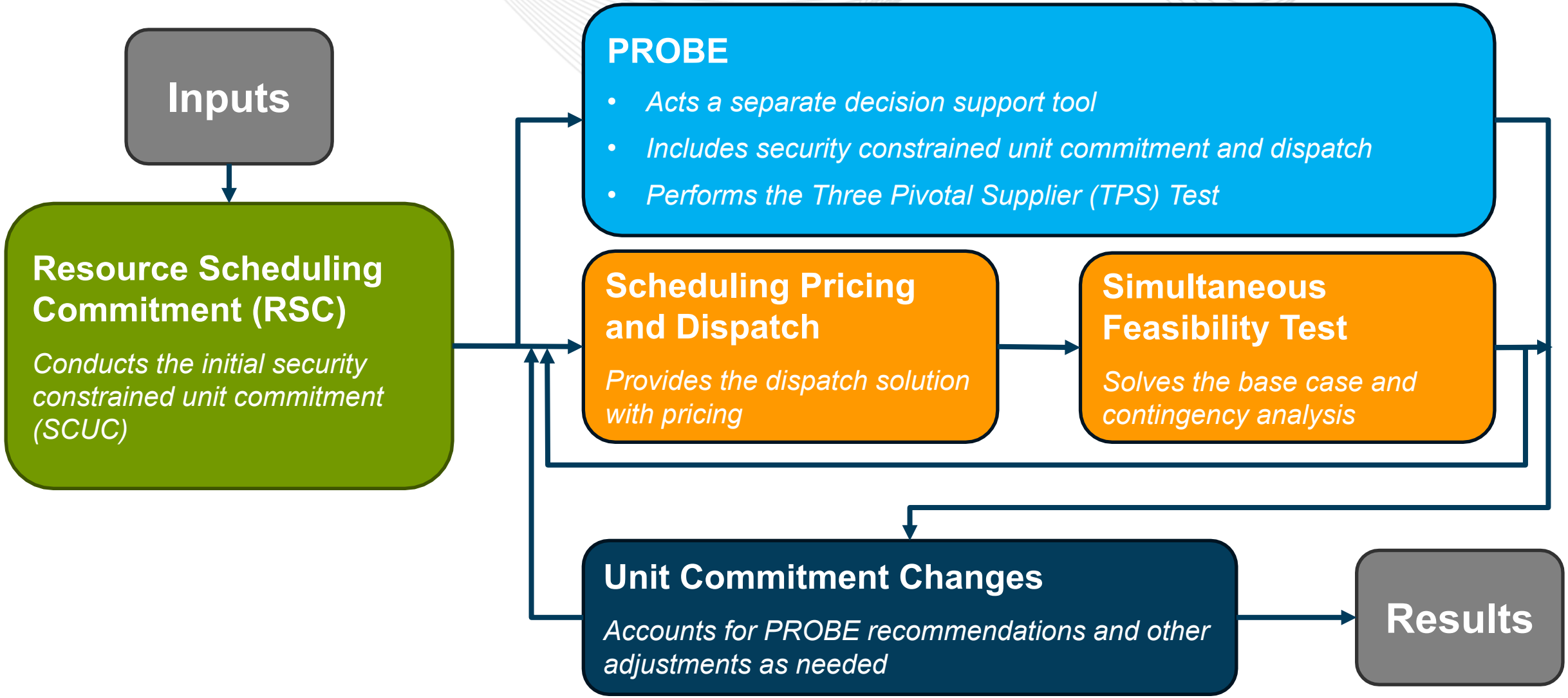
Day-Ahead Market Flow: Background



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24-Hour Optimization in the DA SCUC

- PJM performs a 24-hour optimization in the Day-ahead Security Constrained Unit Commitment (DA SCUC) to make optimal commitment decisions.
- Once state of charge tracking is implemented in the day-ahead market, the DA SCUC will use a state of charge constraint that ensures energy-limited resources are used in the hours in which their energy provides the most value to the system.
- How energy-limited resources are used then informs the commitment of other resources.

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The Alternate Approach

- PJM is considering an approach that would leverage data from DA Security Constrained Unit Commitment as a proxy for opportunity-cost-based offers for mitigated energy storage resources.
- Because the day-ahead commitment engine does a time-coupled optimization, the marginal value of a MWh of a resource's state of charge can be extracted from the optimization.
- Under this approach, if an energy storage resource is mitigated, it's price-based offer would be replaced with an endogenously calculated opportunity-cost-based offer and then that offer would be fed into the day-ahead Scheduling Pricing and Dispatch engine.

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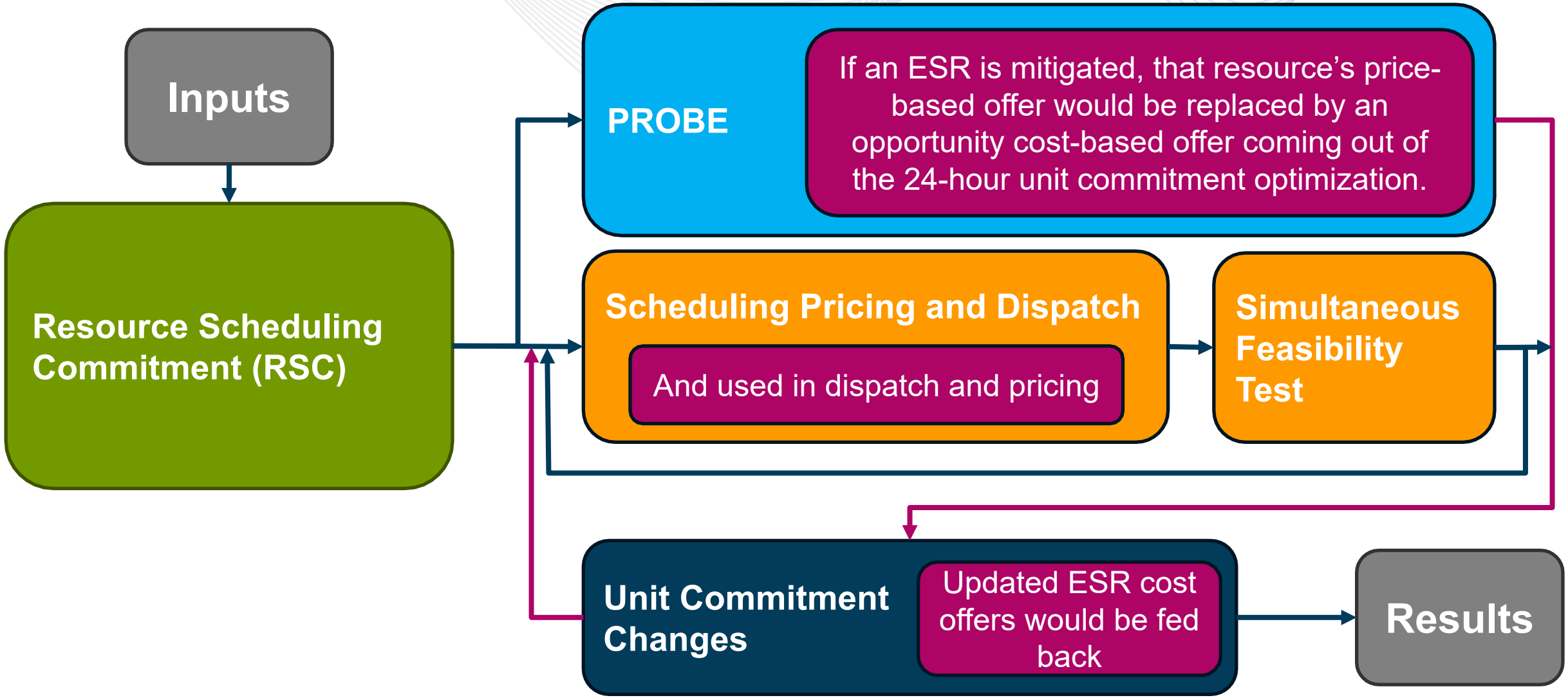
Day-Ahead Market Flow w/ the DA SCUC Opp Cost Approach



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Potential Advantages of the Approach

- By endogenously calculating the opportunity cost as part of the unit commitment process, the representation of opportunity cost would be specific to the day in question.
- It would alleviate market power concerns that might stem from a uniform cost offer cap.
- It would also mitigate the exercise of market power in both uneconomically high offers, which might seek to increase prices, and uneconomically lower offers, which might seek to force premature dispatch of energy storage resources, thus increasing prices during peak times.

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Potential Challenges/Limitations to the Approach

- The day-ahead market is deterministic, which could lead to an under-representation of a marginal megawatt-hour of state of charge.
- Implementation of this approach would require more extensive software changes than the other approaches discussed for representing opportunity costs in cost-based offers.
- If implementation is expected to take an extended period, a stop gap approach would likely be required in the interim.

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Using Opportunity Costs From DA Commitment Run for Cost Offers in DA Dispatch & Pricing Runs

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Components of Day-Ahead Opportunity Costs for ESRs

Temporal Opportunity Cost for Energy	• Cost of forgone future revenue due to energy dispatch actions that impact energy SOC constraints in the given hour
Opportunity Cost of Price Uncertainty	• Expected cost of forgone revenue associated with price uncertainties due to day-ahead energy dispatch that impacts SOC in the given hour • ESRs have a relatively higher risk associated with price uncertainties due to the need to replenish their SOC
Energy Cost Offer	• In DA, PJM co-optimizes unit commitment over a 24-hour horizon while it solves the dispatch and pricing runs on a sequential, hourly basis • Consequently, the temporal opportunity cost is endogenous to the optimization in the unit commitment run • However, in the dispatch and pricing runs, it needs to be included as an exogenous offer

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Representing Day-Ahead Opportunity Costs

ESR Opportunity Cost in DA unit commitment

- The temporal opportunity costs are ***endogenously*** determined in the unit commitment run due to co-optimization over a 24-hour horizon
- The temporal opportunity cost for each hour is the ***shadow price of the optimization constraint representing the SOC dynamics for that hour*** representing
  - Marginal value of a MWh of future SOC trajectory
  - Sensitivity of the optimal value function to SOC perturbations

Representing Opportunity Cost in the Dispatch & Pricing Cost Offers

- Since the DA Dispatch and Pricing runs are solved sequentially for each hour rather than being co-optimized across a 24-hour horizon, the opportunity costs determined endogenously from the DA unit commitment run, weighted by ESR efficiency, would be included as ***exogenous*** terms in the energy cost offers used the Dispatch & Pricing runs

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“Switch to Cost” Option for Non-Mitigated ESR

- PJM allows generation resources an option to “switch to cost schedule” which remains in effect till end of operating day [Manual 11, Section 2.3.3.2].
- Given the proposed optimization-based opportunity cost determination process in day-ahead, non-mitigated ESRs have the option to “switch to cost” in day-ahead. Opting in would imply that opportunity costs from the unit commitment run are included in the cost offer for dispatch and pricing runs, same as for mitigated ESRs.
- If an ESR chooses to “switch to cost” in DA, existing intra-day offer update rules would require that it update that offer based on the max DA LMP opportunity cost cap for the real-time market.
- Non-mitigated ESRs choosing not to “switch to cost schedule” would remain on their price-based offers.

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Ten Percent “Uncertainty” Adder for ESRs in Day-Ahead

- Generation resources are allowed to include a Ten Percent Adder to cost offers as per the rules in Manual 15, Section 2.9
- Given the proposed optimization-based opportunity cost determination process in day-ahead, PJM is exploring avenues on whether a Ten Percent Adder can be represented in the day-ahead cost offer
- One option is to calculate the Ten Percent Adder based on the endogenously determined opportunity costs from the day-ahead unit commitment run, and modify the offer curve from the ESR on the cost schedule based on this Ten Percent Adder cap. This cost would be additive to the exogeneous opportunity costs to be used in the cost offer for the Dispatch & Pricing runs.
- The exact process would need to be defined, but would potentially be similar to the modifications of the ESR offer curves made by California ISO based on the “default energy bid”

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Summary

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Representation of forward opportunity costs in cost-based offers is essential for efficient and reliable dispatch of ESRs	Utilize ***endogenously*** determined Opportunity Costs from co-optimization over a 24-hour horizon in Day-Ahead Unit Commitment to set Cost Offers in Day-Ahead Dispatch & Pricing Runs	Energy Cost Offer in the Dispatch & Pricing Runs should capture the opportunity cost of hourly energy SOC change. These opportunity costs are ***exogenous*** terms in the cost offers for these runs

Design Goal: balance risk preferences of market participants including accurate representation of opportunity costs with must offer obligations and market power mitigation

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ESR Model Enhancements



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