ESR Participation Model: Opportunity Cost in Cost Offer

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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 a reliability issue.

If PJM is relying on a large battery fleet for resource adequacy, cost offers that do not recognize opportunity cost may result in premature dispatch of this resource, leaving the RTO with fewer MW in tight system conditions.

1. See Operating Agreement, Schedule 2

Principles for Opportunity Cost Methodology

- Opportunity cost is based on an expectation of future prices, which can be estimated but not definitively known
- Because these future prices need to be estimated, a methodology is necessary to accomplish this.
- PJM identified a set of **design principles** to guide the methodology's development.

Design Principles

1. **Align ESR Dispatch with System Reliability:** Methodology prevents premature dispatch under most emergency system conditions (tested against emergency conditions such as WSF, early July 2026 heatwave, etc.)
2. **Support Accurate Price Formation:** Methodology addresses the interplay between incremental energy costs (charging costs/any VOM adders), intertemporal opportunity cost, and LMPs
3. **Strive for Simplicity:** Methodology is simple, transparent and replicable
4. **Establish an Upper Bound on Opportunity Cost:** Methodology recognizes that it will serve as a cap; actual cost offers may and will likely be below it

Where should the opportunity cost be defined?

- The methodology for calculating the opportunity cost may be left to the Fuel Cost Policy (FCP), or a default methodology may be included in Manual 15.
- In the interest of transparency, and to lay the foundation for how opportunity cost may be considered in the FCP if an alternate is desired, PJM prefers to develop a common methodology and explicitly include this methodology in Manual 15 as the “default” for participants in the ESR model.
- As today, resources would be able to propose alternate methodologies in collaboration with PJM and the IMM.

Day-Ahead Cost Offer

Day-Ahead Cost Offer Cap	A uniform cap of $1,000/MWh corresponding to the price-based soft offer cap may be reasonable to fully realize the reliability and market efficiency benefits of ESRs.
Key Considerations	• **Companion to changes to ESR Must Offer:** To prevent physical withholding, ESRs with a capacity commitment would be required to offer their full operating range across all hours of the day. • **Improved Price Formation Aligned with System Needs:** Granting flexibility to ESRs to bid competitively across the full range of expected opportunity costs improves price formation. • **Addressing Market Power:** ESRs are fundamentally different than other resources because they are energy-limited. An uneconomic dispatch of this resource can cause an increase in market prices during the peak—an outcome that market power mitigation seeks to avoid. PJM recognizes the need to ensure that these resources bid their full capability to prevent the exercise of market power through physical withholding and therefore needs to provide them the flexibility to manage their discharge through economic offers. Virtual participation further reduces any exercise of market power via price convergence, provided there are mitigation mechanisms in the real-time market. • **Value of Arbitrage:** As ESRs need to both discharge and charge, they have a higher risk exposure than baseload gen (i.e., they are more akin to virtuals). Their ability to arbitrage increases liquidity and efficiency and supports accurate price formation. As ESRs can act in RT, they have lower risk exposure compared to virtuals. Therefore, the ESR cost offer cap is appropriately lower than $2,000/MWh.

Alternative Approaches to Day Ahead Cost Offer

- Alternative approaches may be reasonable but have drawbacks.
  - Using historic LMPs as is done by several other ISOs/RTOs (e.g., average of the max DA LMP over the prior X days) as a proxy for the DA opportunity cost may be insufficient because prices on the days when the system would most benefit from optimal use of battery storage – under tight system conditions – are likely to be much higher than the values obtained by averaging prices over some set number of prior days.
  - Using the LMPs that come from the market power run, as is done by CAISO, results in cost offers that are based on non-public price data (as PJM does not publish prices from its DA unit commitment run).
  - It may be possible to develop a statistical model for predicting LMPs, but this would add significant complexity and reduce transparency and replicability.

Real Time Cost Offer

- The RT cost offer cap calculated as the maximum of the battery's incremental energy cost and its opportunity cost, capped at $2,000.

Cost Offer Cap = Max(Incremental Energy Cost, Opportunity Cost), capped at $2,000

Incremental Energy Cost	Opportunity Cost
Charging Cost + VOM Adder *where:* Charging Cost = Average of N* lowest DA LMPs at applicable pnode/ Efficiency Factor	Maximum DA LMP at applicable pnode, capped at $2,000

* N = battery duration

Real Time Cost Offer – Incremental Energy Cost

Incremental Energy Cost

Charging Cost + VOM Adder

where:

Charging Cost = Average of N lowest DA LMPs at applicable pnode/Efficiency Factor

- The components of the incremental energy cost would remain the same as today: 1) charging cost and 2) Variable Operation and Maintenance (VOM) Adder.
- Today, however, charging cost is not explicitly defined.
  - Per Manual 15 charging cost = average charge cost/efficiency factor. The "average charge cost" methodology is determined separately by the Market Participant in the Fuel Cost Policy.
- PJM could introduce an explicit default charging cost calculation.
  - One option: average of the N lowest DA LMPs at the applicable pnode, where N is the battery's duration, divided by roundtrip efficiency.
  - This calculation assumes that the battery will charge during the lowest-priced intervals.
  - The use of DA LMPs aligns the input data used to determine the charging costs with that used to calculate opportunity cost.
- VOM Adder will continue to be defined as today.

Real Time Cost Offer – Incremental Energy Cost

- An alternative method to calculating charging cost could employ an inventory approach, one that considers actual LMPs at the applicable pnode, in intervals when the ESR was charging, over a pre-defined lookback period. (This is similar to the method defined in Manual 15 for pumped storage.)
  - This would introduce differences between the input data and lookback periods used to calculate the different components of the cost offer, making comparison—or taking the maximum value—difficult.

Real Time Cost Offer – Opportunity Cost

Opportunity Cost
Maximum DA LMP at applicable pnode, capped at $2,000

- DA LMPs are a good proxy for RT prices, and their use strikes the right balance between simplicity and accuracy.
- The use of the max DA LMP is sensible because the calculation serves as a cap on the cost-based offer, rather than a default value inserted by the RTO. Market participants may submit values that are below this cap.
  - Because batteries derive revenue from energy arbitrage, they have an incentive to submit lower cost-based offers if necessary to clear during the highest-priced hours.
- Meanwhile, reliance on the max DA LMP as the opportunity cost offers sufficient protection from premature RT dispatch and protects PJM from entering tight operating conditions with a depleted battery fleet

Real Time Cost Offer – Opportunity Cost

- PJM considered several alternatives to the use of the max DA LMP:
  1. Nth highest DA LMP at the applicable pnode, where N is the battery duration
     - This is akin to the approach used by CAISO and attempts to ensure that the battery captures the highest priced hours corresponding to its duration
     - Makes sense in a market design where the bid is inserted as the default value (CAISO), but perhaps not where the cost offer serves as a cap (PJM)
     - This approach led to suboptimal dispatch in PJM's analysis of discharge under emergency system conditions, especially without a multiplier to account for deviations between RT and DA LMP
  2. Average of N highest DA LMP at the applicable pnode, where N is the battery duration
     - This approach also led to suboptimal dispatch in PJM's analysis of discharge under emergency system conditions, especially without a multiplier to account for deviations between RT and DA LMP; however, performance was better than alternative #1
     - In some instances, the max DA LMP and the average approach leads to similar values, limiting the usefulness of the average approach.

Real Time Offer – Opportunity Cost

- Because RT prices may deviate from DA prices, an opportunity cost adjustments may be warranted.
- The following adjustments may be reasonable to prevent premature dispatch:
  - **Multiplier:** A multiplier on the opportunity cost that reflects deviations between RT and DA LMPs under tight system conditions. A multiplier may be more justified if a value other than the max DA LMP is used to set the opportunity cost.
  - **Emergency Conditions Trigger:** Opportunity cost may be permitted to go higher, up to $2,000 under specific emergency conditions (e.g., at least an EEA1/Max Gen Alert)
  - **RT Price Trigger:** Opportunity cost may be adjusted in RT if prices are sufficiently higher than the max DA price.
- Specific conditions and adjustment rules would need to be developed if any of the above are to be adopted.
- Interplay between any new adjustment and the existing limited 10% cost offer adder.

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