Incorporating Electric Storage Resources into Wholesale Electricity Markets While Considering State of Charge Management Options

2019 Grid of the Future Symposium

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Outline

- FERC Order 841:
  - Electric Storage Resource (ESR) participation in ISO/RTO markets
  - ISO/RTO ESR market design proposals and implementations
- State of charge management
- Next steps

FERC Order 841: Summary

- ISOs must include a **participation model** for electric storage resources (ESRs) that allows them to participate in energy, ancillary service, and capacity markets when technically capable of doing so
- ESRs must be eligible to **set the wholesale price** as both a buyer and seller when the marginal resource
- ISOs must **account for physical parameters** of ESRs through bidding or otherwise
- ISOs must allow a minimum size requirement that is at most **100 kW**
- Sale of energy that is stored from purchases in the wholesale market must be **sold at wholesale nodal prices**
- ISOs must allow **self-management** of state of charge (SOC)

[1] *Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators, FERC Order 841, Final Rule, 162 FERC 61, 127 (February 15, 2018) ("Order No. 841").*

ISO/RTO Implementation Details

841 Aspect	NYISO	PJM	SPP	ISO-NE	MISO	CAISO
Participation Model	1. Most entities are proposing two separate participation models: Continuous (e.g., batteries) and discontinuous (e.g., PSH) models 2. Can participate in energy, AS, and capacity markets (wherever applicable)					
	ESRs and **ELRs**; PSH cannot submit a charge and discharge offer in the same hour	**ESRs;** PSH plants can still use **pumped hydro optimizer**	**MSRs**; PSH plants cannot submit a charge and discharge offer in the same hour	**CSFs** and **BSFs**	**ESRs**	**NGRs** and **PSH model**
Offer Parameters	1. Almost all entities are proposing a continuous model for ESRs (continuous offer curve, excludes commitment related parameters, e.g., min and max charge and discharge/run times, fixed costs)					
	ESRs must submit SOC (RT telemetry) and roundtrip efficiency; excludes max and min charge and run times	ESRs must submit RT SOC telemetry for **situational awareness**; excludes max and min charge and run times	MSRs must submit SOC (DA offer/RT telemetry), loss factor and SOC limits; introduced max and min charge and run times	ESFs must submit two new telemetry points in RT; min charge and run times required in DAM & RTM	Must submit SOC (DA offer/RT telemetry), efficiency factor and SOC limits; max and min charge and run times managed by ESR owner	ISO manages SOC if SOC limits submitted; min charge and run times for NGRs to be managed by SOC parameters or offers
Pricing and Settlement	1. All entities are allowing ESRs to: set wholesale prices in all markets when marginal, purchase/sell at wholesale prices, and receive make-whole payments if dispatched out-of-market 2. Almost all entities are proposing that withdrawals from ESRs will not be subject to transmission charges when charging to provide a specific service to the ISO/RTO (including withdrawals for later injection of energy)					
	Self-committed fixed or flexible ESRs ineligible to receive DA BPCG, self-committed flexible eligible for RT BPCG; ISO-SOCM ESRs ineligible for RT BPCG; withdrawals exempt from transmission charges	PSH using hydro optimizer cannot set wholesale prices and offer negative dispatchable range		Limited duration CSFs will not be paid an opportunity cost payment when dispatched below 15 minute available energy to provide reserve	Transmission charges to ESRs applicable when charging to resell energy at a later time (only regulation exempted)	NGRs not charged transmission charges when charging to resell energy later

AS: Ancillary Service; **BPCG**: Bid Production Cost Guarantee; **BSF**: Binary Storage Facility; **CSF**: Continuous Storage Facility; **DAM**: Day-ahead Market; **ELR**: Energy Limited Resource; **ESF**: Energy Storage Facility; **ESR**: Electric Storage Resource; **MSR**: Market Storage Resource; **NGR**: Non-Generator Resource; **PSH**: Pumped Storage Hydro; **RTM**: Real-time Market; **SOC**: State of Charge

ISO/RTO Implementation Details

841 Aspect	NYISO	PJM	SPP	ISO-NE	MISO	CAISO
Ancillary Services	1. All ISOs are allowing ESRs to provide AS (without requiring energy schedules) provided ESRs respect AS duration requirements while allowing for capacity de-rates to meet the duration					
	1-hour duration; AS schedules will respect RT telemetered SOC regardless of SOCM mode	ESRs providing synchronized reserve must update SOC in RT; ESRs can offer synchronized reserve without energy offers	1-hour duration; MSRs can provide AS without energy schedule but require energy offers	BSFs cannot provide regulation as DARD until 2024; automatic de-rating for CSFs to meet duration requirements (1-hour AS duration, 0.25-hour duration for DARD AS); limited duration CSFs can use the reserve down flag to opt out of reserve provision and only provide energy	1-hour duration; regulation deployment by ESRs should meet energy storage limitations	1-hour duration in DAM, 0.5-hour in RTM; NGRs providing AS must telemeter SOC; restricted market participation for NGRs if opting for reg. energy management in DA
Capacity Market	1. All ISOs have modified their tariffs to allow ESRs to de-rate their capacity to meet their capacity market's minimum duration requirements					
	4 sustained hours (proposed to be modified to 6 hours); ESRs should elect ISO-SOCM in DAM if participating in capacity market, but can opt for Self-SOCM in RTM	**10 sustained hours**	**4 sustained hours** to meet RA requirements	**2 sustained hours**	**4 sustained hours**	**4 sustained hours** for RA participation; aggregation allowed across multiple PNodes for capacity provision

AS: Ancillary Service; **BSF**: Binary Storage Facility; **CSF**: Continuous Storage Facility; **DAM**: Day-ahead Market; **DARD**: Dispatchable Asset Related Demand; **ESF**: Energy Storage Facility; **ESR**: Electric Storage Resource; **MSR**: Market Storage Resource; **PSH**: Pumped Storage Hydro; **RA**: Resource Adequacy; **RT**: Real-time; **SOC**: State of Charge; **SOCM**: SOC Management

[2] ***Electricity Market Design Implications for Bulk Energy Storage.*** **EPRI, Palo Alto, CA: 2019. 3002013865.**

ISO/RTO Implementation Details

841 Aspect	NYISO	PJM	SPP	ISO-NE	MISO	CAISO
State of Charge Management	1. Only a few ISOs are proposing to allow for both ISO-SOCM and Self-SOCM 2. Entities that are offering only the Self-SOCM option, i.e., SPP, ISO-NE and MISO, are ensuring SOC feasibility					
	ISO-SOCM (ensures SOC feasibility, but not optimality) and **Self-SOCM** (does not ensure SOC feasibility, but ISO will align schedules with telemetered SOC in RTM); ESRs can switch between SOCM modes within RTM, between DAM and RTM; **PSH plants – Self-SOCM**	**ESRs** (continuous model) – **Self-SOCM** (does not ensure SOC feasibility, current SOC telemetry will not be used to optimize ESRs across intervals); **PSH plants – ISO-SOCM**	**Self-SOCM**; ensures SOC feasibility; can submit max daily MWh limit	**Self-SOCM**; two new telemetered points in RT (15-mins and 1-hr available energy and storage) to ensure SOC feasibility; ESFs can submit max daily MWh charge and discharge limits in the DAM	**Self-SOCM**; ensures SOC feasibility; max daily MWh limit included only for PSH plants	**ISO-SOCM** (ensures SOC feasibility, but not optimality) and **Self-SOCM** (does not ensure SOC feasibility); can submit daily min and max MWh limits for DAM
Minimum Size	1. All entities have reduced their minimum size limit to 100 kW for all markets					
	Allows aggregation behind the same T node	Allows aggregation behind the same electrical location		Allows aggregation behind a single POI (unlike DR assets)	Phased approach with limited number (50) of ESRs at this size in Y1	500 kW for AS; allows aggregation across multiple PNodes
Metering	1. All entities have required ESRs to be directly metered					
			Meter agents required to submit settlement meter values			

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[2] *Electricity Market Design Implications for Bulk Energy Storage.* EPRI, Palo Alto, CA: 2019. 3002013865.

Order 841: Key 2019 Updates

- No ISO/RTO is implementing the target end of day SOC constraint
- CAISO ESDER Phase IV Proposal
  - RT-SOCM: End of hour and end of horizon SOC constraints
  - Incorporation of degradation costs
- FERC approved compliance filings of PJM and SPP on Oct 17th
  - Additional directive to submit tariff provisions reflecting their rules and practices regarding RA and capacity minimum run-time requirements for all resources
  - Established paper hearing procedures to examine PJM's minimum run-time rules and procedures as applied to capacity storage resources
- NYISO, MISO and SPP have requests for a waiver of the implementation deadline (anticipated software changes considerably more complicated)

State of Charge Management Study

[3] *Integrating Electric Storage Resources into Electricity Market Operations: Evaluation of State of Charge Management Options*. EPRI, Palo Alto, CA: 2019. 3002013868.

SOC Management: Introduction

- Traditionally, in the power systems sector, SOC management (SOCM) was used as part of **automatic generation control** (AGC)
  - A few ISOs would manage the SOC of ESRs providing regulating reserve by explicitly monitoring the telemetered SOC and providing regulation control signals that would maintain a desired SOC
  - SOC management in AGC ensured that, given the random movements, ESR would still maintain a SOC as desired and that was feasible
  - ***This is different from provision of energy in DA and RT markets***
- No definitive statement within Order 841 on what SOCM means resulting in different interpretations and requests for clarifications (does not require ISO-SOC-Management; requires provision of SOC related bid parameters by ESRs)

SOC Management: Options

Self-Schedule

- ESR self-dispatches its output and is insensitive to price.

Allowed by all ISOs/RTOs

Self-SOC-Management

- ESR provides an offer curve analogous to traditional resources.
- ESRs can modify submitted offers to ensure desired and feasible SOC levels.

PJM ESRs

SOC-Management-Lite

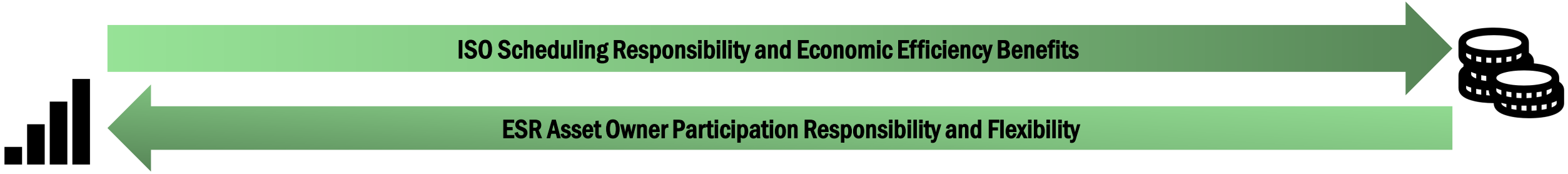
- ESR provides offer curve.
- ISO does not schedule ESR if it would lead to infeasible SOC.

MISO, ISO-NE, SPP, NYISO, CAISO

ISO-SOC-Management

- ESR does not provide offer curve.
- ISO ensures SOC feasibility and schedules ESR to meet desired SOC level.

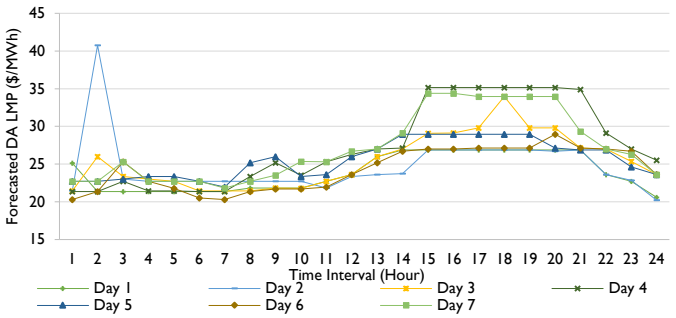
PJM PSH units



SOC Management: Self SOCM Offers

Alternatives: Similar historical day, average prices from historical data, etc.

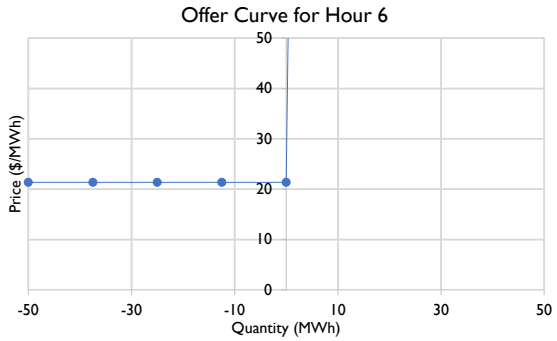
Anticipated or forecasted day-ahead energy price signals at ESR's location

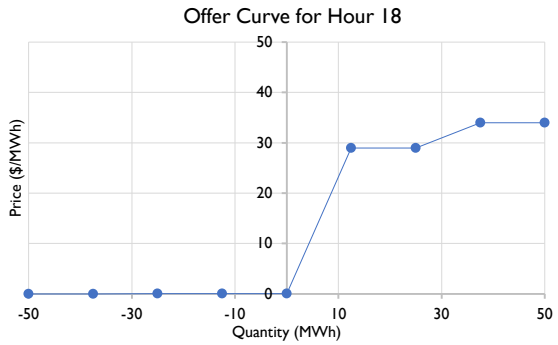


ESR Bidding Strategy Problem

- **Objective**: Maximize the ESR's expected profit for the inputted price signals
- **Subject to**: ESR's physical and operations restrictions
  - Ensure monotonicity of offer curves
  - SOC management constraints, e.g., ensure feasible & desirable SOC levels
  - Scheduling constraints, modes, etc.
  - Partial equilibrium constraints to help attain convergence with inputted price signals

Offer curves for participation in DA energy markets





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Case Studies

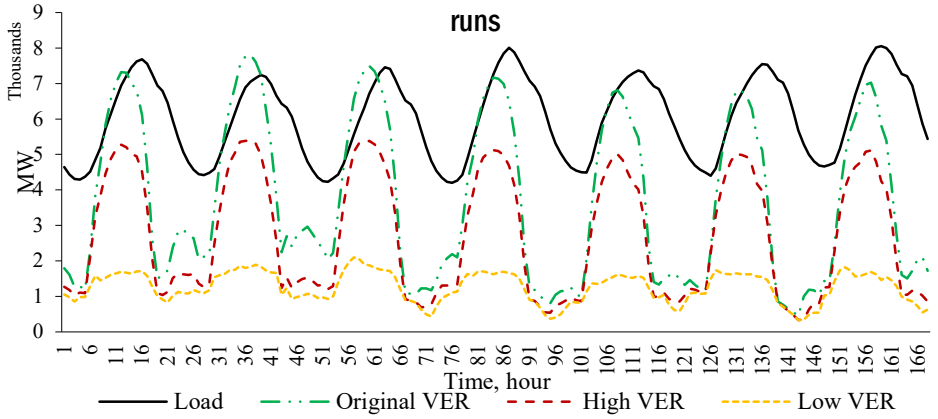
- **Goal:**
  - Evaluate the key differences that the various SOC management options have on economic efficiency (operating costs/societal welfare) and reliability of the system
  - Other anticipated impacts include: Price setting, market settlements, make-whole payments, market mitigation, and computational efficiency
- **Initial assumptions:**
  - No A/S (next steps)
  - DA SCUC, RT SCUC, RT SCED, and AGC modeled in one integrated manner
  - Real-time follows the day-ahead schedule unless SOC limit is hit (next steps)
  - Power system test case: RTS-GMLC bulk system model
  - Market clearing simulation tool: Flexible Energy Scheduling Tool for Integrating Variable generation

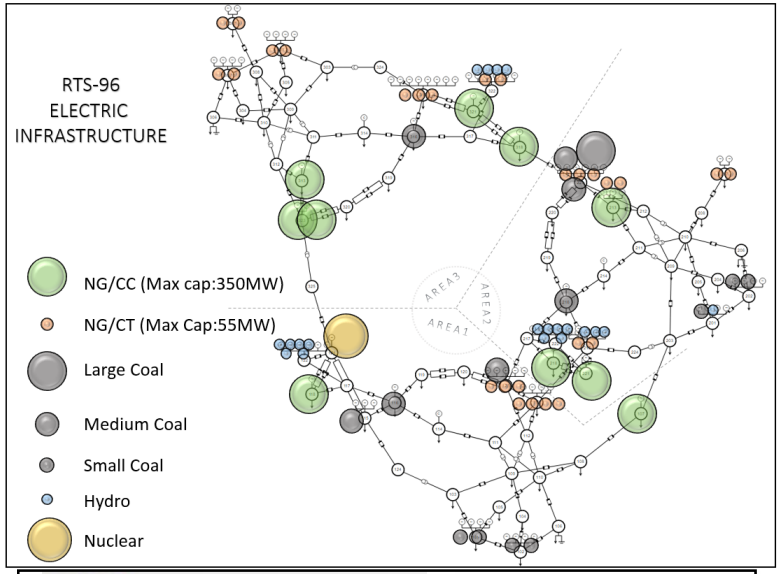
DA SCUC: Day-ahead Security Constrained Unit Commitment, **RT SCUC:** Real-time Security Constrained Unit Commitment,
RT SCED: Real-time Security Constrained Economic Dispatch, **AGC:** Automatic Generation Control

Case Studies: RTS-GMLC System*

Resource Type	Number of Generating Units	Minimum Power Capacity (MW)	Maximum Power Capacity (MW)	Ramp Rate (MW/minute)
Steam	7	5	12	1
Steam	7	30	76	2
Steam	7	62	155	3
Steam	2	140	350	4
Combustion Turbine	12	8	20	3
Combustion Turbine	27	22	55	3.70
Combined Cycle	10	168	350	4.14
Nuclear	1	396	400	20
Hydro	20	0	50	--
Wind	5	0	3000*	--
Utility PV	27	0	9850*	--
Rooftop PV	5	0	2000*	--

Expected hourly (DA) system-wide load and expected hourly (DA) VER forecast for the weekly simulation runs





Grid Modernization LABORATORY CONSORTIUM

NREL NATIONAL RENEWABLE ENERGY LABORATORY

- Realistic moderate-sized system, small enough to see specific changes with sensitivities
- Dispatchable generation: 8,076 MW, hydro: 1,000 MW, VER: 14,850 MW
  - Low VER: 2,250 MW
  - High VER: 11,000 MW

*https://github.com/GridMod/RTS-GMLC

Case Studies: Simulation Case Matrix

Simulation Case	VER Penetration Level	ESR Penetration Level	SOC Management Option	Duration of ESR
1	Low VER	No ESR	N/A	N/A
2	Low VER	Low ESR	Self-SOCM	4 hours
3	Low VER	Low ESR	SOCM-Lite	4 hours
4	Low VER	Low ESR	ISO-SOCM	4 hours
5	Low VER	High ESR	Self-SOCM	4 hours
6	Low VER	High ESR	SOCM-Lite	4 hours
7	Low VER	High ESR	ISO-SOCM	4 hours
8	Low VER	High ESR	Self-SOCM	1 hour
9	Low VER	High ESR	ISO-SOCM	1 hour
10	High VER	No ESR	N/A	N/A
11	High VER	Low ESR	Self-SOCM	4 hours
12	High VER	Low ESR	SOCM-Lite	4 hours
13	High VER	Low ESR	ISO-SOCM	4 hours
14	High VER	High ESR	Self-SOCM	4 hours
15	High VER	High ESR	SOCM-Lite	4 hours
16	High VER	High ESR	ISO-SOCM	4 hours
17	High VER	High ESR	Self-SOCM	1 hour
18	High VER	High ESR	ISO-SOCM	1 hour

- Variable energy resource (VER) penetration level:
  - **Low VER**: Average penetration is 9% of energy demand
  - **High VER**: Average penetration 32% of energy demand
- Electric storage resource (ESR) penetration level:
  - **Low ESR**: 300 MW (six 50-MW ESRs, 0.85% roundtrip efficiency), 4% of peak demand
  - **High ESR**: 800 MW (sixteen 50-MW ESRs, 0.85% roundtrip efficiency), 10% of peak demand
- Each case was simulated for a 1-week time period

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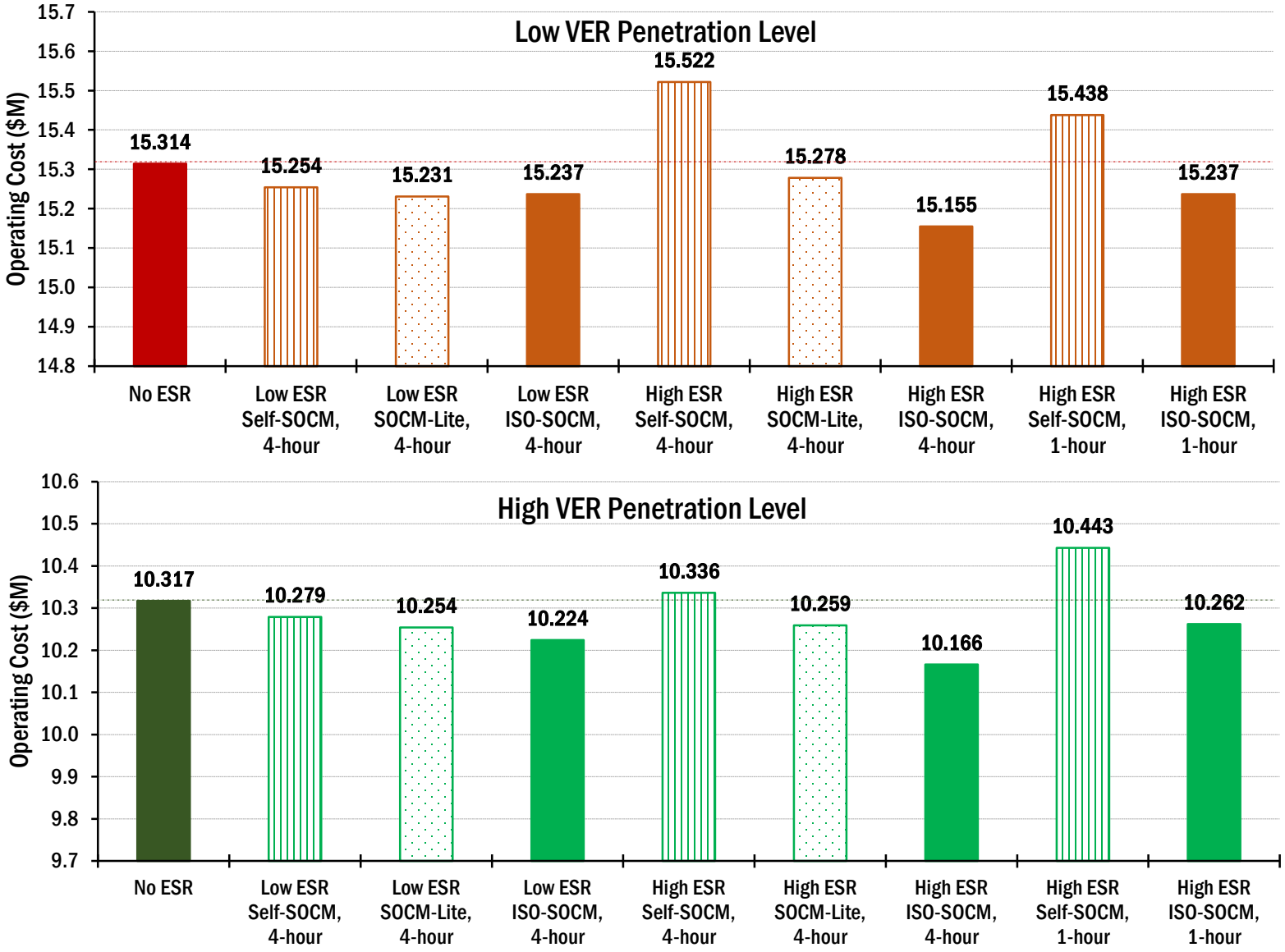
Case Studies: SOCM Cost Impacts



- ***Self-SOC-Management*** option
  - Seems to have a negative impact for high ESR levels
  - Causes imbalance and need for expensive quick starts
- ***SOC-Management-Lite*** option
  - Consistent cost reduction irrespective of VER level or ESR level
  - Hint: Cost increase in *Self-SOC-Management* due to infeasibility of SOC level and not the developed offer curves primarily
- ***ISO-SOC-Management*** option
  - Seems to have the greatest economic efficiency benefits
  - Benefits seem to increase with increasing ESR levels or VER levels

Other Market Modeling Aspects

- **2019 research plans:**
  - Continue following ISO/RTO software implementation details and external design factors
  - Continue SOC management studies:
    - Evaluate real-time SOC management
    - Evaluate ancillary service SOC management
    - Evaluate price setting logic
  - Identify challenges of integrating hybrid co-located resource technology in electricity market design
- **Future research topics:**
  - Variable efficiency loss formulation
  - Binary storage representation (e.g., PSH resources)
  - Enhanced energy usage representation for SOC calculation (e.g., interpolation errors)
  - Make-whole payment calculation
  - ESR cycling degradation representation
  - ESR utilization in reliability unit commitment process
  - Potential for FERC to release a DER market participation order

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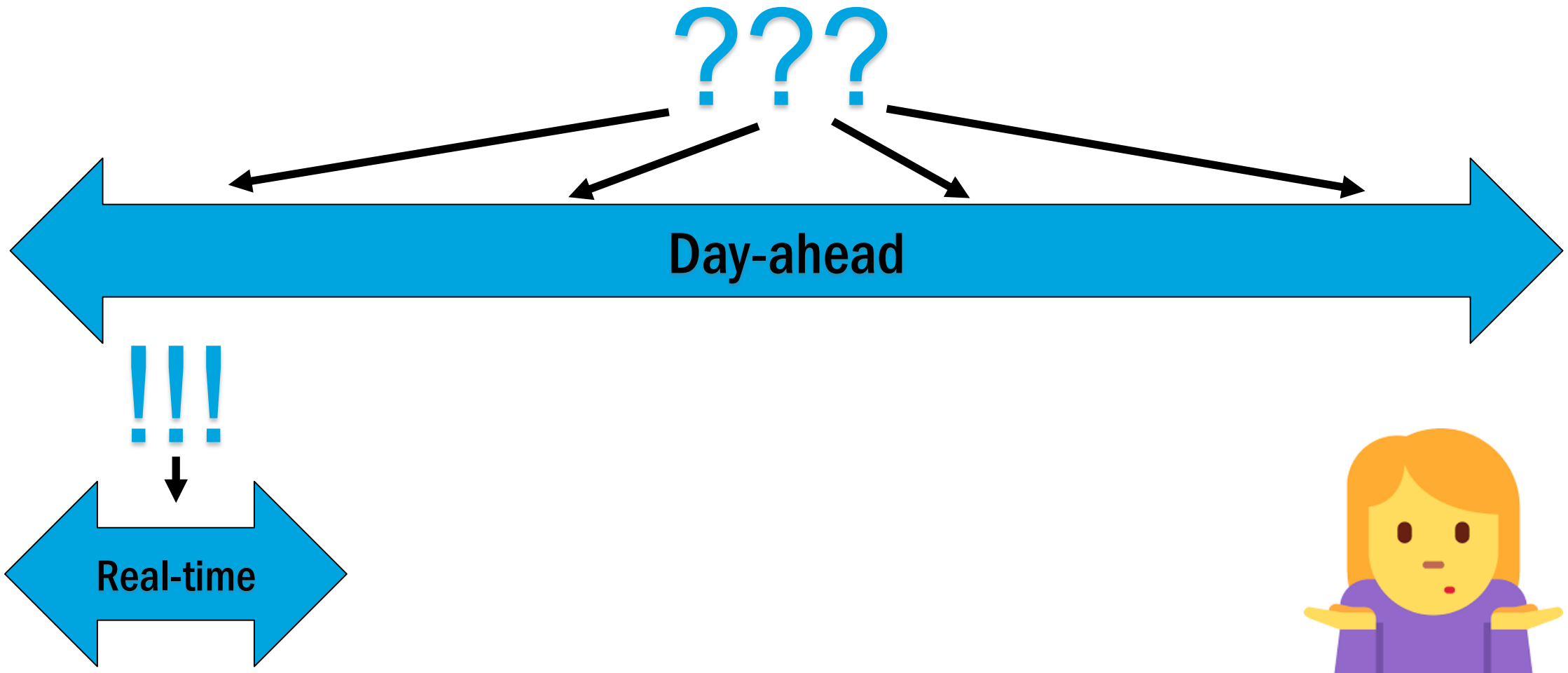
The Forecast Dilemma



Lots of data, but potentially "bad data" versus good data, but not much of it…

Questions and Comments?

Together...Shaping the Future of Electricity

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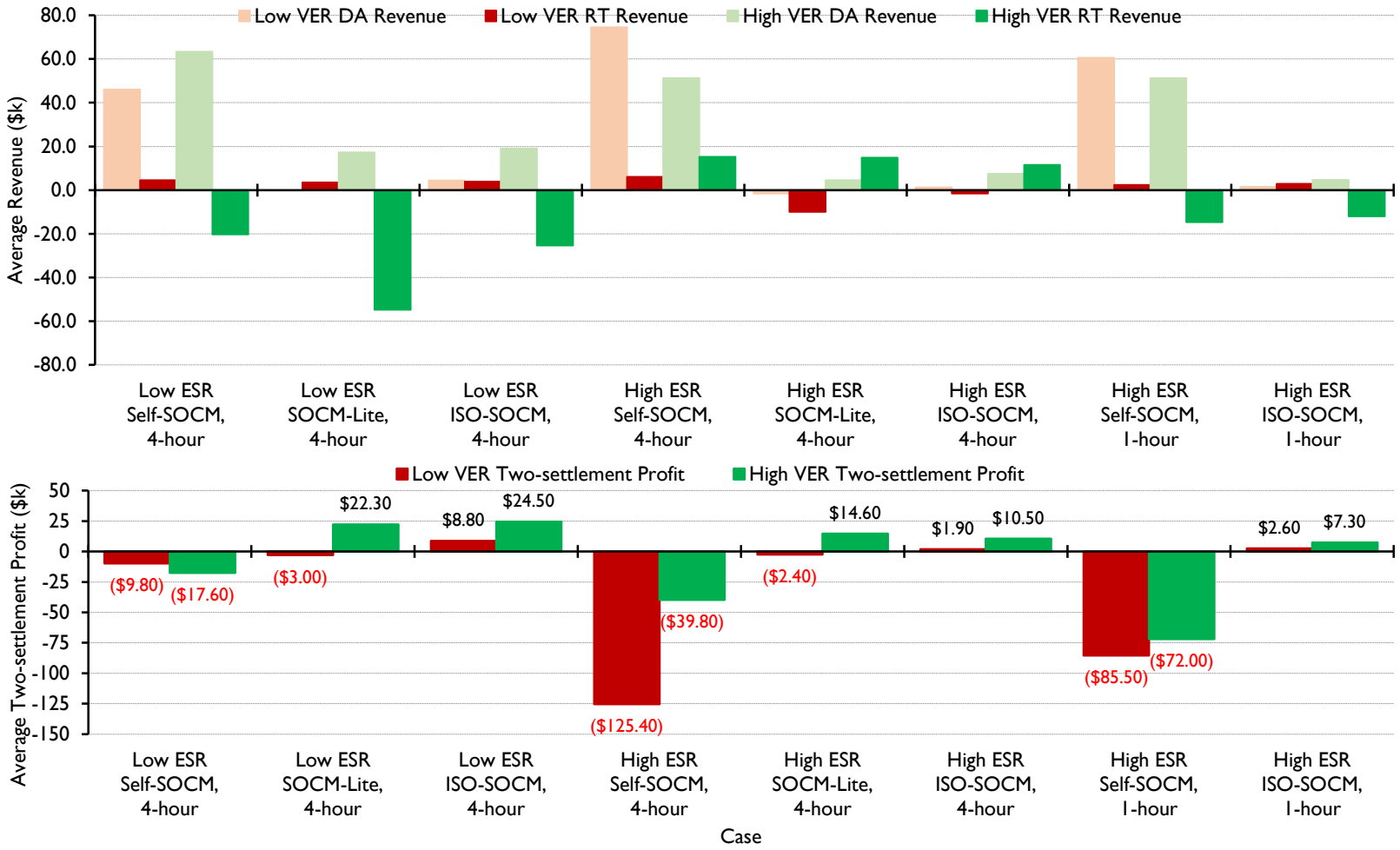
Appendix

SOC Management: Introduction

- **Energy Storage Alliance[4]:**
  - **SOCM**: involves monitoring and causing to change the SOC, normally by adjusting resource operating parameters or power level, and perhaps including the placing and/or adjusting of offers/bids, to modify dispatch, generally to achieve a desired SOC level or range, or avoid an undesired SOC level or range, generally in real-time.
  - **Self SOCM**: should include the ability to adjust offers/bids and/or operating parameters, such as upper and lower limits, on a short-term basis, including from one dispatch interval to the next (i.e., every 5 minutes).
- **Electric Power Research Institute:**
  - **ISO-SOCM**: The ISO monitors current SOC, anticipated SOC, and other related ESR parameters (e.g., round-trip efficiency levels) and makes scheduling decisions and schedules that explicitly lead to a desired and feasible SOC level at all times.
  - **Self SOCM**: ESR asset owners (market participants) provide cost/quantity offer curves that, to the best ability of the owner, lead to desired and feasible SOC level at all times without need for explicit ISO intervention.

[4] *Private communication with the Energy Storage Alliance, used with permission.*

Case Studies: SOCM Profit Impacts



- ***Self-SOC-Management* option**
  - Negative average individual profits (SOC limitations require ESRs to buy back energy in RT)
- ***SOC-Management-Lite* option**
  - Positive average profits in high VER cases (greater arbitrage opportunities)
  - Low ESR: Higher profits (does not saturate the arbitrage value)
- ***ISO-SOC-Management* option**
  - Positive average profits in all cases (high VER: greater arbitrage opportunities)
  - Low ESR: Higher profits (does not saturate the arbitrage value)
- **Further research: Settlements for RTM when interpolated schedules used for ESRs participating in DAM, e.g., PSH in PJM**

- **Average results: Excludes make-whole payments, and cycling and O&M costs**
  - **DA (RT) revenue**: Sum of the product of DA (RT) schedules and DA (RT) LMPs for each hour (five-minute real-time period)
  - **Two-settlement profit**: Adds (subtracts) the product of positive (negative) deviation from the DA schedules based on RT schedule and the RT LMP

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Case Studies: Reliability Impacts

Case	RT imbalance (MWh)	# 5-minute intervals with imbalance	Largest imbalance within a 5-minute interval (MW)
Low VER, **No ESR**	49.9	28	96
Low VER, Low ESR, Self-SOCM	41.4	17	90
Low VER, Low ESR, SOCM-Lite	49.1	27	83
Low VER, Low ESR, ISO-SOCM	34.5	15	78
Low VER, High ESR, Self-SOCM	97.1	50	96
Low VER, High ESR, SOCM-Lite	94.5	41	101
Low VER, High ESR, ISO-SOCM	26.8	9	95
Low VER, High ESR, Self-SOCM, 1 Hr	71.4	45	101
Low VER, High ESR, ISO-SOCM, 1 Hr	48.9	18	96
High VER, **No ESR**	1152.6	34	102
High VER, Low ESR, Self-SOCM	1520.1	56	93
High VER, Low ESR, SOCM-Lite	1129.5	36	95
High VER, Low ESR, ISO-SOCM	935.9	37	85
High VER, High ESR, Self-SOCM	2565.7	69	113
High VER, High ESR, SOCM-Lite	2297.2	64	133
High VER, High ESR, ISO-SOCM	2284.1	63	153
High VER, High ESR, Self-SOCM, 1 Hr	1983.1	76	128
High VER, High ESR, ISO-SOCM, 1 Hr	836.2	28	94

- ***Note: ESRs are fixed to the interpolation of their DA schedule; simulations exclude A/S***
  - ESRs' fixed non-dispatchable energy displaces dispatchable energy in RT
- ***Numerical analysis: High ESR level***
  - More ESRs scheduled in the DAM → Other generation is not committed in the DAM and less flexible capacity is available in the RTM
  - Imbalance increases with more RT fixed schedules
  - Important to include A/S (or flexibility reserve constraint), RT SOCM, and AS SOCM of ESRs (next phase)
- ***All case scenarios***
  - There were sufficient quick-start resources to meet the RT conditions
  - High ESR levels and self-SOCM can lead to potential reliability issues in systems with fewer quick-start resources

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