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Energy Storage Integration into Electricity Markets: Current Status and Ongoing Research

ESIG Webinar Series

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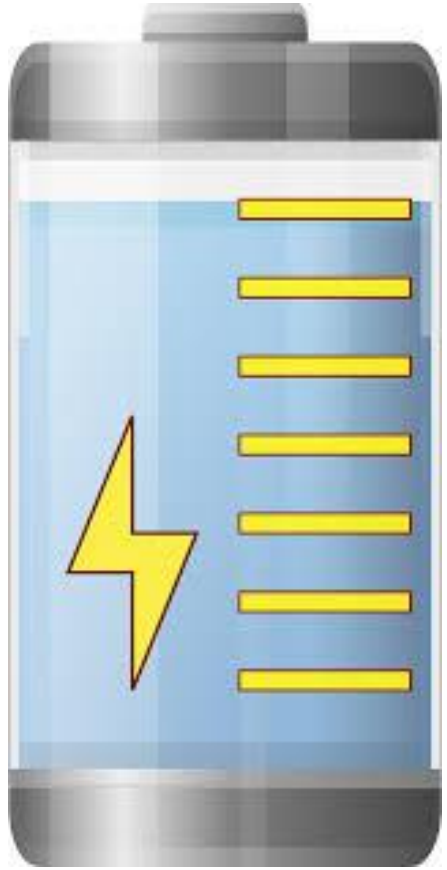
Outline

- FERC Order 841: Electric Storage Resource Participation in ISO/RTO Markets
  - State-of-the-Art: How ESRs participated in wholesale markets before the Order
  - Summary of FERC Order 841
  - Comparison of current ISO/RTO Order 841 implementation design proposals
- State of Charge Management
  - What does state of charge management mean?
  - Different SOCM options?
  - How may it affect economic efficiency and profitability
- Future Research Topics

State-of-the-Art: ESR Wholesale Participation (before 841)

- Pumped storage hydro (participates in **majority** of ISO services)
  - Offer as **separate** pump/generator participants
  - **PJM**: Hydro optimizer, **optimize** mode of operation to minimize cost and **ensure SOC targets**
- **Limited energy storage** primarily in **ISO regulation market**
- CAISO **non-generator resource (NGR)**: Offer curve from max consumption to max generation (**benchmark** model?)
- Industry was unsure how much **capacity value** ESRs provide to peak needs



Limited Energy Storage Resources

Tariff

- Prioritization through stakeholder process
- Participation models
- Specific technology language

Confidence

- Confidence in ability to provide longer duration services due to limited energy
- Less experience in performance characteristics

Economics

- Regulation typically highest priced ancillary service – so no benefit to provide others?
- Regulation generally energy neutral over short time periods – probability of SOC depletion lower
- Energy prices have little arbitrage value (low spread)
- Real-time markets traditionally averaged out settlements to the hourly level, leaving no intra-hour arbitrage opportunity (changing due to FERC Order 825)

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").*

Order 841: ESR Definition

- "A resource capable of receiving electric energy from the grid and storing it for later injection of electric energy back to the grid"
  - Regardless of location (T or D)
  - Does not include BTM that do not inject energy (i.e., this is demand response)
  - Definition includes a minimum set that can be further defined by ISO
  - Does not require ESR that is under this definition to participate in the wholesale markets
  - Hybrid resources out of scope (although can use participation model)
- ESRs under this definition do not have to use ESR participation model
  - ISO that already has ESR participation model does not have to consolidate existing model with one described in this rule

Order 841: Market Product Participation

- Energy, all ancillary services, capacity markets when technically capable
  - ISO determines what/when the asset is capable of providing
  - Also includes ability to provide services that are not procured through organized market (frequency response, voltage support, black start)
- Ancillary service provision
  - No changes to NERC glossary or standards
  - Can provide spinning reserve when idle but available
  - No requirement for the ISOs to change rules to allow for ESRs to provide ancillary services without energy schedule, but encourage them to allow it when appropriate
- Capacity markets
  - Allow de-rate to minimum run hour to participate
  - No changes to must offer rules required

Order 841: Capacity Market Eligibility

- ESR must be allowed to participate in capacity markets if technically able to do so
- Capacity contribution based on ratio of power to energy duration

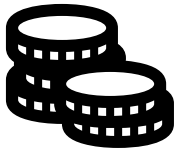
Example: Energy Storage Capacity Value	
Existing Way*:	**Ruling:**
Power Capacity: 10 MW	Power Capacity: 10 MW
Energy Storage: 40 MWh	Energy Storage: 40 MWh
Capacity Value: 10 MW	*Capacity Value: 10 MW*
Power Capacity: 10 MW	Power Capacity: 10 MW
Energy Storage: 20 MWh	Energy Storage: 20 MWh
Capacity Value: 0 MW	***Capacity Value: 5 MW***

*In some markets

Key Question: What is the most appropriate way to measure capacity contribution from energy storage?

Order 841: Price Setting & Settlement

- Must pay/be paid price as a wholesale buyer and seller and set price as wholesale buyer and seller and when available as a dispatchable resource and marginal resource
  - If minimum generation or self-scheduled, cannot set price

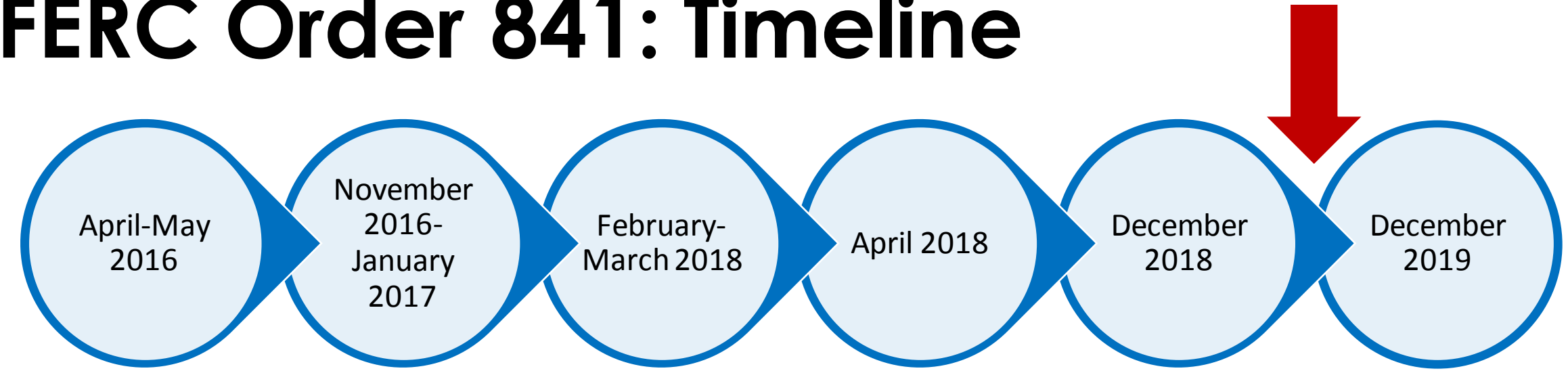


- Include make whole payments (e.g., cost recovery guarantee) when price is higher than bid price when charging or lower than offer price when discharging
- Prices for buying and selling at nodal level, not zonal level

- Transmission charges to load can be applied to ESR when charging, unless providing "service" to the ISO/RTO

- Require direct metering for better accounting of wholesale contribution

FERC Order 841: Timeline



- FERC Docket AD16-20: Requests information on energy storage participation in ISOs/RTOs

- FERC NOPR Docket RM16-23: Energy storage participation in wholesale markets
- NOPR includes DER aggregations

- FERC issues Order 841
- Calls for a technical conference on DER issues (Docket RM18-9)
- Motions for rehearing filed by several parties

- FERC rules on motions for rehearing
- FERC defers DER proposed rulings and instead holds a technical workshop

- Deadline for submission of compliance filings
- Opportunity to respond to filings

- Deadline to implement changes

- **NYISO, MISO and SPP have requested for a waiver of the implementation deadline:** Anticipated software changes are considerably more complicated than initially projected in 2018

Current ISO/RTO Order 841 Implementation Design Proposals

ISO/RTO Implementation Details

Order 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	SOC limits submitted if ISO manages SOC; Min charge and run times for NGRs to be managed by SOC parameters/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 (including withdrawals for later injection of energy) to the ISO/RTO					
	Self-committed fixed or flexible ESRs ineligible for DA BPCG payments, ISO-SOCM ESRs ineligible for RT BPCG, self-committed flexible eligible for RT BPCG payments; 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; **NCPC**: Net Commitment Period Compensation; **NGR**: Non-Generator Resource; **PSH**: Pumped Storage Hydro; **RTM**: Real-time Market; **SOC**: State of Charge

ISO/RTO Implementation Details

Order 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 for ISO-SOCM in the DAM if participating in capacity market, but can opt for self-SOCM in the RTM.	**10 sustained hours**	**4 sustained hours** to meet RA requirements	**2 sustained hours**	**4 sustained hours**	**4 sustained hours** for RA participation; allows aggregation 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

Order 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 the RTM); **PSH plants – Self-SOCM;** ESRs have the option to switch b/w SOCM modes within RTM, and b/w DAM and RTM	**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, i.e., 15-minute and 1-hour available energy and available 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 & optimality) and **Self-SOCM** (does not ensure SOC feasibility); can submit daily min and max energy 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 of ESRs (50) at this size in year 1	500 kW for AS; allows aggregation across multiple PNodes
Metering	1. Almost all entities have required ESRs to be directly metered					
			Meter agents required to submit settlement meter values			

AS: Ancillary Service; **BSF**: Binary Storage Facility; **CSF**: Continuous Storage Facility; **DAM**: Day-ahead Market; **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; **SOCM**: SOC Management

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

State of Charge Management

[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

- **Energy Storage Alliance[4]**:
  - **ISO-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.***

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, NYISO, SPP

ISO-SOC-Management

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

PJM PSH units, CAISO

ISO Scheduling Responsibility and Economic Efficiency Benefits

ESR Asset Owner Participation Responsibility and Flexibility

Case Studies

Case Studies

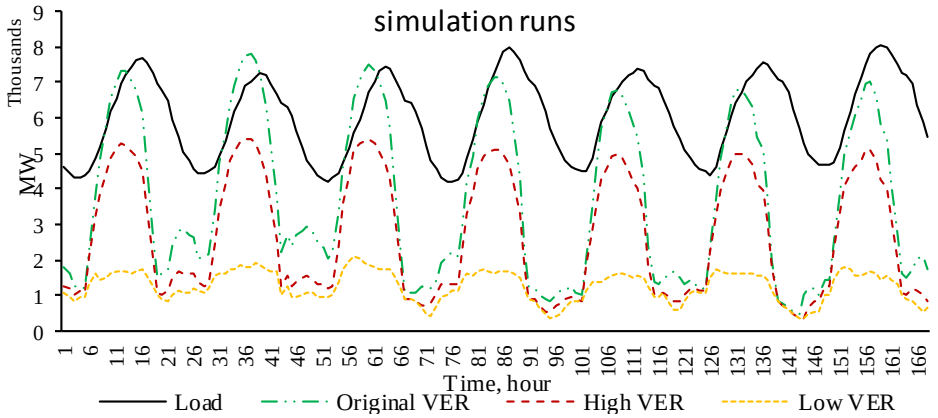
- **Goal**:
  - Evaluate the key differences that the various SOC management options have on economic efficiency (operating costs/societal welfare) and reliability of the system
  - Other anticipated impacts include: Price setting, market settlements, make-whole payments, market mitigation, and computational efficiency
- **Initial assumptions**:
  - Ignore Ancillary Services
  - 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
  - Power system test case: RTS-GMLC bulk system model
  - Market clearing simulation tool: **F**lexible **E**nergy **S**cheduling **T**ool for **I**ntegrating **V**ariable generation
  - Varying levels of ESR, levels of VER

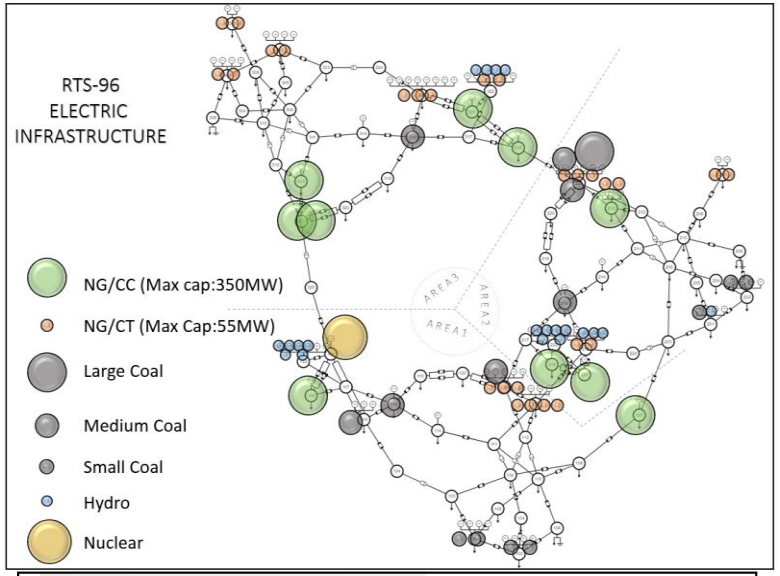
DA SCUC: Day-ahead Security Constrained Unit Commitment, **RT SCUC**: Real-time Security Constrained Unit Commitment,
RT SCED: Real-time Security Constrained Economic Dispatch, **AGC**: Automatic Generation Control

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

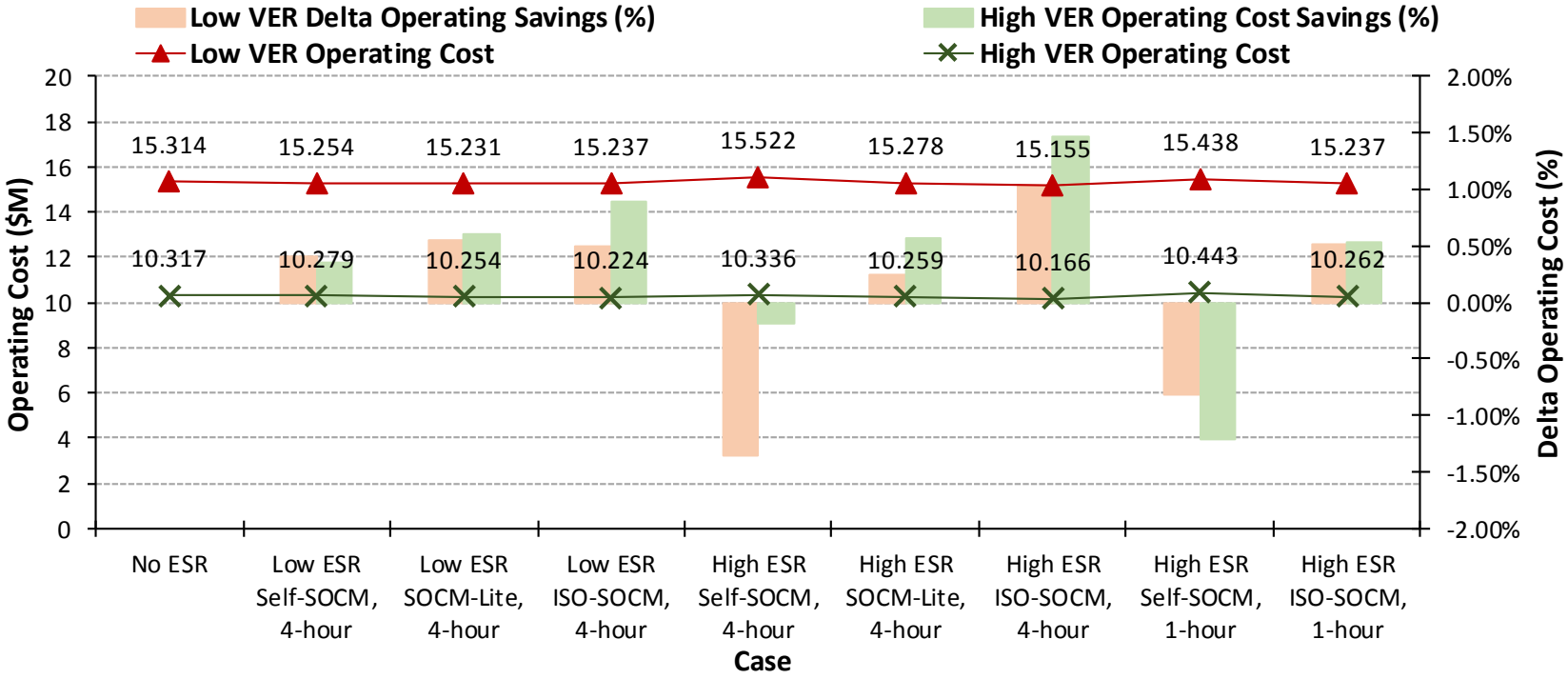
- Realistic moderate-sized system, small enough to see specific changes with sensitivities
- Dispatchable generation: 8,076 MW, hydro: 1,000 MW, VER: 14,850 MW
  - Low VER: 2,250 MW
  - High VER: 11,000 MW

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

Case Studies: Simulation Case Matrix

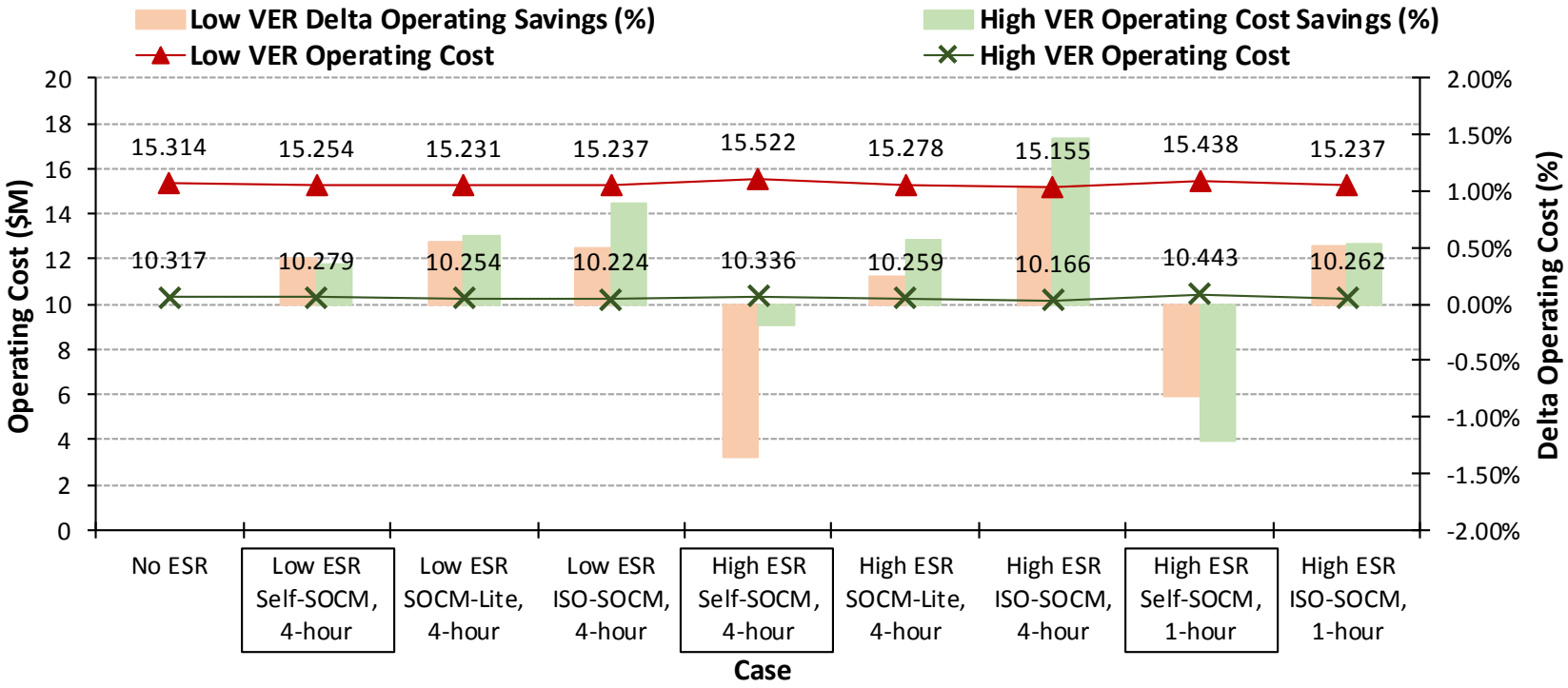
Simulation Case	VER Penetration Level	ESR Penetration Level	SOC Management Option	Duration of ESR
1	Low VER	No ESR	N/A	N/A
2	Low VER	Low ESR	Self-SOCM	4 hours
3	Low VER	Low ESR	SOCM-Lite	4 hours
4	Low VER	Low ESR	ISO-SOCM	4 hours
5	Low VER	High ESR	Self-SOCM	4 hours
6	Low VER	High ESR	SOCM-Lite	4 hours
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

Case Studies: SOCM Cost Impacts



- 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

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

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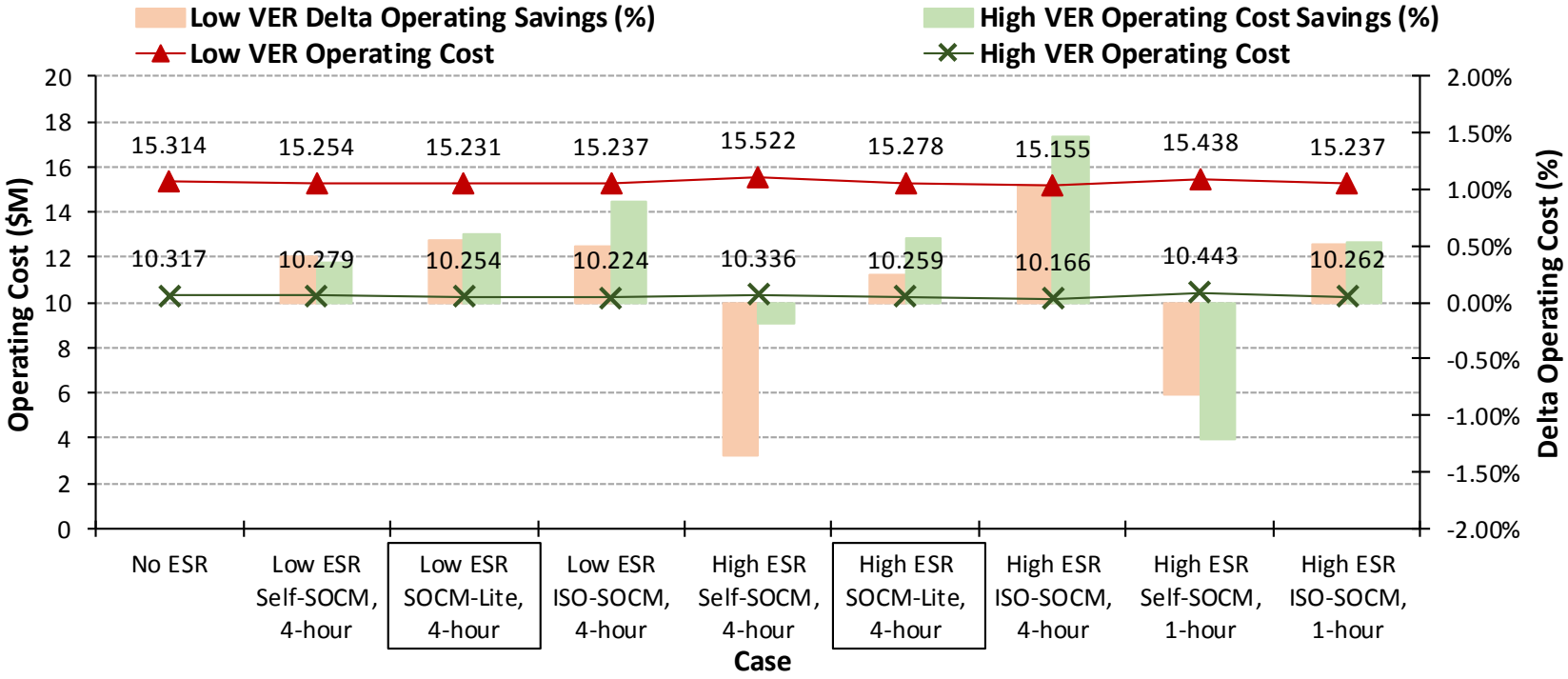

- ***SOC-Management-Lite*** option
  - Consistent cost reduction irrespective of VER level or ESR level
  - Hint: Cost increase in *Self-SOC-Management* due to infeasibility of SOC level and not the developed offer curves primarily

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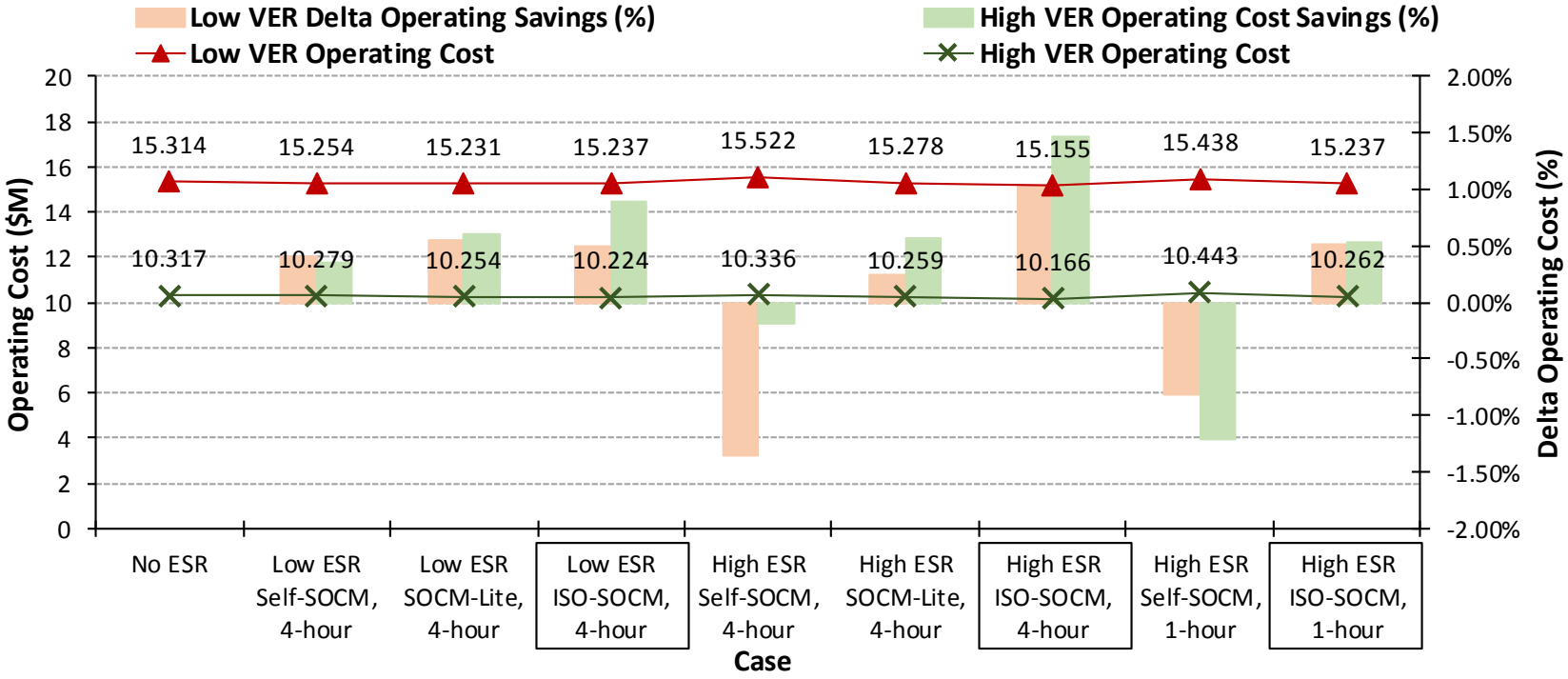

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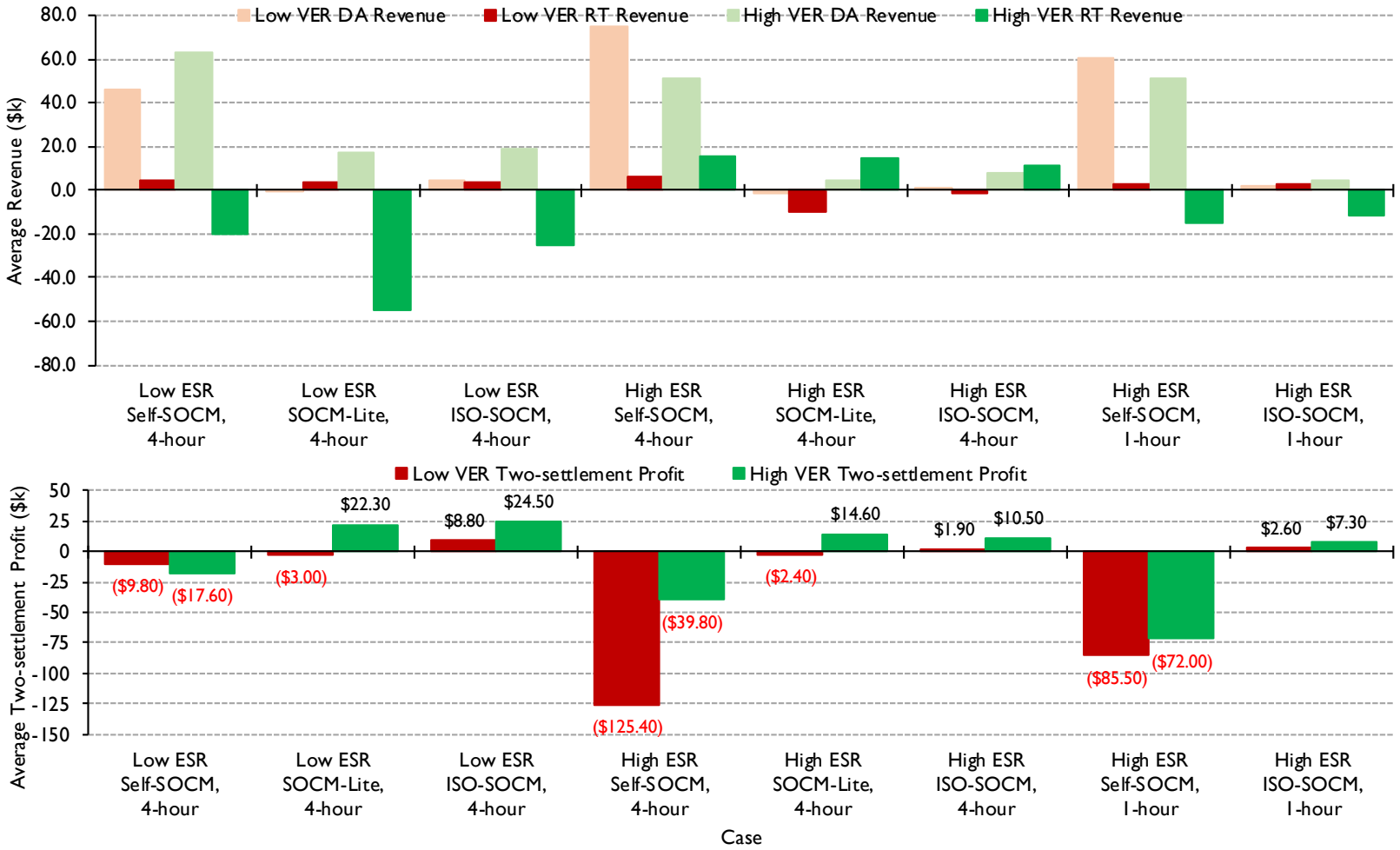
- Each case was simulated for a 1-week time period

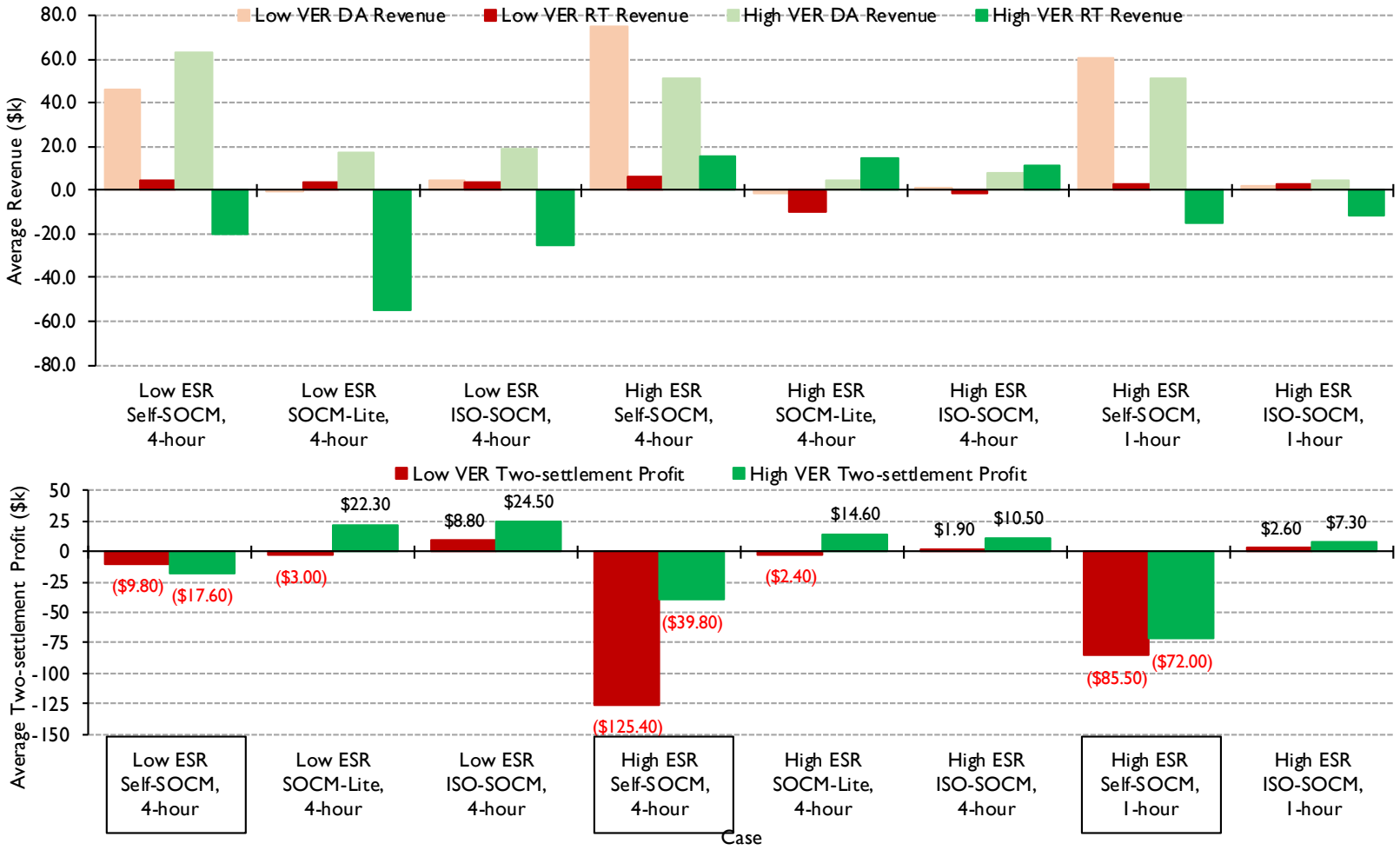
- ***ISO-SOC-Management*** option
  - Seems to have the greatest economic efficiency benefits
  - Benefits seem to increase with increasing ESR levels or VER levels

Case Studies: SOCM Profit Impacts



- 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

Case Studies: SOCM Profit Impacts



- ***Self-SOC-Management*** option
  - Negative average individual profits (SOC limitations require ESRs to buy back energy in RT)

- Average results: Excludes make-whole payments, and cycling and O&M costs
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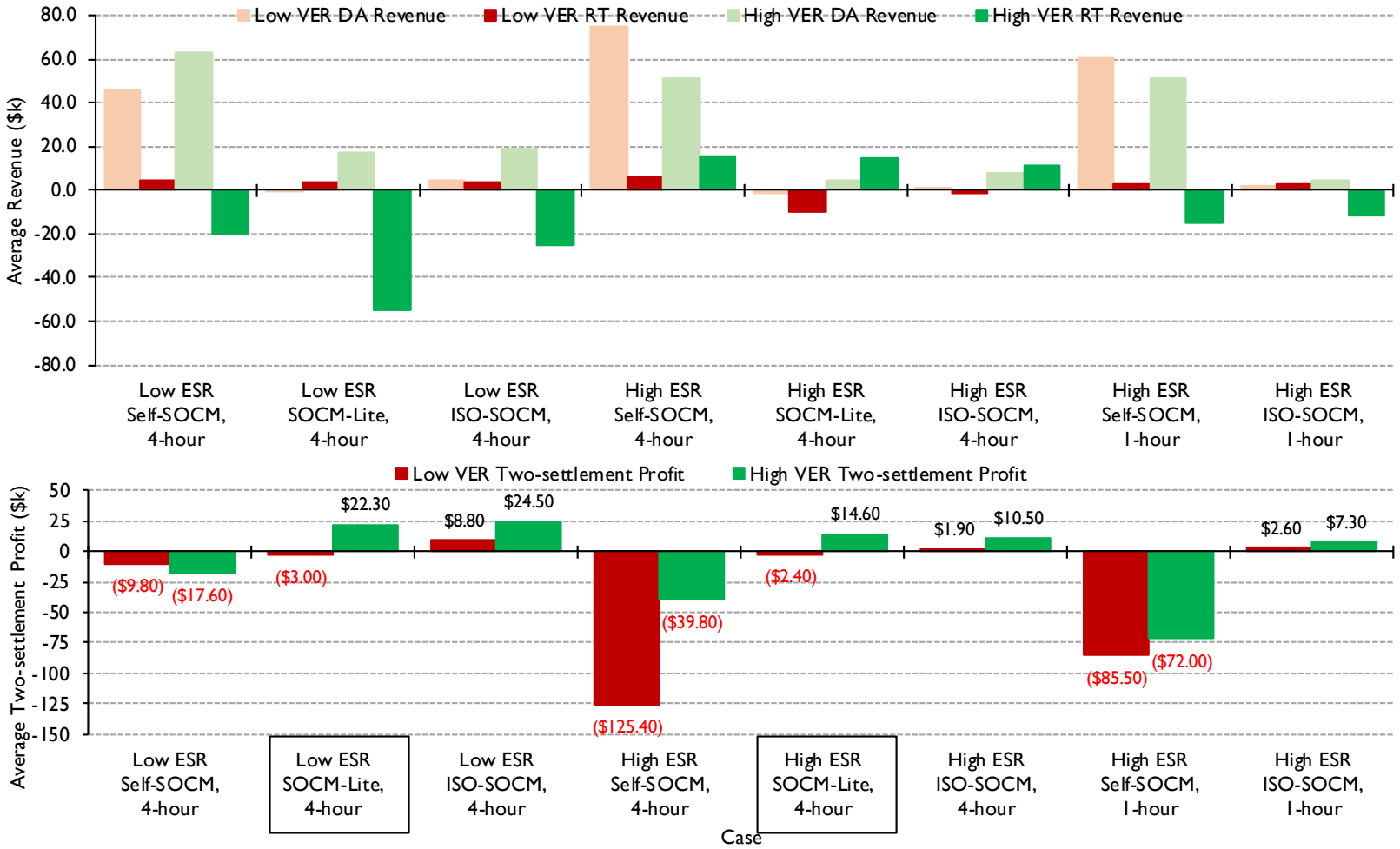
Case Studies: SOCM Profit Impacts



- ***SOC-Management-Lite*** option
  - Positive average profits in high VER cases (greater arbitrage opportunities)
  - Low ESR: Higher profits (does not saturate the arbitrage value)

- Average results: Excludes make-whole payments, and cycling and O&M costs
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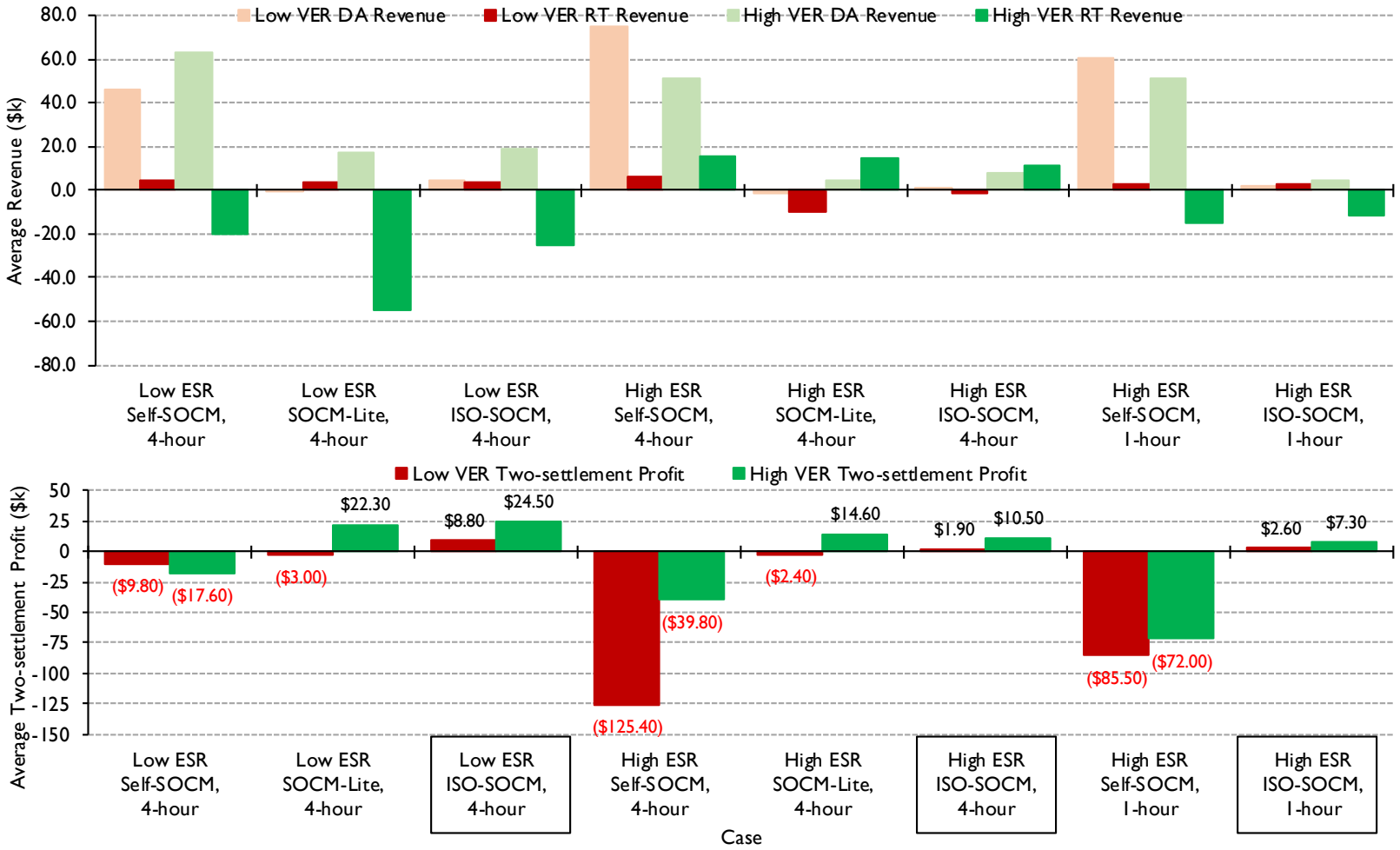


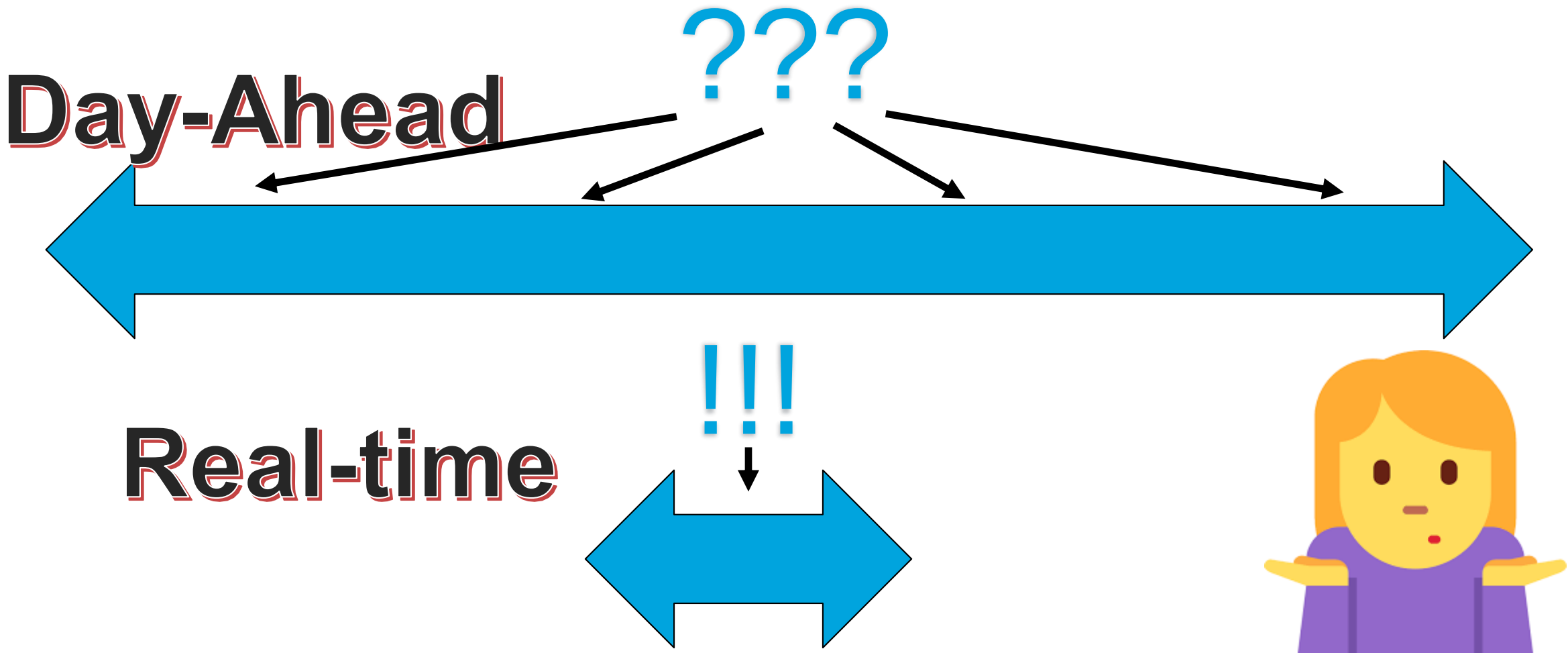
- ***ISO-SOC-Management*** option
  - Positive average profits in all cases (high VER: greater arbitrage opportunities)
  - Low ESR: Higher profits (does not saturate the arbitrage value)
- Further research: Settlements for RTM when interpolated schedules used for ESRs participating in DAM, e.g., PSH 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

Additional Research Questions

- How do ISOs ensure SOC is sufficient for meeting schedules?
  - Evaluate real-time SOC management
  - Evaluate ancillary service SOC management
- Evaluate price setting logic for ESRs
- Additional challenges of integrating “hybrid” co-located resource technology in electricity market design
- Enhanced energy usage representation for SOC calculation (energy vs. power)
- Make-whole payment calculation
- ESR cycling degradation representation
- ESR utilization in reliability unit commitment process

The Forecast Dilemma



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

Questions and Comments?

Together...Shaping the Future of Electricity

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