Storage Integration Efforts in the U.S. Wholesale Electricity Markets

IESO Energy Storage Design Project

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Energy Storage Advisory Group: Webinar

March 26, 2020

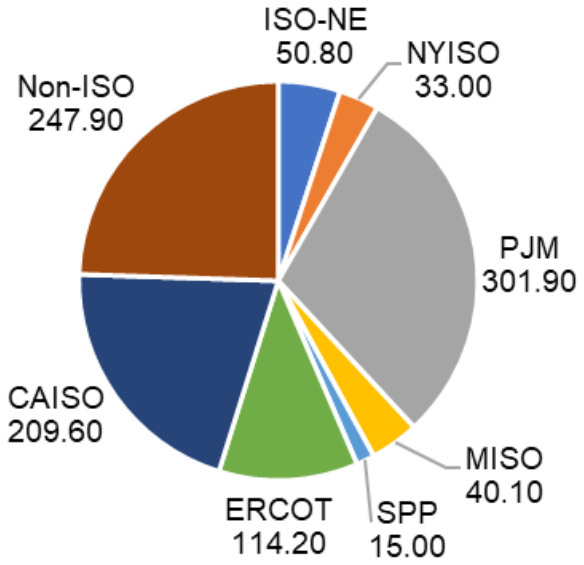
Agenda

- State of the Art Electric Storage Resource (ESR) Participation
- FERC Order 841
- ISO/RTO ESR Market Design Proposals and Implementations
- Comparison of FERC Order 841 Topics with IESO's Storage Design Project Questions
- State of Charge Management

Current Participation Status of ESRs

- All U.S. ISO interconnection queues have >1 GW of energy storage
- California dominates energy storage capacity in ISO interconnection queues

Battery Energy Storage Capacity Operating as Electric Power Resources by ISO in September 2019, categorized by installed nameplate capacity (MW)



(Source: EIA Form 860) (includes some behind-the-meter)

Energy Storage Capacity in North American ISO Interconnection Queues

ISO	Energy Storage in Interconnection Queue	
	Capacity (MW)	No. of Projects
CAISO	31,947	127
ERCOT	3,680	47
IESO	41	6
ISO-NE	2,996	24
MISO	2,586	52
NYISO	5,769	55
PJM	5,784	110
SPP	6,796	76
Total	**59,599**	**497**

State of Art – ESR Wholesale Participation

- Pumped Storage Hydro (PSH): participates in majority of ISO products
  - Offer as separate pump/generator participants
  - PJM – Hydro optimizer, optimizes mode of operation to minimize cost and ensure SOC targets
- Other storage (e.g., batteries, flywheels) primarily in ISO regulation market
  - Software limitations for provision of energy and other A/S
  - Regulation service typically most lucrative for limited energy characteristics
  - Typically only requires 15 minutes of sustained energy
- CAISO Non Generator Resource (NGR) – Energy offer curve from max consumption to max generation

Why are Batteries not Providing all Products and Services?

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)

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").*

Key ESR Design Topics

Participation Model and Registration

Offer Parameters

Ancillary Service Provision

Pricing and Settlement

State of Charge Management

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

[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 Design Proposals: 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 **Rationale**: ESRs are continuously dispatchable; PSH resources have forbidden operating regions that need to be accounted for appropriately 2. ESRs can participate in energy, AS, and capacity markets (wherever applicable) **Rationale**: Requirement from FERC Order 841					
	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**

- Key Questions:
  - What does an ESR register as?
  - What is the difference between continuous and discontinuous participation models?
  - What are the key differences from separate load and generator models vs. a single combined model?

AS: Ancillary Service; **BPCG**: Bid Production Cost Guarantee; **BSF**: Binary Storage Facility; **CSF**: Continuous Storage Facility; **DAM**: Day-ahead Market; **DAMAP**: Day-Ahead Margin Assurance Payment; **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

Order 841: ESR Parameters

Physical or Operational Characteristic	Definition
State of Charge (% or MWh)	State of Charge represents the amount of energy stored in proportion to the limit on the amount of energy that can be stored, typically expressed as a percentage. It represents the forecasted starting State of Charge for the market interval being offered into.
Maximum State of Charge (% or MWh)	Maximum State of Charge represents a State of Charge value that should not be exceed (i.e., gone above) when a resource using the participation model for electric storage resources is receiving electric energy from the grid.
Minimum State of Charge (% or MWh)	Minimum State of Charge represents a State of Charge value that should not be exceeded (i.e., gone below) when a resource using the participation model for electric storage resources is injecting electric energy to the grid.
Maximum Charge Limit (MW)	Maximum Charge Limit represents the maximum MW quantity of electric energy that a resource using the participation model for electric storage resources can receive from the grid.
Maximum Discharge Limit (Pmax) (MW)	Maximum Discharge Limit represents the maximum MW quantity that a resource using the participation model for electric storage resources can inject to the grid.
Minimum Charge Time (minutes/hours)	Minimum Charge Time represents the shortest duration that a resource using the participation model for electric storage resources is able to be dispatched by the RTO/ISO to receive electric energy from the grid.
Maximum Charge Time (minutes/hours)	Maximum Charge Time represents the maximum duration that a resource using the participation model for electric storage resources is able to be dispatched by the RTO/ISO to receive electric energy from the grid.
Minimum Run Time (minutes/hours)	Minimum Run Time represents the minimum amount of time that a resource using the participation model for electric storage resources is able to inject electric energy to the grid (already provided by other generators).
Maximum Run Time (minutes/hours)	Maximum Run Time represents the maximum amount of time that a resource using the participation model for electric storage resources is able to inject electric energy to the grid.
Minimum Discharge Limit (MinGen) (MW)	The minimum MW output level that a resource using the participation model for electric storatge resources can inject onto the grid.
Minimum Charge Limit (MW)	The minimum MW level that a resource using the participation model for electric storage resources can receive from the grid.
Discharge Ramp Rate (MW/min)	The speed at which a resource using the participation model for electric storage resources can move from zero output to its Maximum Discharge Limit
Charge Ramp Rate (MW/min)	The speed at which a resource using the participation model for electric storage resources can move from zero output to its Maximum Charge Limit.

“the following chart summarizes the physical and operational characteristics of electric storage resources for which each RTO’s/ISO’s participation model for electric storage resources must account”-FERC

ISO/RTO Design Proposals: Implementation Details

Order 841 Aspect	NYISO	PJM	SPP	ISO-NE	MISO	CAISO
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) **Rationale**: ESRs have a continuous range of operation that extends from the maximum charge limit to the maximum discharge limit. ESRs do not have fixed costs such as no-load costs and startup 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** (to be modified); 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 (these values will be telemetered for three different horizons); 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 are submitted; min charge and run times for NGRs to be managed by SOC parameters or offers

- Key Questions:
  - What are the different physical and operating characteristics that potentially need to be accounted for?
    - State of charge (SOC, MWh); minimum SOC limit (MWh); maximum SOC limit (MWh); minimum charge limit (MW); maximum charge limit (MW); minimum discharge limit (MW); maximum discharge limit (MW); minimum charge time (minutes); maximum charge time (minutes); minimum run time (minutes); maximum run time (minutes); discharge ramp rate (MW/min); charge ramp rate (MW/min)
  - How will ISOs ensure that conflicting dispatch instructions will be avoided for ESRs?
  - What offer curve shape can be allowed?
  - What does an offer curve represent (e.g., simple cost to charge or discharge vs. price spread)?
  - How can degradation costs be included in an offer?

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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

[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 Design Proposals: Implementation Details

Order 841 Aspect	NYISO	PJM	SPP	ISO-NE	MISO	CAISO
Ancillary Services	1. Almost all ISOs are allowing ESRs to provide AS such as regulation and operating reserves (without requiring energy schedules) provided ESRs respect AS duration requirements while allowing for capacity de-rates to meet the duration **Rationale**: Requirement from FERC Order 841					
	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; ESRs participating in the DA scheduling reserve market require an energy schedule; introduced a new non-energy resource mode	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

- Key Questions:
  - What restrictions need to be put in place for ESRs providing ancillary services for reliability purposes?
  - What is the duration requirement for each ancillary service? Are these explicit in NERC/NPCC rules?
  - What is the cost of an ESR to provide an ancillary service?
  - Are there benefits to providing different regulation signals to ESRs due to fast response speed?

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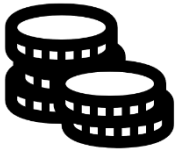
Order 841: Price Setting & Settlement

- 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

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ISO/RTO Design Proposals: Implementation Details

Order 841 Aspect	NYISO	PJM	SPP	ISO-NE	MISO	CAISO
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 **Rationale**: Requirement from FERC Order 841					
	ISO-SOCM ESRs ineligible for RT BPCG; ESRs are not eligible to receive DAMAP; withdrawals exempt from transmission charges	PSH using hydro optimizer cannot set wholesale prices and offer negative dispatchable range	ESR withdrawals exempt from transmission charges	Limited duration CSFs will not be paid for ancillary services; ESFs will be exempt from transmission charges when instructed by the ISO to charge	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

- Key Questions:
  - Should ESRs be eligible to set market clearing prices?
  - When should ESRs be charged uplift and when should they be exempt?
  - Should ESRs be eligible to receive make-whole payments when prices are less than offers (or greater than bids to buy)?

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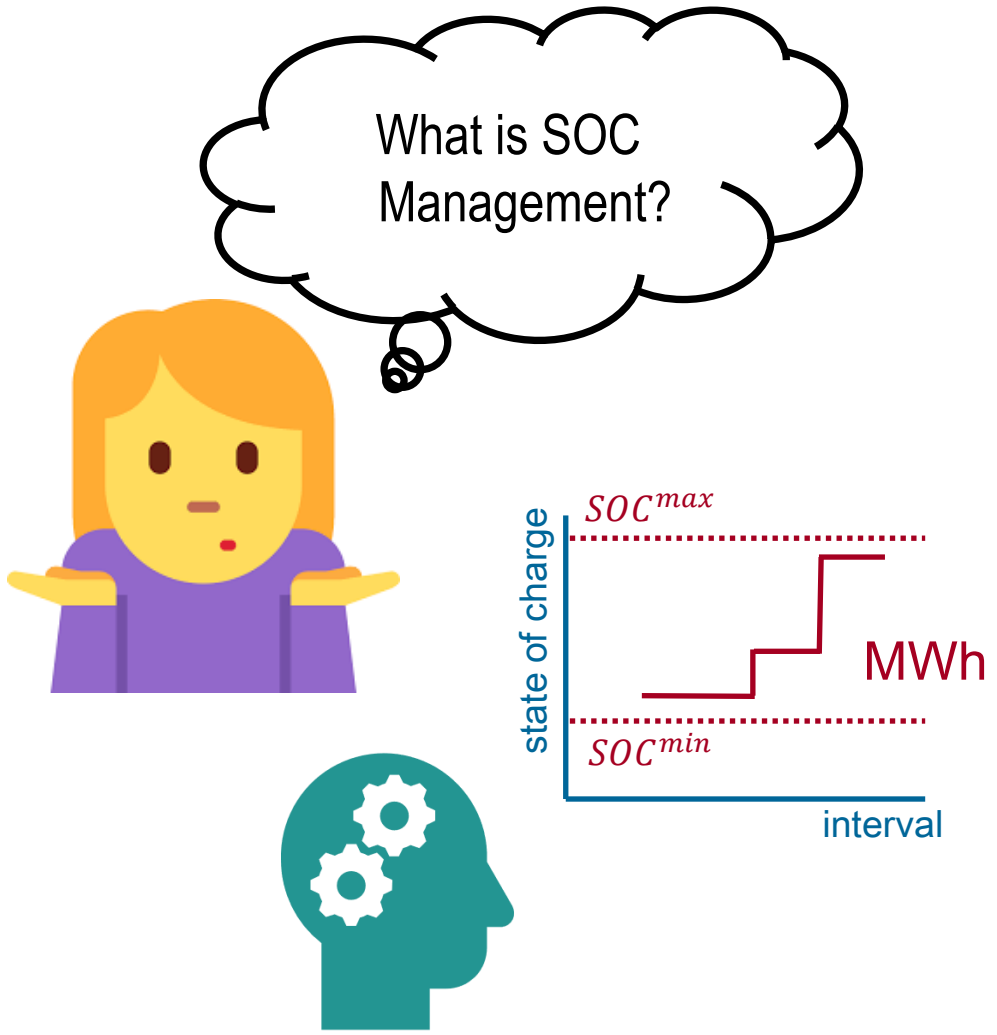
Order 841: State of Charge Management

- Required ISO to allow self-management of SOC by ESR
- Required “consideration” of SOC related parameters through bidding, telemetry, or otherwise (e.g., SOC limits, round-trip efficiency)

[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”).*

State of Charge Management: Introduction

- No *definitive* statement within FERC Order 841 on what SOC-Management means resulting in different interpretations and requests for clarifications (does not require ISO-SOC-Management; requires provision of SOC related bid parameters by ESRs and for ISOs to "*consider them*")

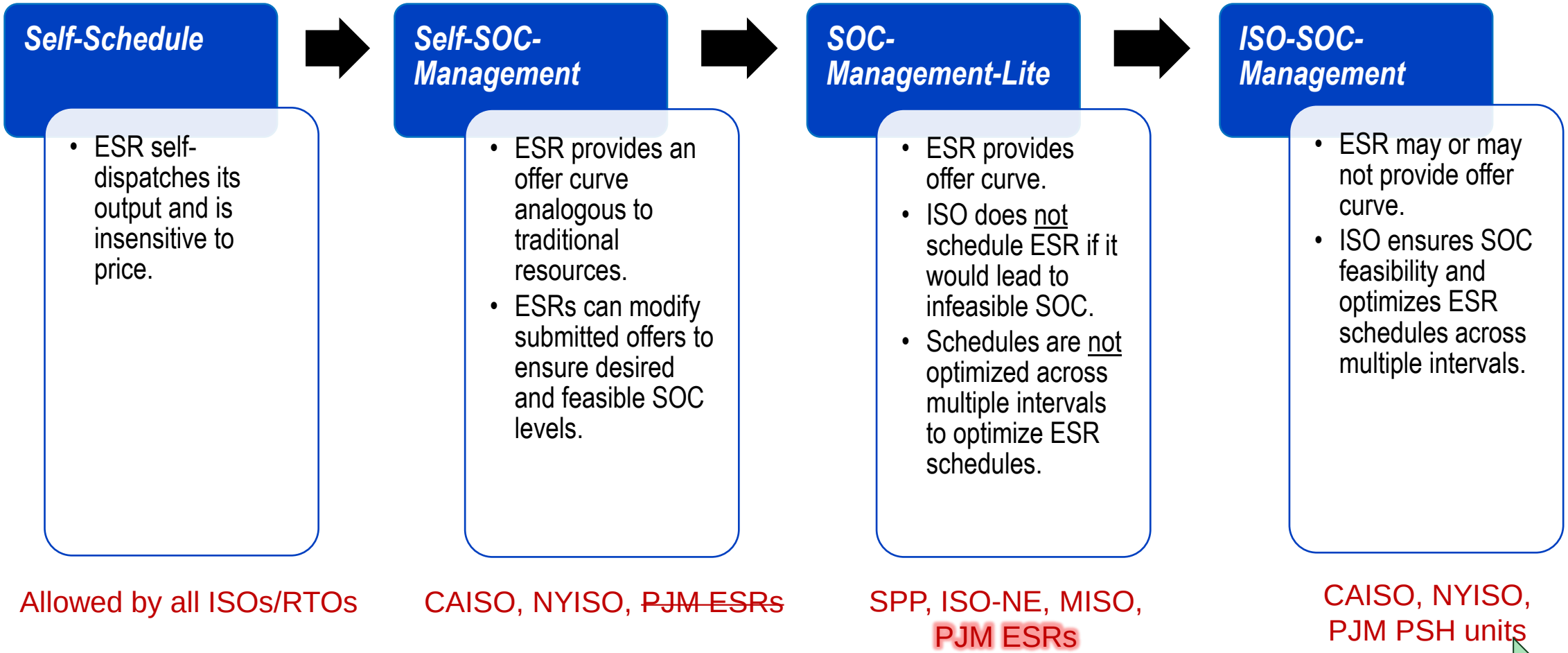


State of Charge Management: Introduction

- **Energy Storage Alliance**[1]:
  - **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**: ISO monitors current SOC, monitors and calculates anticipated SOC, and other related ESR parameters (e.g., roundtrip efficiency levels) and makes scheduling decisions that explicitly lead to a bid-based optimal and feasible energy 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.

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

State of Charge Management: Options



Anticipated SOC Management Impacts

Physical or Operational Characteristic	Self-SOC-Management	SOC-Management-Lite	ISO-SOC-Management
Economic Efficiency (theoretical)	Dependent on ESR offer curves. Infeasible schedules can lead to reliance on more expensive resources.	Dependent on ESR offer curve.	Improved economic efficiency in theory, schedules used to provide overall system-wide least cost based on offers.
SOC Feasibility	Feasibility cannot be guaranteed.	Excepting unforeseen conditions, feasibility can be guaranteed.	Excepting unforeseen conditions, feasibility can be guaranteed.
ESR Asset Owner Responsibility	Provide an offer that maximizes its profit and ensures feasibility. Subject to real-time imbalance payments and/or uninstructed deviation penalties if SOC violated.	Provide an offer that maximizes profit; must have some indication of what prices will potentially be to make most profit. SOC forecast, SOC limits and roundtrip efficiency used by the ISO.	Offer can be used to achieve a minimum profit based on anticipated costs beyond charging. Desired SOC level, SOC forecast and other operating parameters are used by the ISO.
ISO Responsibility	Schedule ESR like a traditional generator but that can be negative injection or positive injection.	Schedule ESR like a traditional generator with two additional SOC feasibility constraints (maximum and minimum SOC) and SOC calculation.	Schedule ESR to meet desired (or optimal) SOC point, aim to provide a price profit/spread, and ensure SOC feasibility constraints.
Optimization in Real-time	Same as day-ahead with offer curve.	Same as day-ahead with offer curve.	Complex. Shorter horizon with updated (more accurate) information. Need to know whether to overwrite day-ahead solution.

Anticipated SOC Management Impacts

Physical or Operational Characteristic	Self-SOC-Management	SOC-Management-Lite	ISO-SOC-Management
Price Setting	ESRs can set price equal to offer curve value when marginal.	ESRs can set price equal to a combination of the offer curve value and the shadow price of the SOC constraint when marginal. SOC limit similar to maximum capacity limit in that ESR cannot be marginal if binding SOC constraint.	Complex. ESR can be marginal throughout time period. Price can be based on various dual values (i.e., shadow prices) of several SOC constraints and influence by offers if provided.
Make-Whole Payments	ESR can earn make-whole payments based on offered costs if either revenue less than offer costs when injecting, or greater than bids when withdrawing.	ESR can earn make-whole payments based on offered costs, but not when SOC limits binding.	Complex. ESR can earn make-whole payments if total revenue (payments to minus payments from) is negative. If desired SOC is less than starting SOC, additional modifications to calculation may be warranted.
Market Mitigation and Withholding	Complex. Must distinguish between high prices used to avoid SOC infeasibility with high prices or de-rated range used for withholding.	Fairly straightforward. Higher prices than expected may be mitigated.	If no offers, fairly straightforward. No offers to mitigate. If offer, may need verifiable spread costs.
Computational Efficiency	Fairly straightforward, just additional resources. No additional variables or constraints needed.	Moderate complexity. Requires separate charging and discharging variables, and additional constraints per ESR. Single economic dispatch still limited computation need.	More complexity. All variables and constraints from SOCM-Lite plus additional time-coupling constraints to respect desired SOC limitations.

ISO/RTO Design Proposals: Implementation Details

Order 841 Aspect	NYISO	PJM	SPP	ISO-NE	MISO	CAISO
State of Charge Management	1. Only a few ISOs are offering both **ISO-SOCM** and **Self-SOCM**. Other ISOs are offering a hybrid **SOCM-Lite** option. **2.** **ISO-SOCM**: SOC is a variable in multi-interval optimization and the ISO ensures SOC feasibility. **SOCM-Lite**: SOC is a parameter in sequential optimization and the ISO ensures SOC feasibility. **Rationale**: Requirements from FERC Order 841; SOCM option is also impacted by the market clearing software design					
	ISO-SOCM (excludes desired ending SOC level) 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, and between DAM and RTM; **PSH plants – Self-SOCM**	**ESRs – Self-SOCM** (current SOC telemetry will not be used to optimize ESRs across intervals; directed by FERC to instead implement **SOCM-Lite**, i.e., ensure SOC feasibility and account for: 1) SOC, and 2) min and max SOC limits in its sequential optimization); **PSH plants – ISO-SOCM**	**SOCM-Lite** (ensures SOC feasibility in sequential optimization); can submit max daily MWh limit	**SOCM-Lite** (includes two new telemetered points in RT, i.e., 15-minute and 1-hour available energy and storage, to ensure SOC feasibility in sequential optimization); ESFs can submit max daily MWh charge and discharge limits in the DAM	**SOCM-Lite** (ensures SOC feasibility in sequential optimization); max daily MWh limit included only for PSH plants	**ISO-SOCM** (excludes desired ending SOC level) and **Self-SOCM** (does not ensure SOC feasibility); can submit daily min and max MWh limits for DAM

- Key Questions:
  - What is state of charge management (SOCM)?
  - What are the different SOCM options?
  - Why do the ISOs differ in the SOCM option that is being offered to ESRs?
  - How does the market clearing software design impact SOCM?

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United States ISO/RTO ESR Integration Status

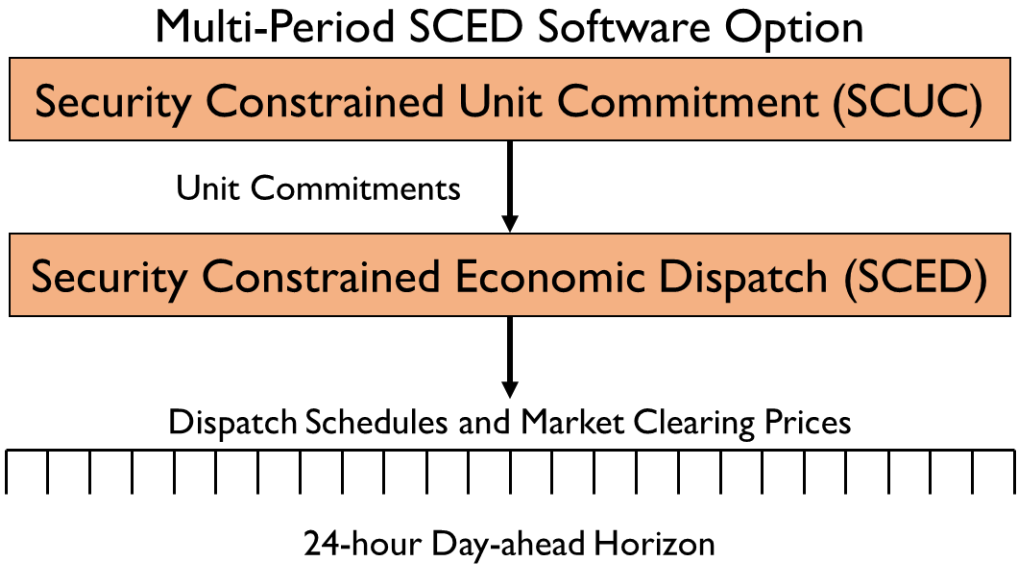
FERC Order 841	NYISO	PJM	SPP	ISO-NE	MISO	CAISO
Status	ESR Tariff revisions anticipated to be implemented no earlier than **May 1, 2020**. Implementation will likely exclude additional modifications to its ELRs model, primarily in place for PSH resources. Modifications to ELR model will commence in 2020 pending stakeholder approval.	On **October 17, 2019**, FERC accepted PJM's revisions to its Open Access Transmission Tariff, with certain modifications, effective December 3, 2019, subject to further compliance filing, and to further become effective on a date that is to be set by PJM.	FERC issued an Order on **October 17, 2019**, accepting in part, and rejecting in part, SPP's compliance filing, subject to further compliance filing, and necessitated that the changes become effective by July 17, 2020.	Most significant changes since 2018 include modifications to the make-whole payments that will be reimbursable to CSFs, provision of an additional option for limited-energy CSFs to opt out of reserve provision, and incorporation of available energy and available storage telemetry for three different horizons.	MISO has requested for an additional 18 months from FERC's acceptance of its proposed Tariff revisions (newly proposed implementation date of **February 2021**).	The most significant changes since 2018 include the proposal for ESRs to aggregate across multiple pricing nodes to meet minimum size requirements, details on its RTM ISO-SOCM approach, and the ISO's proposal to account for ESR's degradation costs.
Rationale for Delays	Significant software enhancements.	Further analysis of PJM's 10-hour requirement for its reliability pricing model (RPM), and appropriate accounting for SOC enhancement in PJM's ESR model.	New Settlement Management System production delays and anticipated software modifications. SPP has further requested a (second) deferral of the implementation deadline to **August 5, 2021**.		Anticipated modifications to MISO's software and business processes are considerably more complicated than initially projected.	

Questions?

Together...Shaping the Future of Electricity

Market Clearing Software Subtleties

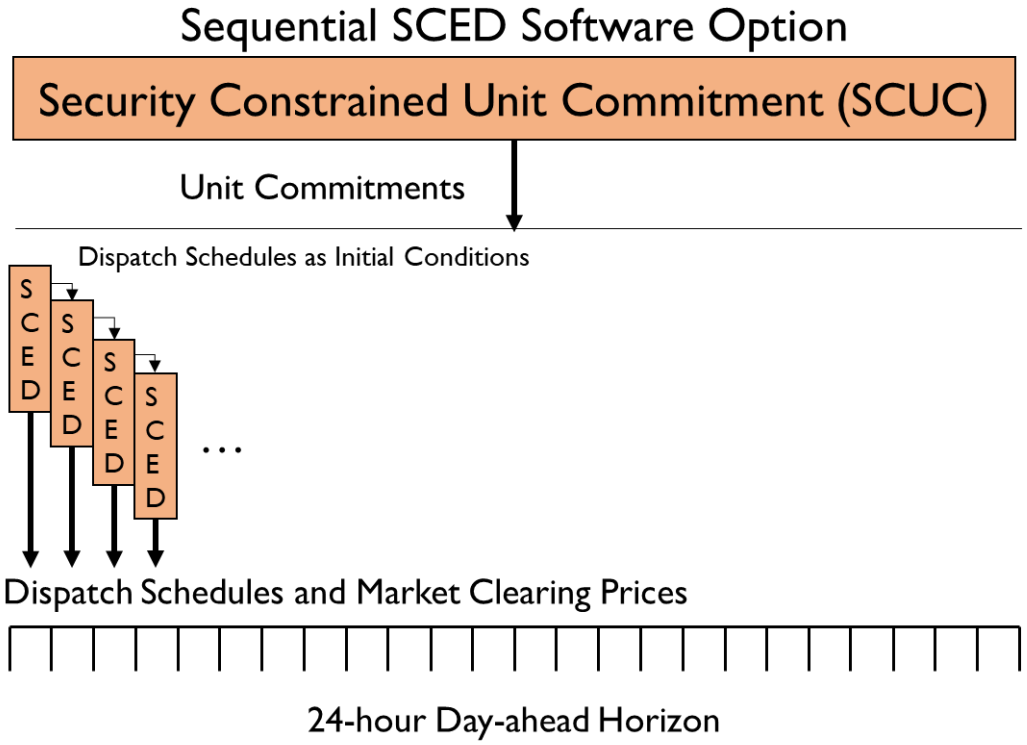
ISO-SOC-Management



CAISO, NYISO

Previous hour's SOC is a variable in dispatch/LMP calculation

SOC-Management-Lite



SPP, ISO-NE, MISO, PJM

Previous hour's SOC is a parameter in dispatch/LMP calculation

1) **SIEMENS**: CAISO, 2) **ABB**: NYISO, ERCOT, 3) **GE/ AREVA**: SPP, ISO-NE, MISO, PJM

State of Charge Management: Options

ISO-SOC-Management

1. Multi-interval economic dispatch
2. Previous hour's SOC is a variable in economic dispatch/ LMP calculation
3. SOC is managed across a known horizon to ensure feasibility and optimality
4. Does not require offers, but ESRs can still submit offers, e.g., to account for degradation costs
5. May include an additional feature to avoid myopic decisions, e.g., a desired SOC at the end of the horizon, or a value in $/MWh provided by the ESR to demonstrate the value of keeping energy left over at the end of the day

SOC-Management-Lite

1. Sequential economic dispatch
2. Previous hour's SOC is a parameter in economic dispatch/ LMP calculation
3. SOC is used in each market interval to ensure the ESR's schedule is feasible
4. Requires offers to be submitted by market participants