Alternative Market Designs for Hybrid Resources

Integration Challenges/ Research Opportunities

Nikita Singhal, Erik Ela, Adriano Abrantes

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Hybrid Resource: (tentative) Definition

- A resource facility consisting of multiple co-located assets comprising of multiple technologies that can potentially inject and/or withdraw under a single (operation) control system and participates as a single resource
  - Co-located (easier to model network impacts, cost reduction, tightly-coupled)
  - Multiple technologies (varied fuel sources)
  - Excludes aggregation of similar technology resources
  - Operates differently than if the multiple technologies comprising the hybrid resource were independent
  - Combined technology focus: Renewables plus electric storage resources (ESRs)

Hybrid Resource: Motivation

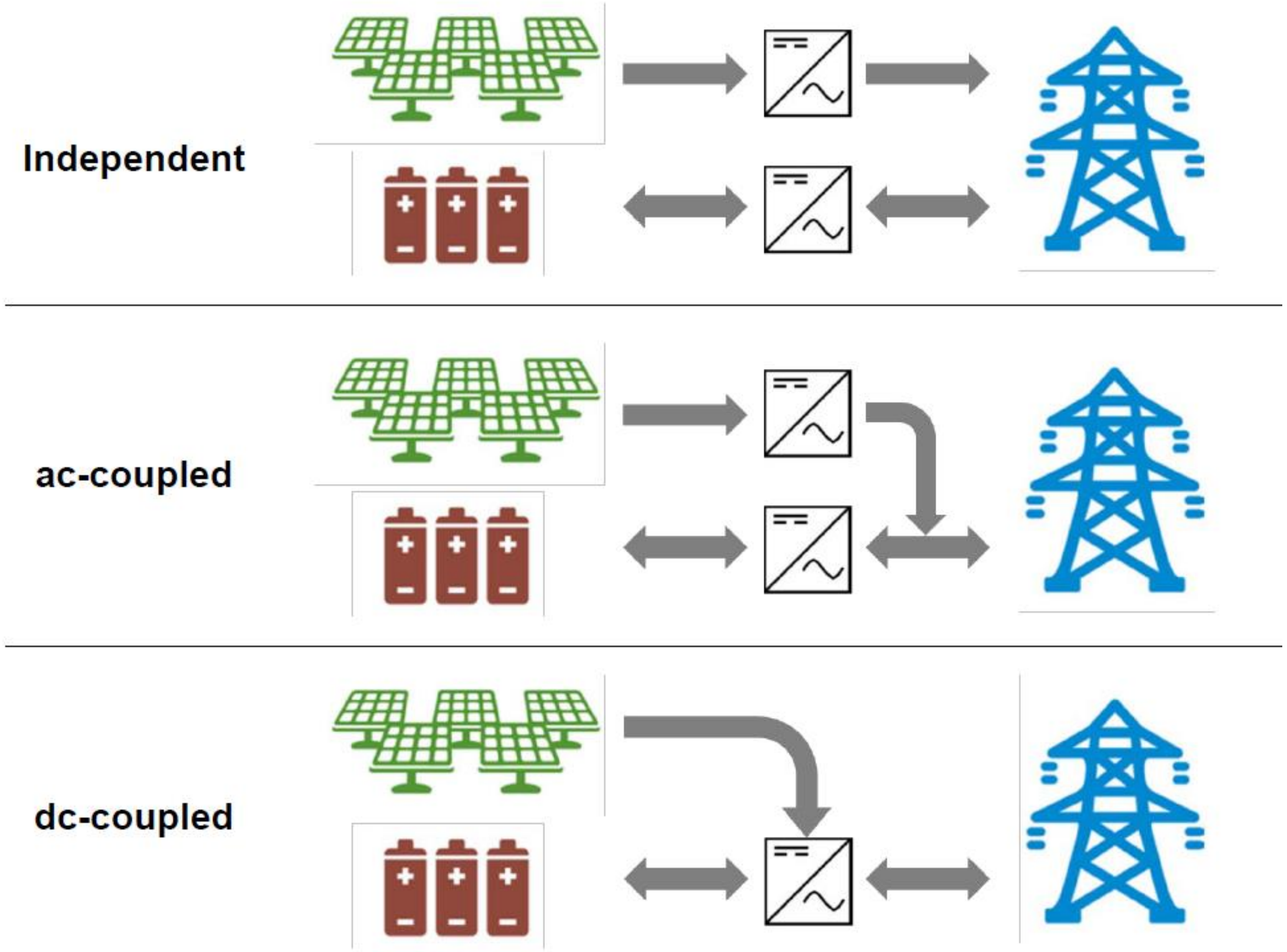
- Additional essential reliability service provision (eligibility requirements, RRS)
- Reduces curtailments: Improved net load, increases penetration levels of VERs
- Assists in shifting PV production to peak demand periods
- Enhances reliable operations and efficiency: increased VER dispatch flexibility, ability to hedge against forecast errors
- Declining costs of individual technologies, reduced costs of combined technology resources (economically competitive with traditional resources)
  - Increased deployment of BTM ESRs: Backup power, demand charge reductions, time shifting, T&D deferrals, Order 841, etc.
  - Increased deployment of PV: Energy production, capacity, demand charge reductions, T&D deferral, potential AS provision
- Rapidly varying market policies: ITC, Order 841, initiatives around improving air quality and reducing emissions by enabling emerging resource technologies (e.g., SWRI-CPS energy 5 MW PV-10 MWh BESS)

Coupling strategies: Renewables-ESRs

- Independent: Not co-located
- ac coupled: Generally co-located; independent inverters to interface with the grid independently
- dc coupled: Generally co-located; single inverter
- Cost and value comparison of different coupling configurations [1]
  - Co-located: Reduces costs (project development, installation, O&M, etc.)
  - ITC: Qualified when tightly coupled (>=75% of charging energy from PV)
  - Equipment sharing: Reduces costs (dc coupled)
  - Value: Inverse relationship with cost? (T&D deferral↓, equipment sharing – sized < maximum combined output↓, clipped energy – dc coupled↑)

[1] *Integration costs and value of solar-and-storage coupled systems.* EPRI, Palo Alto, CA: 2019. 3002015331.

Coupling strategies: PV-ESR



[2] Image source: Evaluating the Technical and Economic Performance of PV Plus Storage Power Plants. National Renewable Energy Laboratory, Golden, CO: 2017. NREL/TP-6A20-68737.

Electricity Market Design Challenges

- Participation model
  - Option 1: Explicitly capture unique characteristics
  - Option 2: Allow for self-management of unique features via offer parameters (associated market implications, acceptable penetration levels)
  - Commitment and dispatch as a single resource? Commitment modes?
  - Impact on constraints beyond traditional constraints (individual/combined resource constraints, SOC constraints, coupling-strategy dependent constraints)
  - Model as two separate resources or one? (existing differences in the manner in which VERs are treated in the market), (existing option to model as separate resources will continue to exist regardless)
  - Computational complexities (advanced configuration-based modeling)
  - Representation when tightly-coupled?
  - ESRs design challenges beyond batteries (CAES)

Electricity Market Design Challenges

- Forecasting-related challenges:
  - Two separate meters? Separate v/s combined metering practices?
  - Should the ISOs/RTOs use the forecasted values in RUC? Who provides the forecasts?
  - Ability to bid/offer into the DAM
  - Ability to adjust their forecasts near real-time? (reliability implications – increased operator confidence due to their enhanced ability to satisfy the submitted offers?)
- Offer parameters:
  - Development similar to VERs or standalone ESRs, Order 841 (13 parameters)

Electricity Market Design Challenges

- State-of-charge management (SOCM):
  - Telemetry from individual resources?
  - ISO-SOCM v/s Self-SOCM: appropriate consideration of SOC limits
- Visibility: Hybrid resources not revealing the ESR capacity (SCADA being off)
- Capacity markets (RA): Rules for qualification, accreditation, and must offer obligations for both separate and combined capacity? Will this be separate if one of the sub-devices is a VER?
- Mitigation rules:
  - Uncertainty around how the submitted offers should be mitigated
  - Which resource incurs the cost (charging from VERs v/s grid)
  - Stand-alone ESRs (Order 841 challenges)

FERC Order 841 Description and ISO/RTO Implementation Proposals

[3] 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”).

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)
- Hybrid resources out of scope (although can use ESR participation model)

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
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					
	Self-committed fixed/flexible ESRs ineli-gible to receive DA BPCG payments but 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				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	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)	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	**10 sustained hours**	**4 sustained hours** to meet RA requirements	**2 sustained hours**	**4 sustained hours**	**4 sustained hours** for RA participation

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

[4] *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 <u>only</u> the Self-SOCM option, i.e., SPP, ISO-NE and MISO, are ensuring SOC feasibility					
	ISO-SOCM (ensures SOC feasibility & optimality) and **Self-SOCM** (does not ensure SOC feasibility but ISO will align schedules with telemetered SOC); **PSH plants – Self-SOCM**	**ESRs** (continuous model) – **Self-SOCM** (does not ensure SOC feasibility); **PSH plants – ISO-SOCM**	**Self-SOCM**; ensures SOC feasibility; can submit max daily MWh limit	**Self-SOCM**; two new telemetered points in RT to ensure SOC feasibility; can submit max daily MWh limit	**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)
Minimum Size	1. All entities have reduced their minimum size limit to 100 kW for all markets					
					Phased approach with limited number of ESRs at this size	
Metering	1. All entities have required ESRs to be directly metered					

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

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

Market Design Research Challenges

- ISO/RTO Energy Storage Market Modeling WG in 2017 [3]

Self management vs. ISO management of SOC– efficiency and reliability impacts	Bidding and scheduling of ESRs in day-ahead (long-horizon, hourly SCUC) energy markets	Bidding and scheduling of ESRs in real-time (single- or limited time-horizon, sub-hourly SCUC & SCED) energy markets
Price formation topics with ESRs as marginal resources – how/when ESRs can set price	Provision of AS, co-optimization with energy considering characteristics of ESRs	Settlement design (including make-whole payments)
AGC enhancements for extracting maximum value out of ESRs	Small resource and computational impacts of significant ESR numbers	Contribution of ESRs in capacity markets

[5] *Independent System Operator and Regional Transmission Organization Energy Storage Market Modeling Working Group White Paper: A report on current state of art in modeling energy storage in electricity markets and alternative designs for improved economic efficiency and reliability*. EPRI, Palo Alto, CA: 2017. 3002012327.

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

ISO-SOC-Management

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

PJM PSH units, NYISO, CAISO

ISO Scheduling Responsibility and Economic Efficiency Benefits →

← **ESR Asset Owner Participation Responsibility and Flexibility**

Topical Challenges: Hybrid Resources

- Design and development of a participation model
  - Offer parameters, unit commitment and economic dispatch design, ancillary service provision, price setting, make-whole payments, etc.
- SOC management options
- Computational challenges
- Evaluation of economic and reliability savings that can potentially be obtained with such hybrid resource technologies
- Evaluation of improved methods for determining capacity value duration levels
- Incentivize the provision of primary frequency response service

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nsinghal@epri.com

eela@epri.com

aabrantes@epri.com

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*.**

SOC Management: Self SOCM

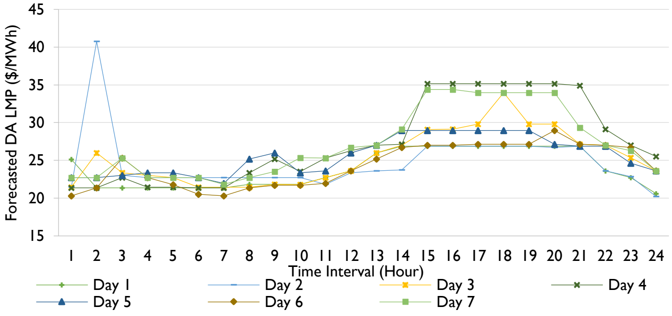
- **Key study assumption**: Self SOCM implies the ISO does NOT explicitly include SOC related constraints, e.g., minimum and maximum SOC, desired SOC, etc.
- **Need**: Represent ESR offer curves appropriately
- **SPP outlook**: Established a development guide for the ESR assets to come up with offer curves – "The fuel cost for an ESR is the unweighted average LMP that is expected for the next Operating Hour adjusted for Round-Trip Efficiency. This expected average LMP for the next Operating Hour is the average of the LMPs for the most recent 45 days comparing like Operating Hours."

[5] Southwest Power Pool, Inc., Open Access Transmission Tariff, Sixth Revised Volume No. 1 ("Tariff").

SOC Management: Self SOCM Offers

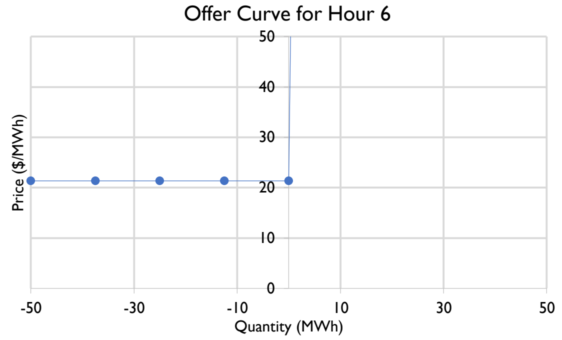
Alternatives: Similar historical day, average prices from historical data, etc.

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

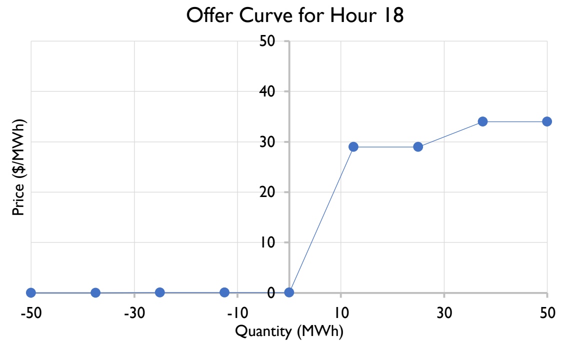


ESR Bidding Strategy Problem

- **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



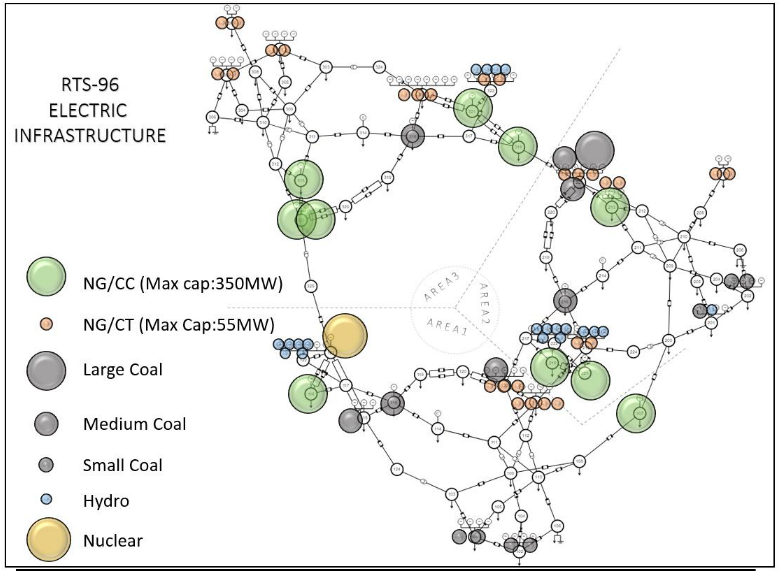
Case Studies Introduction

- **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: **F**lexible **E**nergy **S**cheduling **T**ool for **I**ntegrating **V**ariable generation
  - Varying levels of ESR, levels of VER

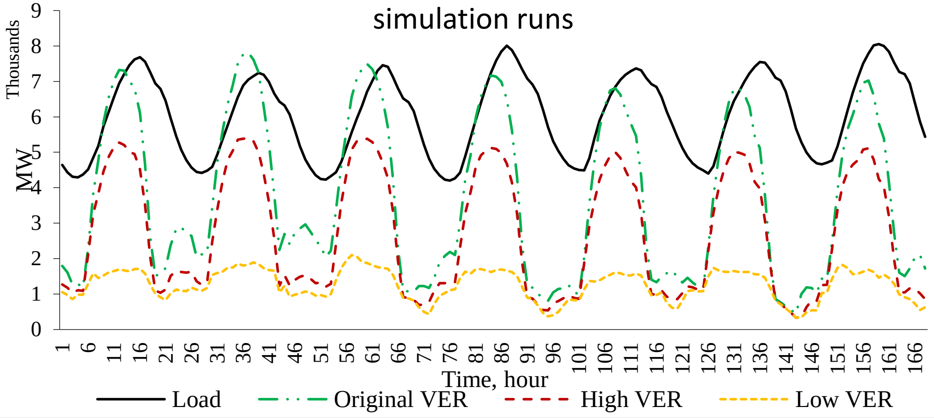
DA SCUC: Day-ahead Security Constrained Unit Commitment, **RT SCUC**: Real-time Security Constrained Unit Commitment,
RT SCED: Real-time Security Constrained Economic Dispatch, **AGC**: Automatic Generation Control

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



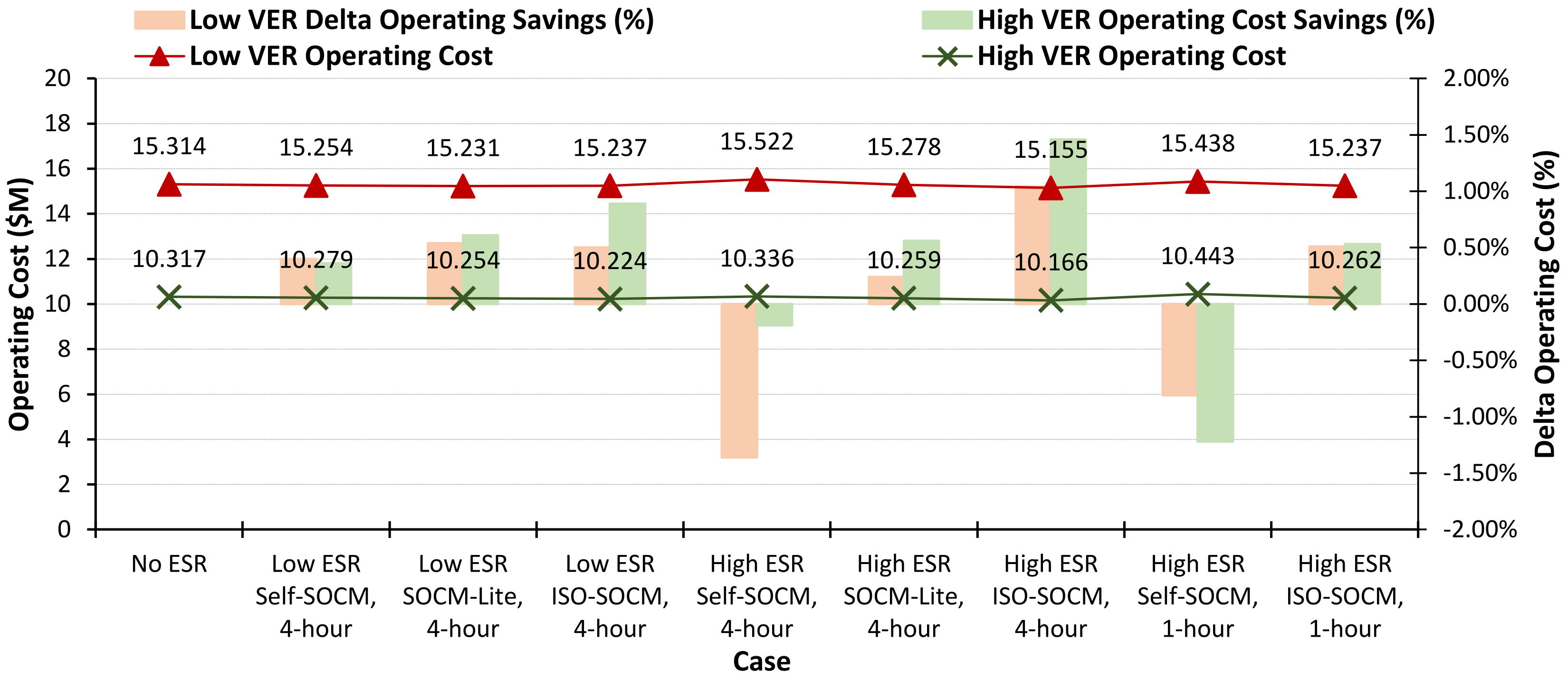
- Realistic moderate-sized system, small enough to see specific changes with sensitivities
- Dispatchable generation: 8,076 MW, hydro: 1,000 MW, VER: 14,850 MW
  - Low VER: 2,250 MW
  - High VER: 11,000 MW

*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

- ***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