Solar + Storage for Resource Adequacy and Ramp Control

Andrew Mills and Pía Rodríguez

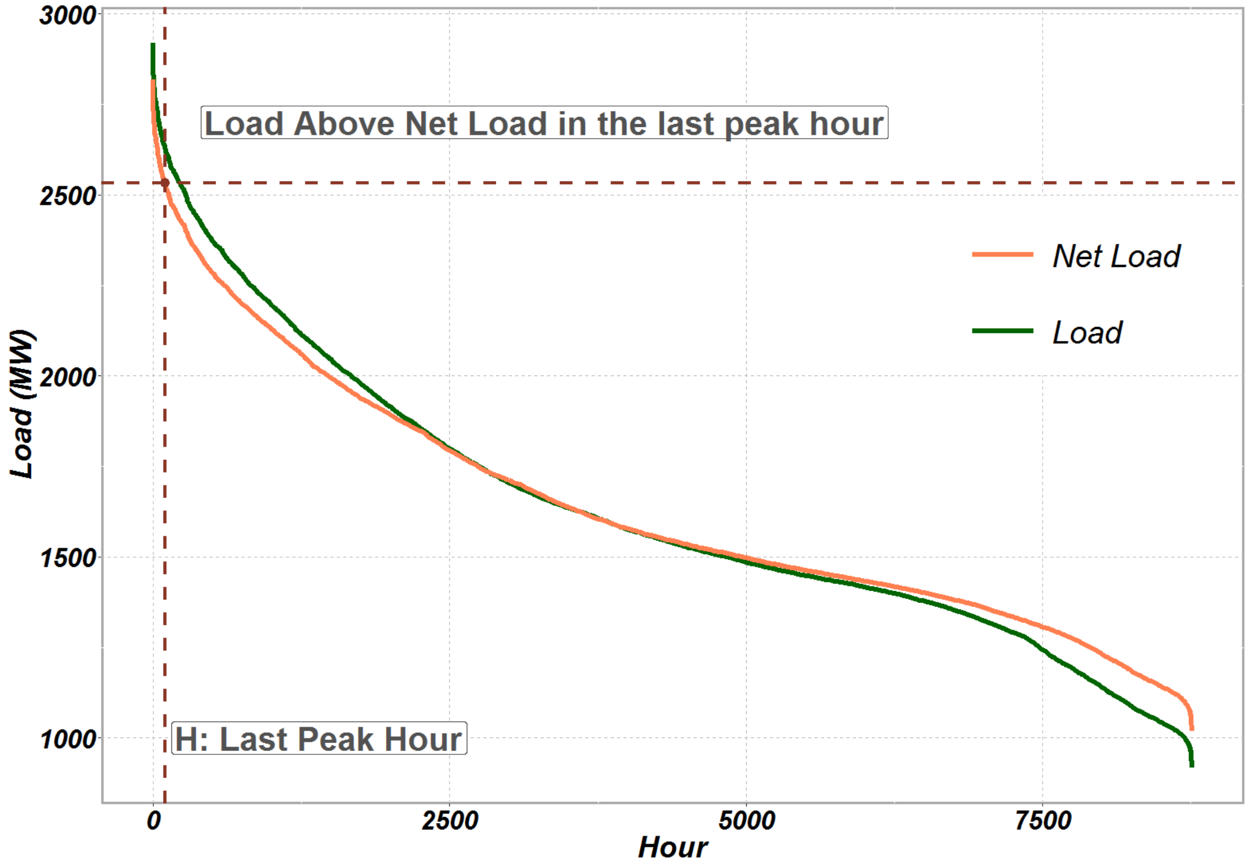
Lawrence Berkeley National Laboratory

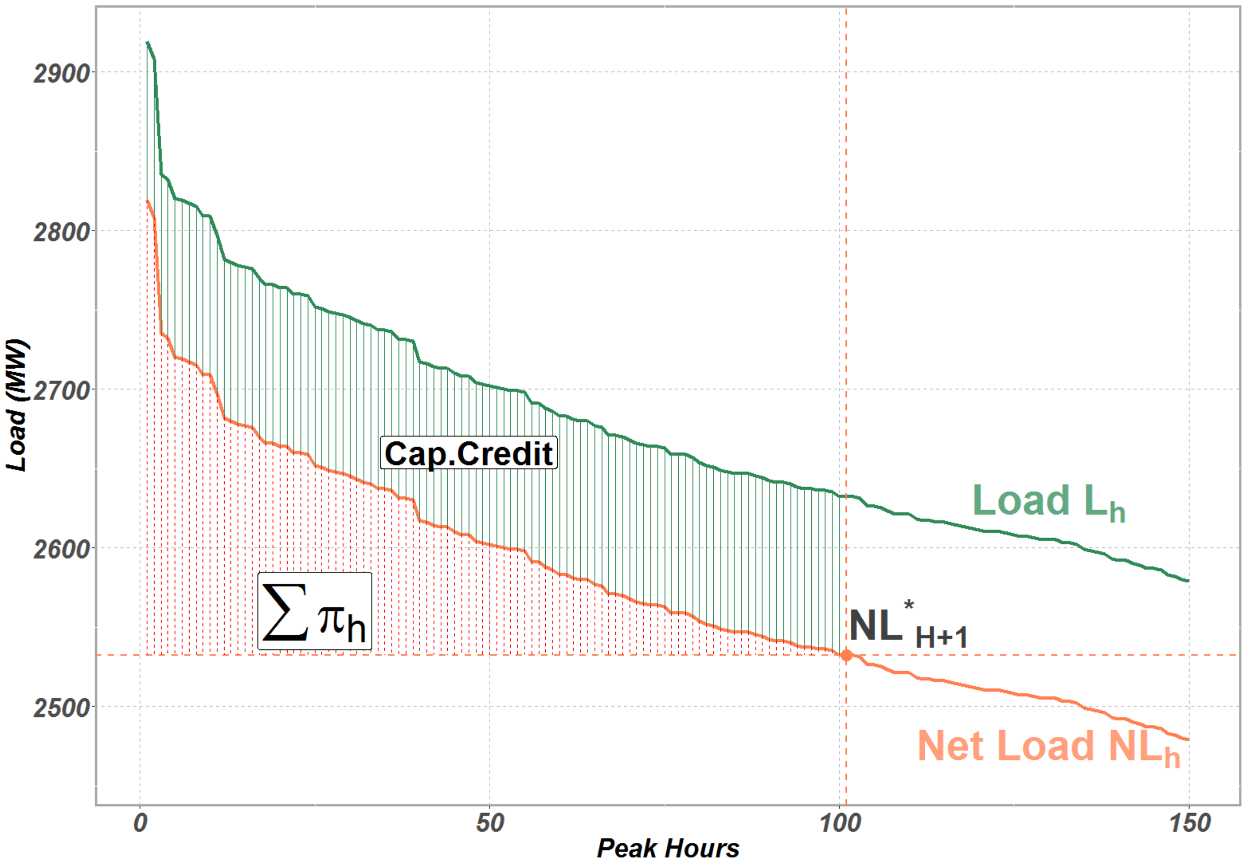
ESIG 2020 Spring Technical Workshop

April 23, 2020

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technology Office, Award Number DE-EE0007668.

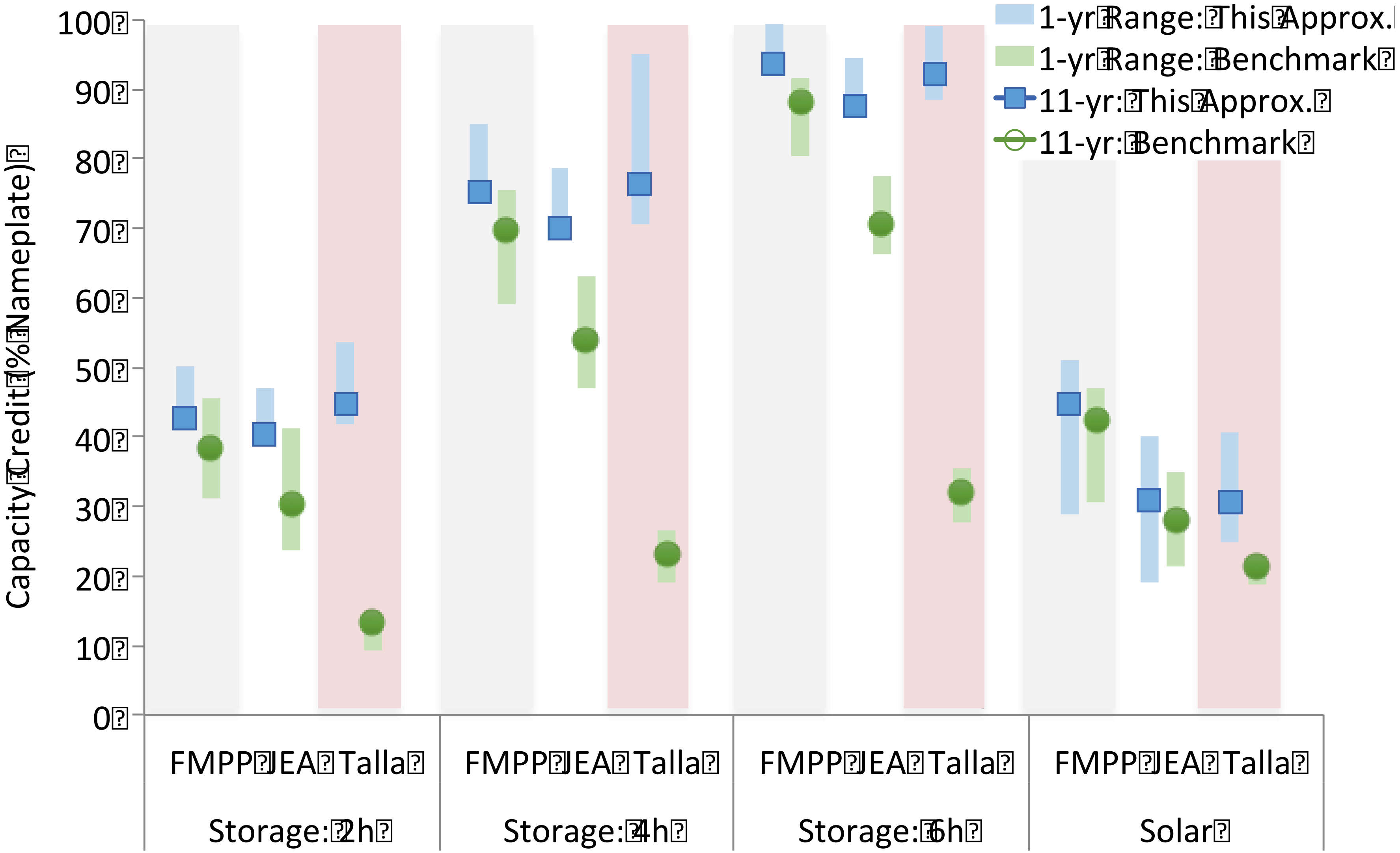
Storage Dispatch to Maximize Capacity Credit of Storage





Define capacity credit similar to NREL's "Resource Planning Model": difference of the highest peak load hours and highest peak net load hours. Use a simple linear model to find the storage dispatch that maximizes this capacity credit.

Capacity Credit Calculated with Simplified Method is Consistent with Probabilistic Benchmark Except for Very Small Utilities

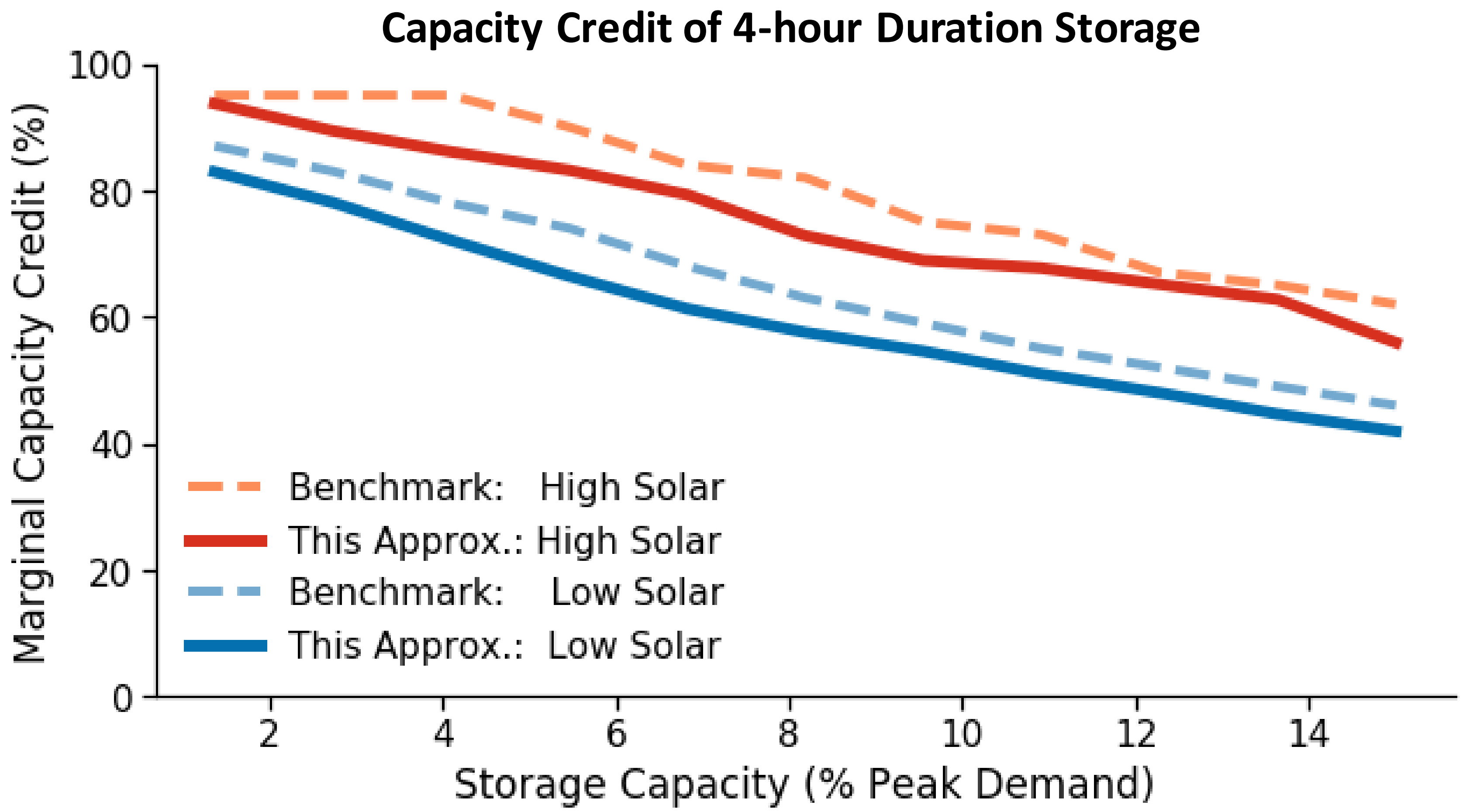


Probabilistic benchmark uses a simple Loss of Load Probability model to calculate the Effective Load Carrying Capability (ELCC).

ELCC represents the amount that the demand can be increased after a resource is added to the generation mix while maintaining the same level of overall reliability (2.4 LOLH/yr).

Approximation method only performs poorly for a small utility with a large generator (Talla).

Approximation Also Validated With a Probabilistic Benchmark from a Utility in the Western US



Probabilistic benchmark is a detailed Loss of Load Probability model used by the utility for planning.

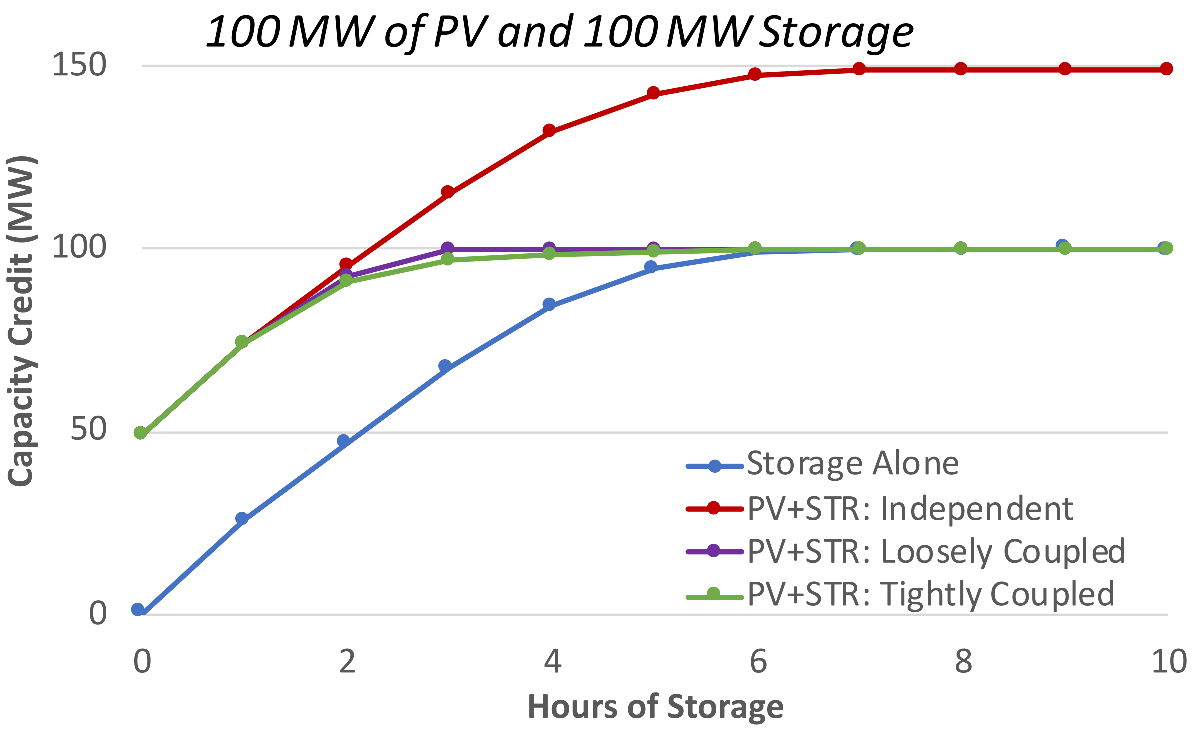
The Benchmark shows the utility's estimated ELCC of 4-hour duration storage with a reliability criteria of 2.4 LOLH/yr.

Approximation method uses the utility's net load data to calculate the capacity credit of storage.

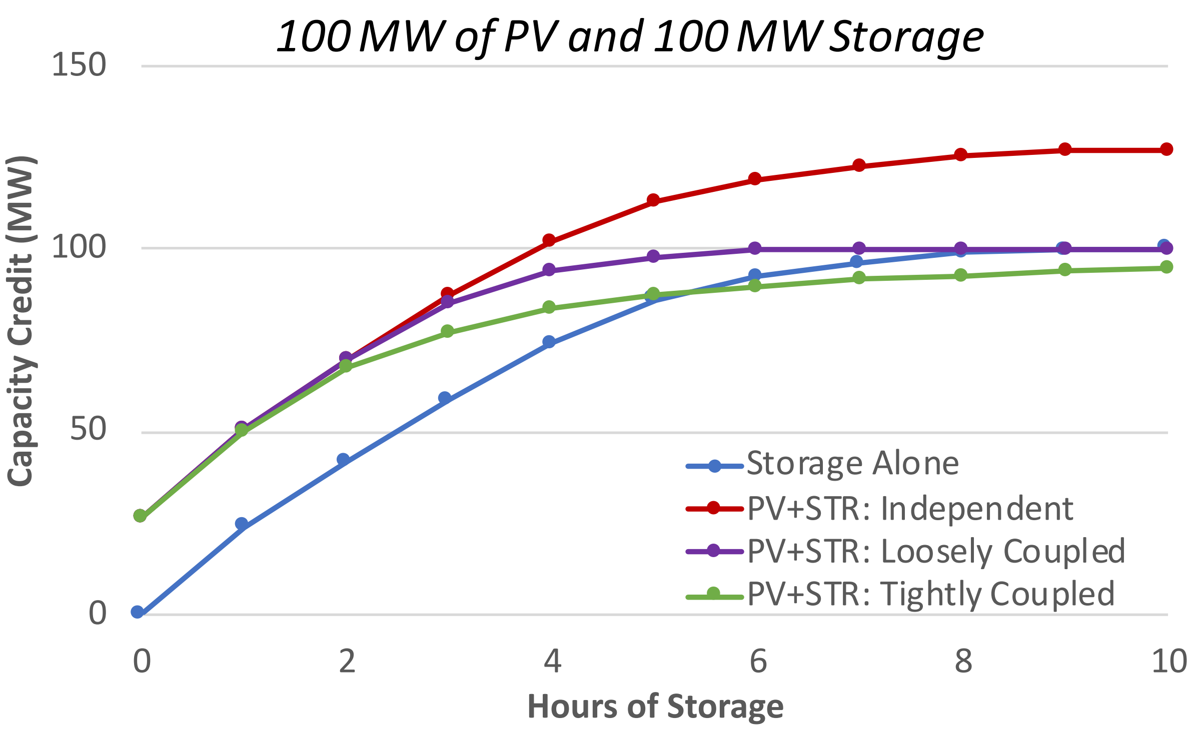
Both approaches show a declining capacity credit of 4-hour duration storage, and increase in capacity credit with high system-wide solar.

Capacity Credit of Solar+Storage Systems With Large Batteries Depends on Configuration

FMPP (Load has high summer peaks)



JEA (Load has high winter and summer peaks)

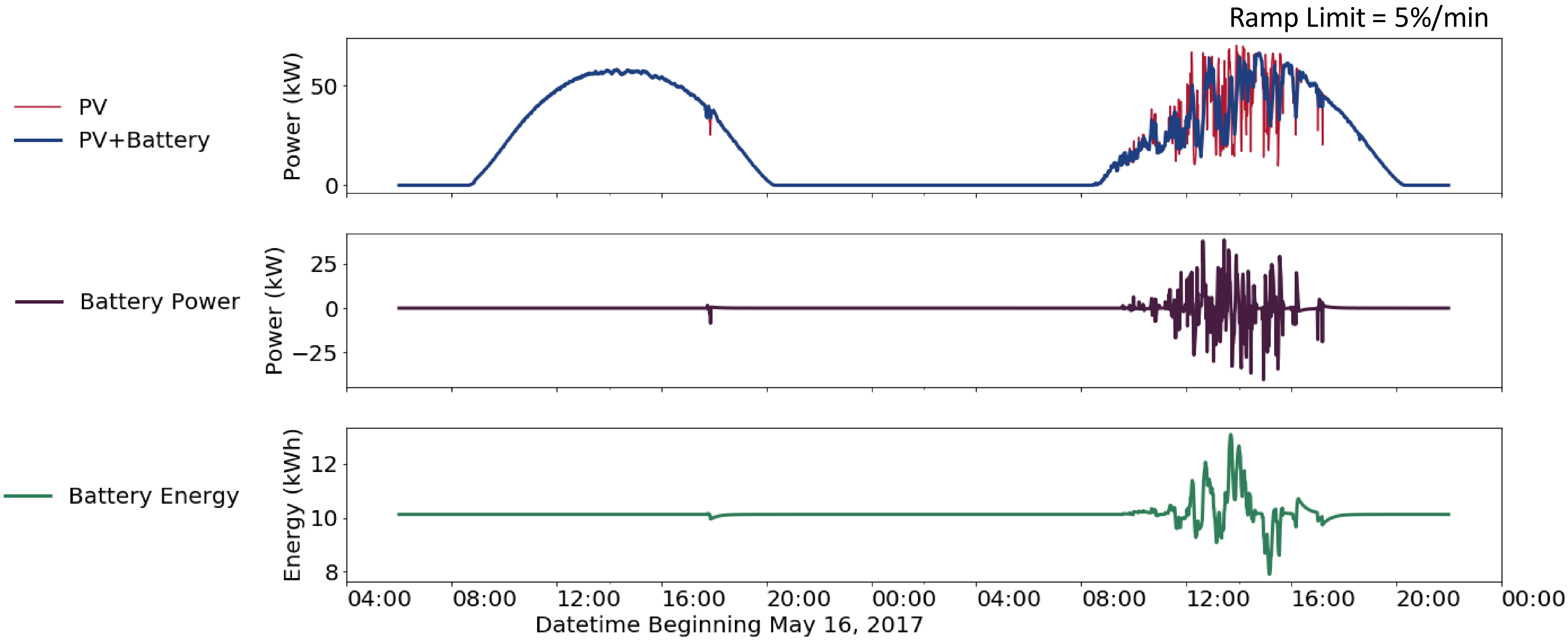


- Capacity credit of PV+Storage can be limited by the shared inverter when DC coupled (or shared point of interconnection limit for AC coupled)
- No significant difference for loosely vs. tightly coupled

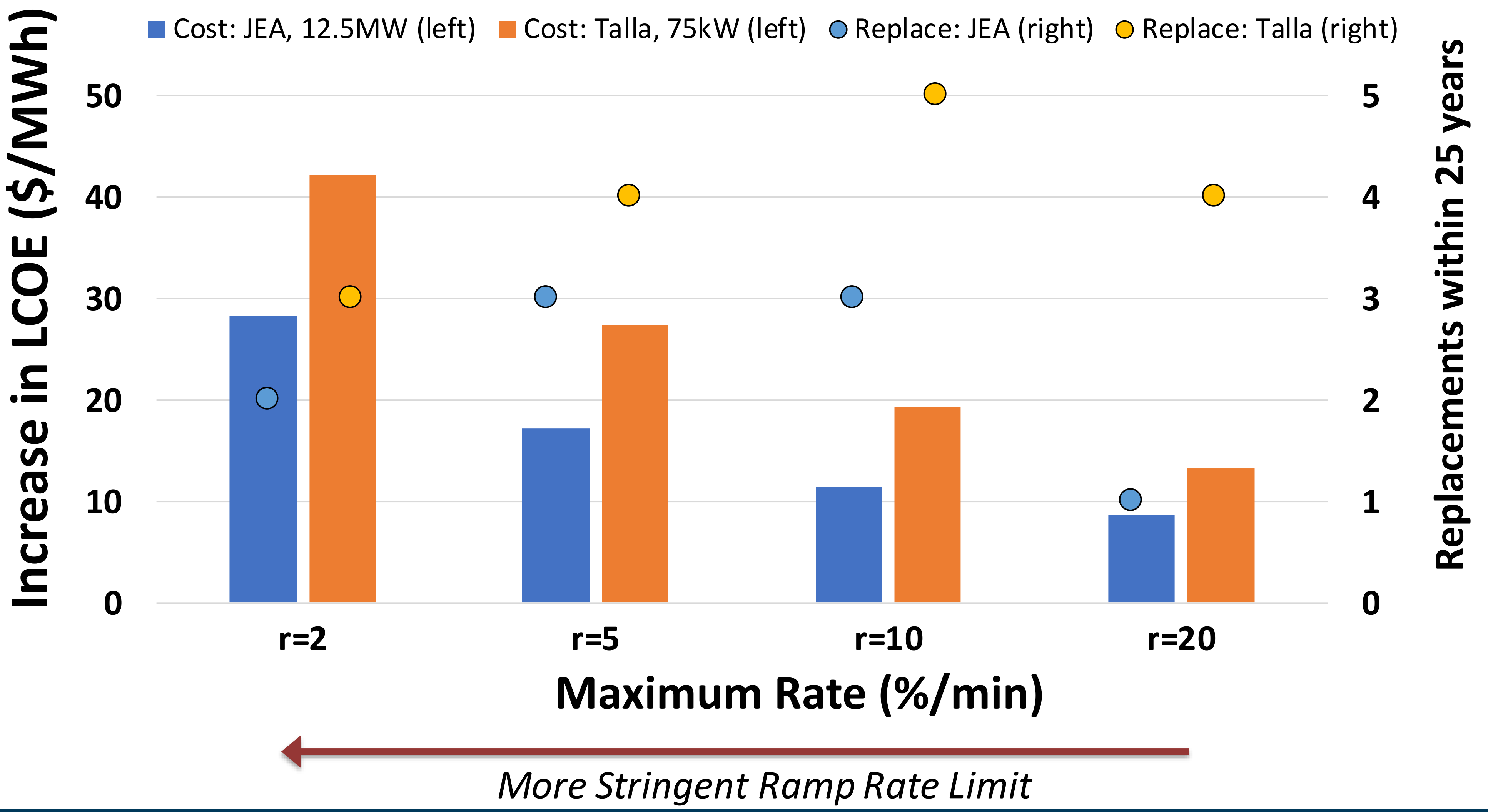
- For a load with high winter peaks, differences between loosely and tightly coupled are more important
- Restricting storage to charge only from solar can lead to a lower capacity credit than storage alone

Solar + Storage Ramp Control

Dispatch Battery Using a Simple Daytime Charging Ramp Control Model



Incremental Battery Costs Increase with Stringency of Ramp Rate Limits



Battery Costs (Fu 2018): = $285/kWh + $106/kW

Battery nameplate equal to solar nameplate

Discount rate of 6.4%

Replacement when battery degrades to 80% of energy capacity

Increase in LCOE represents incremental cost per unit of solar energy to meet ramp limit

Discussion

- Capacity credit of solar varies by utility; capacity credit of storage varies with storage duration
- Capacity credit of solar+storage can be limited by shared inverter (or point of interconnection limit) when batteries are large
- Batteries can be added to solar plants to meet specific ramp-rate limitations, though there are additional costs
- Duration of battery storage and power rating requirements increase with more stringent ramp rate requirements. Larger batteries increase costs.
- Degradation of batteries is more severe with small PV systems that more frequently require large charge and discharge cycles

Additional Directions to Explore

- How do battery size, degradation, and total costs change with various other ramp control strategies?
- How do the costs of ramp-rate limits compare to alternative approaches to managing variability?
  - Geographic diversity: smoothing over larger footprints suggests it may be less expensive to manage aggregate PV ramps rather than ramps at individual PV locations
  - Flexibility from PV curtailment and dispatch
  - Ramping and balancing reserves from dispatchable generators
- How can ramp-control costs be reduced by providing multiple services from the same battery?

Questions?

- Contact information
  - Andrew Mills
  - admills@lbl.gov
  - 510-486-4059

Mills, A.D., and P. Rodriguez. 2019. *Drivers of the Resource Adequacy Contribution of Solar and Storage for Florida Municipal Utilities*. Berkeley, CA: Lawrence Berkeley National Laboratory, October. https://escholarship.org/uc/item/9xz19063

Download all of our work at:

http://emp.lbl.gov/reports/re

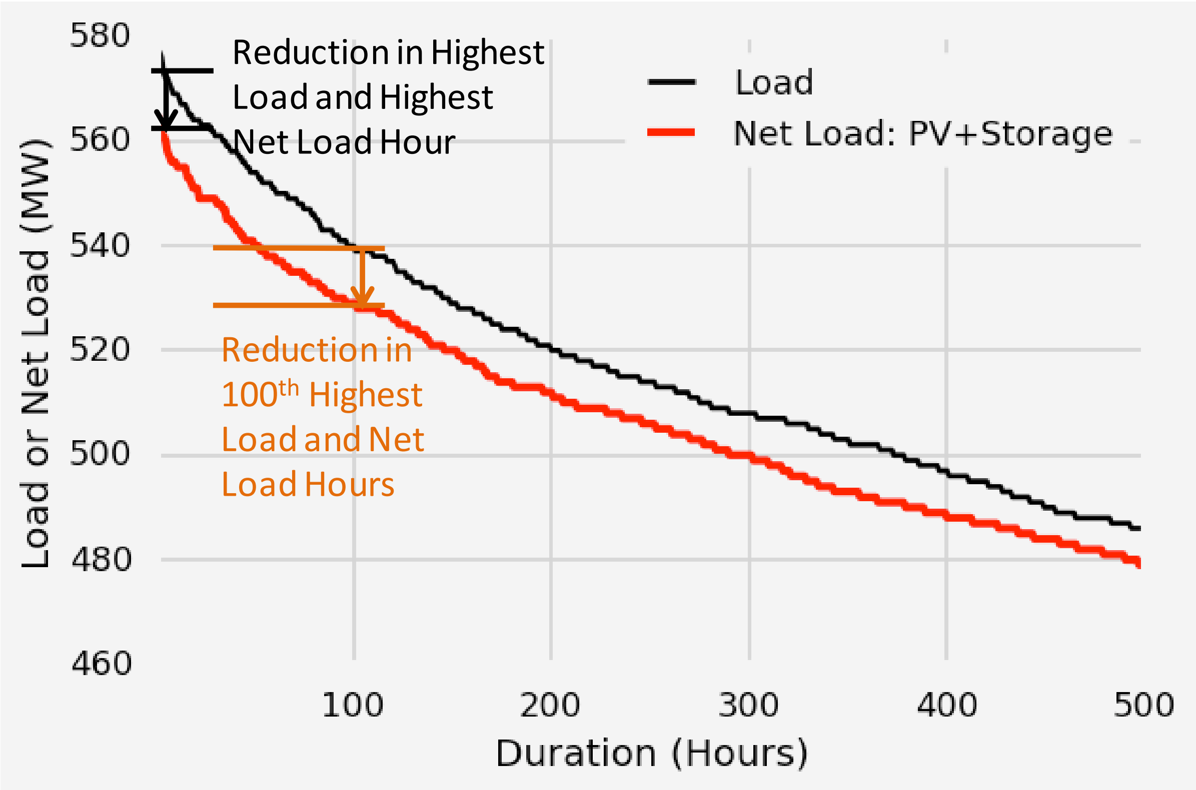
Follow the Electricity Markets & Policy Group on Twitter:

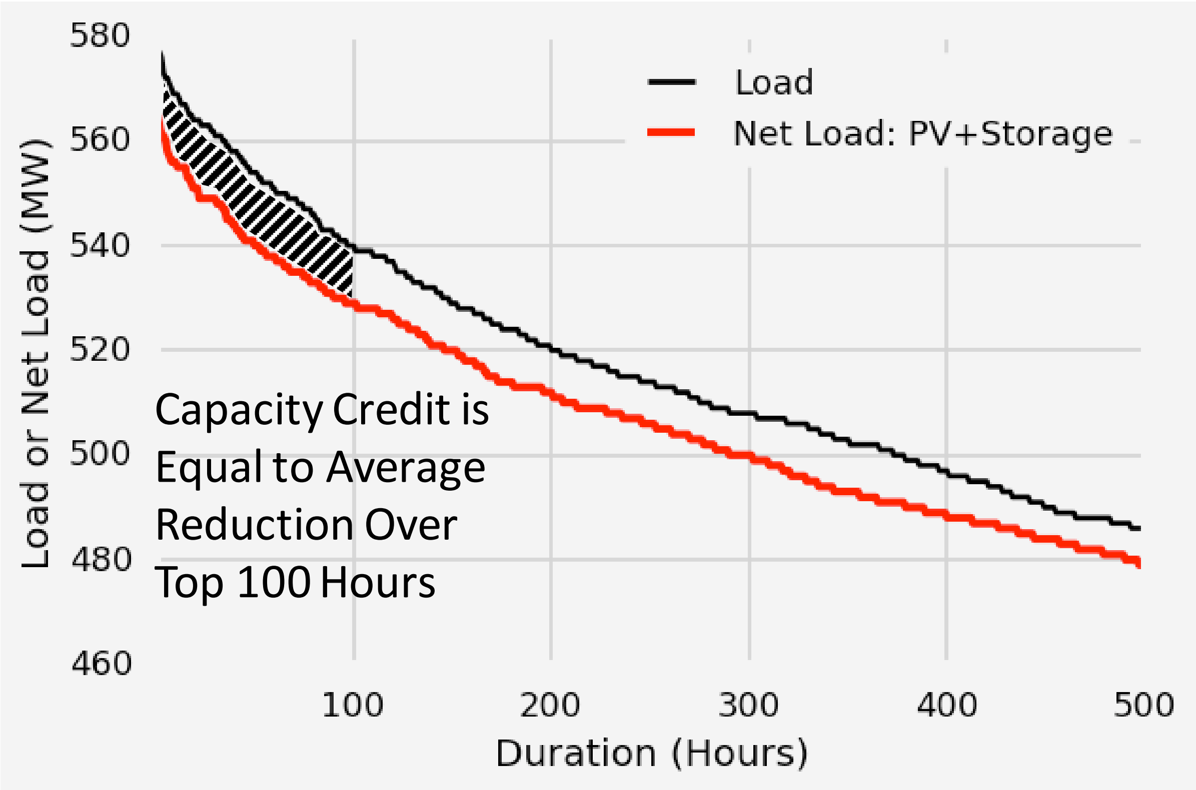
@BerkeleyLabEMP

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technology Office, Award Number DE-EE0007668.

APPENDIX

Capacity Credit Based on Method Used in NREL's Resource Planning Model

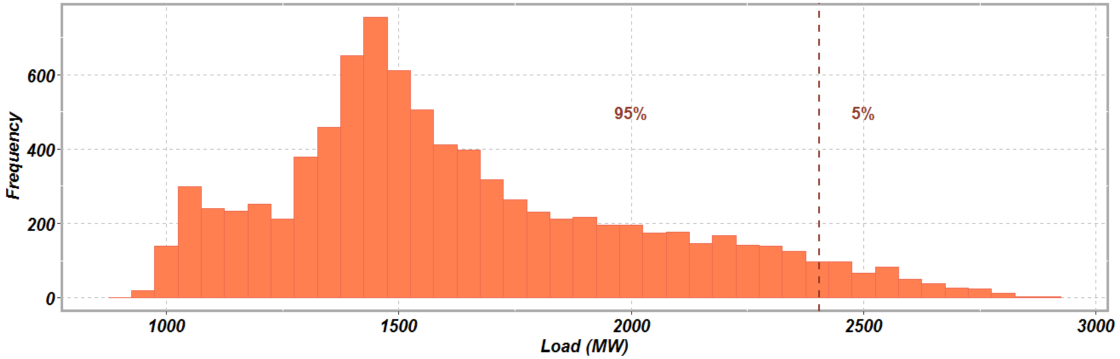




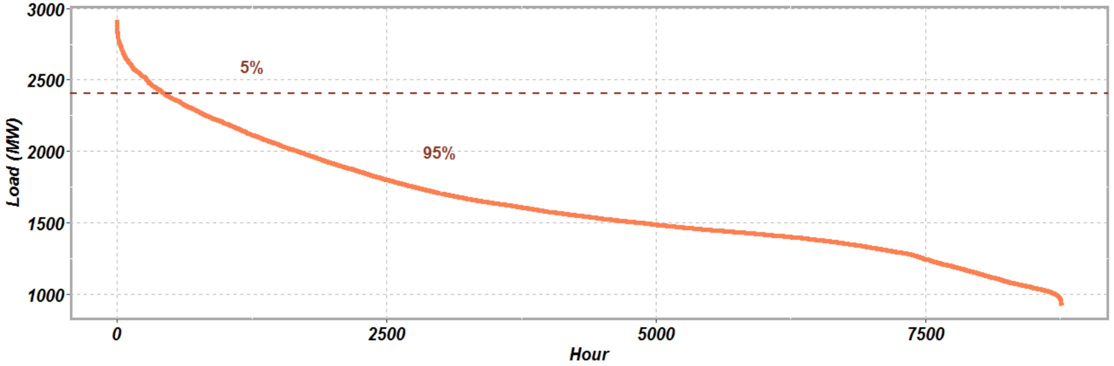
What Storage Dispatch Provides an Upper Bound on Storage Capacity Credit? Insight From CVaR

$$CVAR = min_{VAR,xi,Ls}\left\{VAR_{5\%} - \frac{1}{5\%\ observations}\sum_{\substack{s\\ L_s > VAR}}(L_s - VAR_{5\%})\right\}$$

Histogram of One Year Load Curve



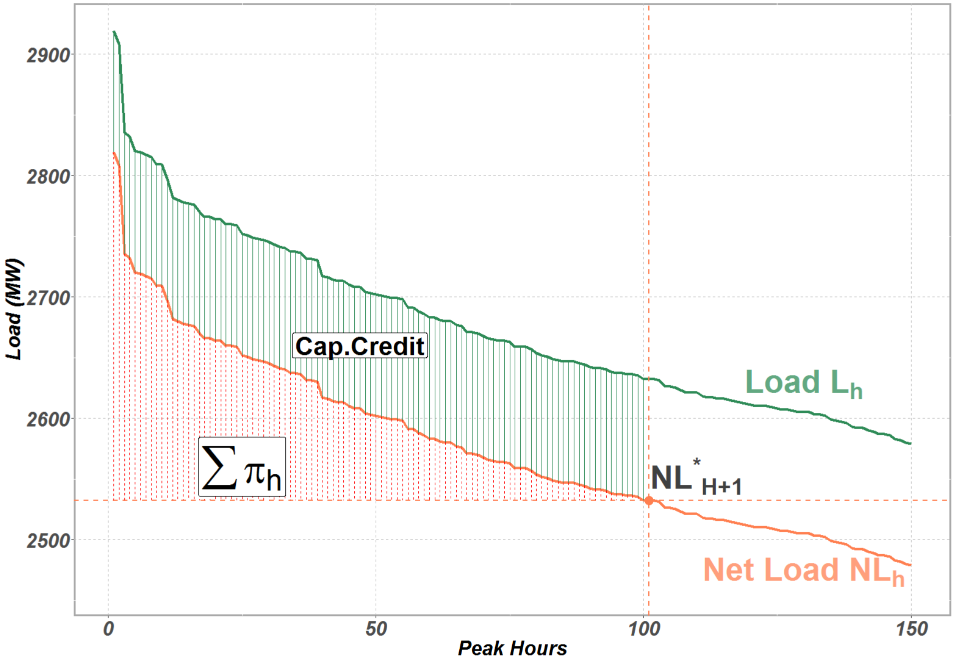
One Year Load Duration Curve



Typical CvaR Problem	**Maximum Capacity Credit Dispatch of Storage**
Min CVaR................................	Min average peak net load
5th Percentile	100 highest hours
Losses	Net load
Portfolio of Stocks	Storage dispatch
VaR.....................................	Net Load in hour 101

Examples: Rockafellar et al. 2000. "Optimization of Conditional Value-at-Risk." *Journal of Risk* 2: 21–42.
Conejo et al. 2010. "Risk Management." In *Decision Making Under Uncertainty in Electricity Markets*

Storage Dispatch to Maximize Capacity Credit of Storage



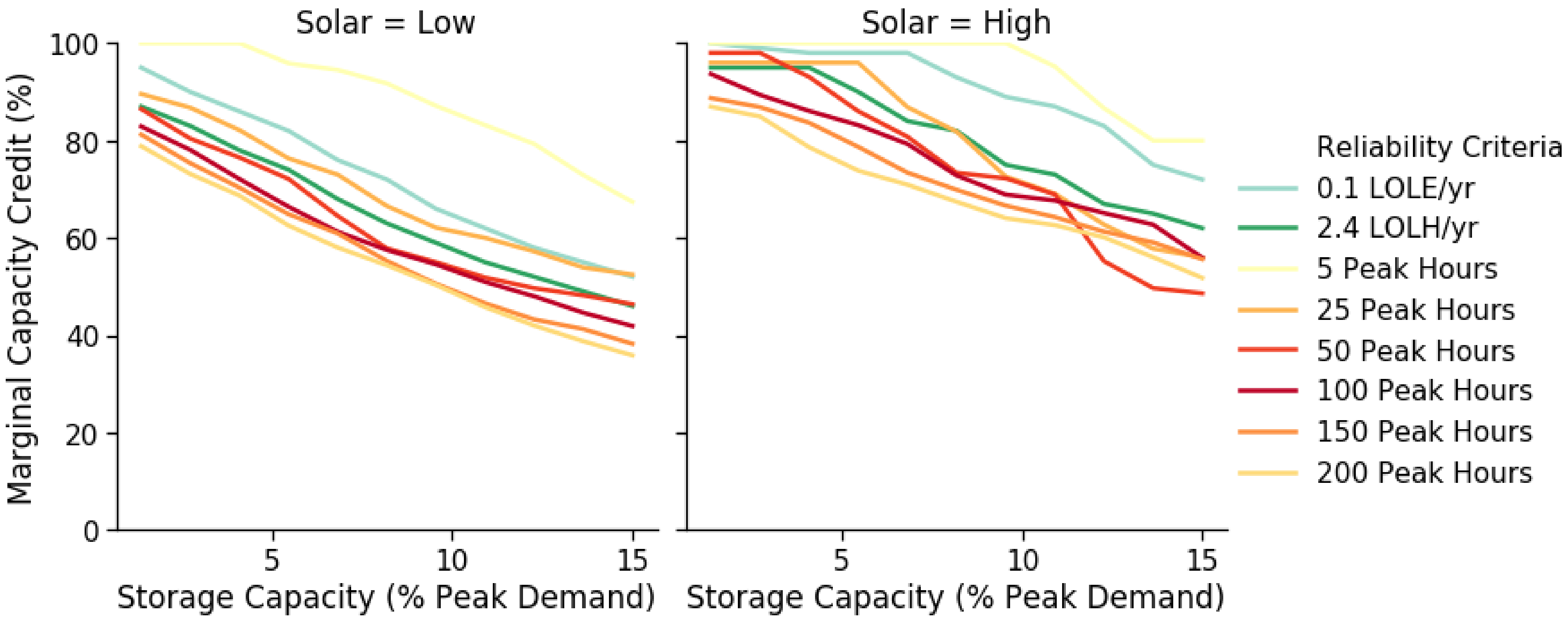
Objective

$$\min \left\{ NL^*_{H+1} + {}^{1}/_{H} \sum_h \pi_h \right\}$$

Operational Constraints

Load and Net Load	$NL_h = L_h + Bi_h - Bo_h$
Identify Peak Hours	$\pi_h \geq NL_h - NL^*_{H+1}$
Ignore Net Load in Non-peak Hours	$\pi_h \geq 0$
Storage Energy Balance	$Bl_h = Bl_{h-1} + \eta \cdot Bi_h - Bo_h$
Maximum Storage Level	$Bl_h \leq Bl_{Max}$
Maximum Storage Production	$0 \leq Bo_h \leq Bp_{Max}$
Maximum Storage Charge	$0 \leq Bi_h \leq Bp_{Max}$

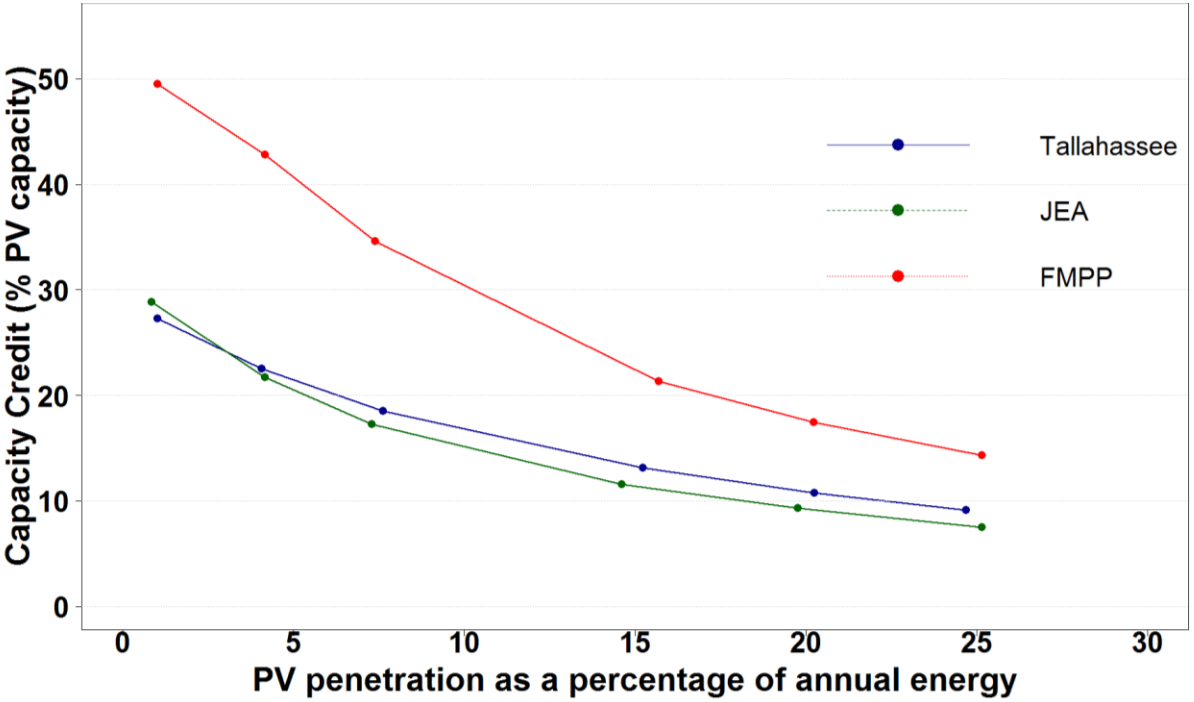
Additional Validation Results from Western U.S. Utility: Numerical Value of Capacity Credit Depends on Choice of Parameters, Though Trends Are Robust

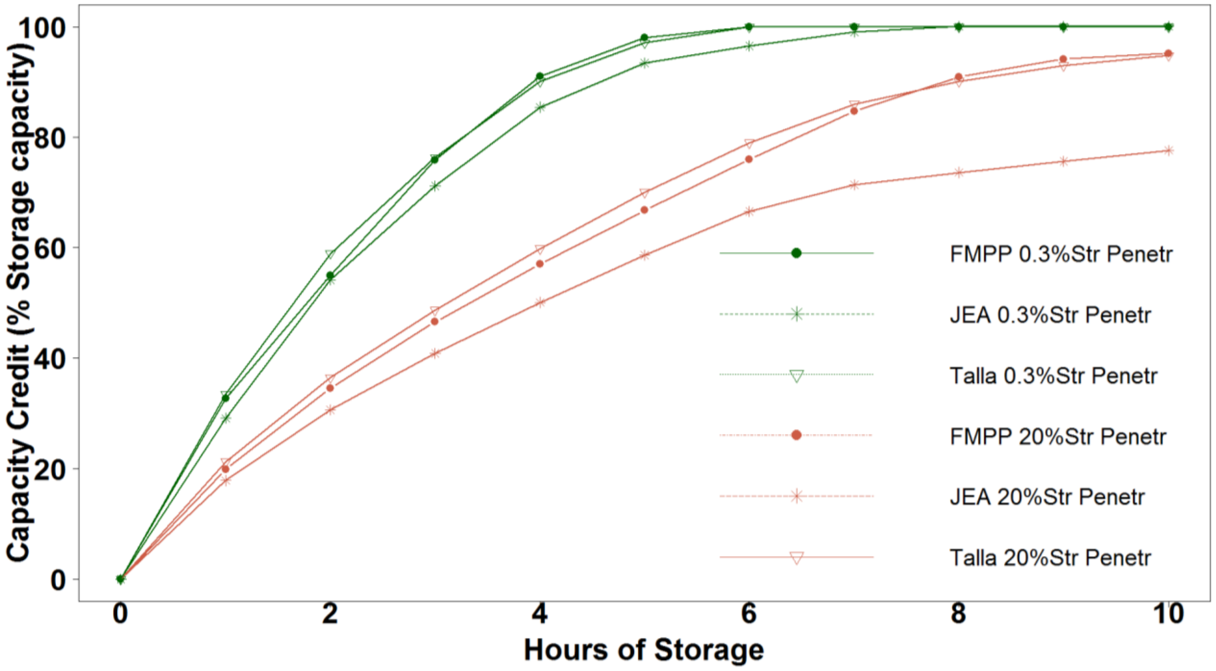


Analytical Approach

Configuration	Questions
PV Alone	• How does the capacity credit vary by site/utility combination? • How much does the capacity credit change depending on solar deployment?
Storage Alone	• How does the capacity credit of storage change storage duration? • Does the capacity credit of storage change with storage deployment?
PV+Storage	• How does the capacity credit depend on the PV+storage configuration? • How do results change with the battery size relative to the PV size?

Capacity Credit of PV and Storage Alone





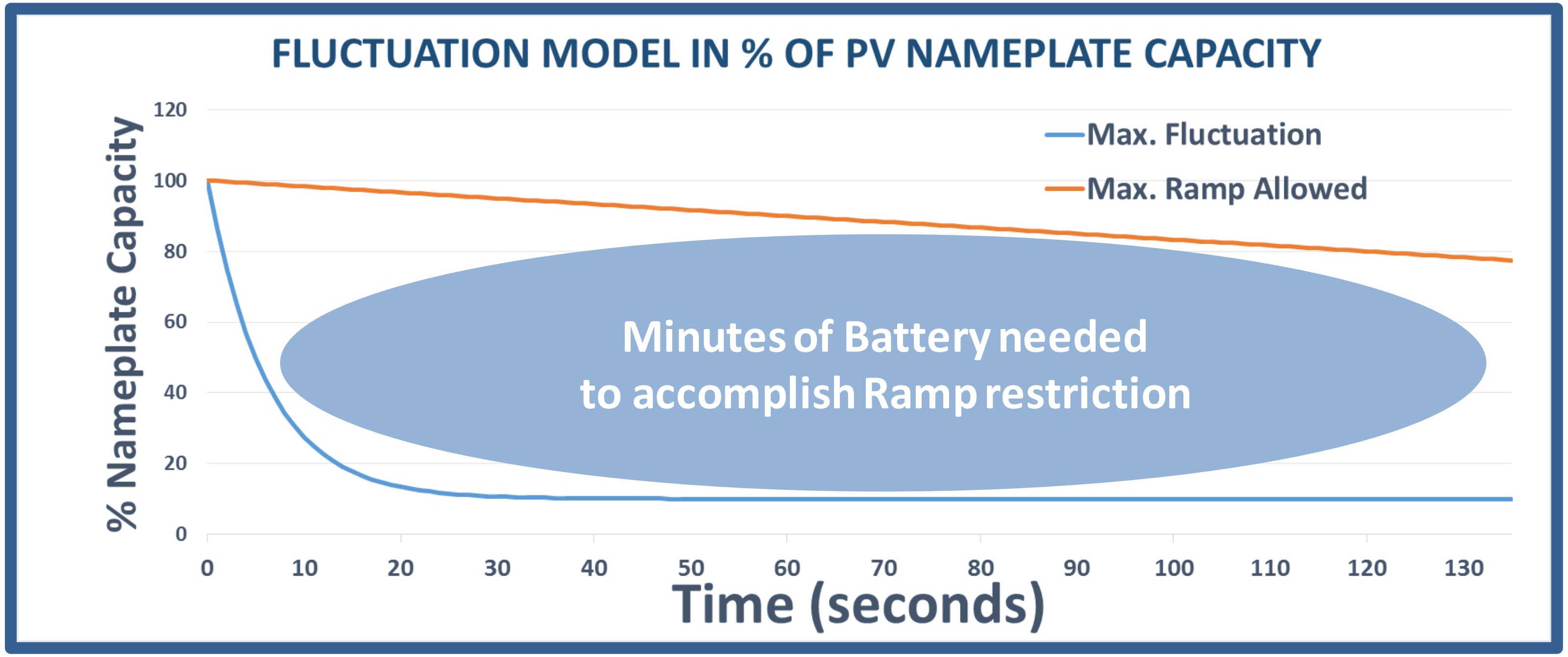
- Capacity credit of PV varies by utility, depending on how well correlated PV production is with peak load.
- Capacity credit of PV declines with increasing penetration.

- Capacity credit of storage depends on duration.
- Duration required to achieve near 100% capacity credit increases with storage deployment.

PV + Storage Configurations

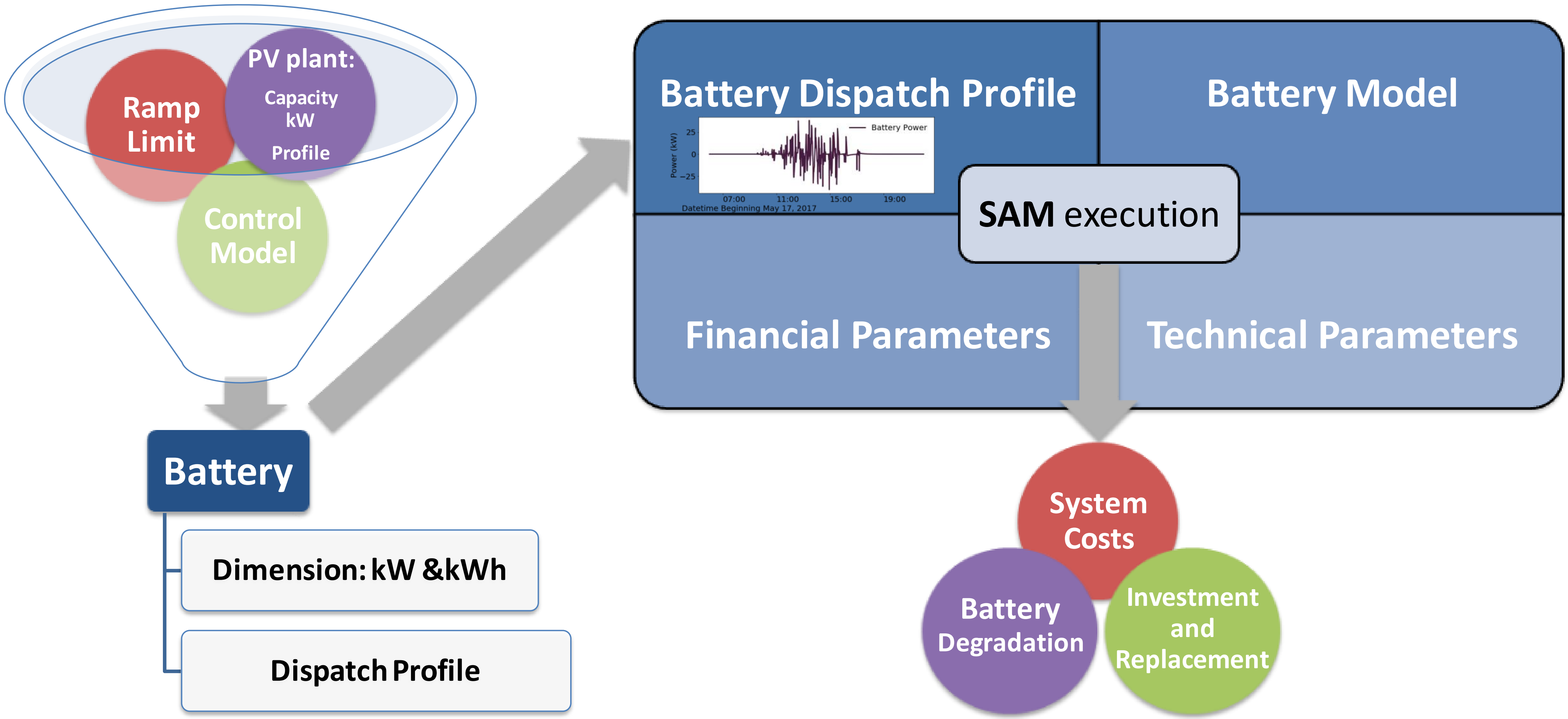
Configuration	Description	Share Equipment?	Source of Electricity for Storage
Independent	PV and storage do not share equipment and storage is charged from the grid	No	Grid
Loosely Coupled	PV and storage both connect on the DC side of shared inverters, but storage can charge from storage or the grid	Shared Inverter	Grid or PV
Tightly Coupled	PV and storage connect on DC side of shared inverters, and storage can only charge from PV	Shared Inverter	Only PV

Size the Battery Using a "Worst Fluctuation" Model



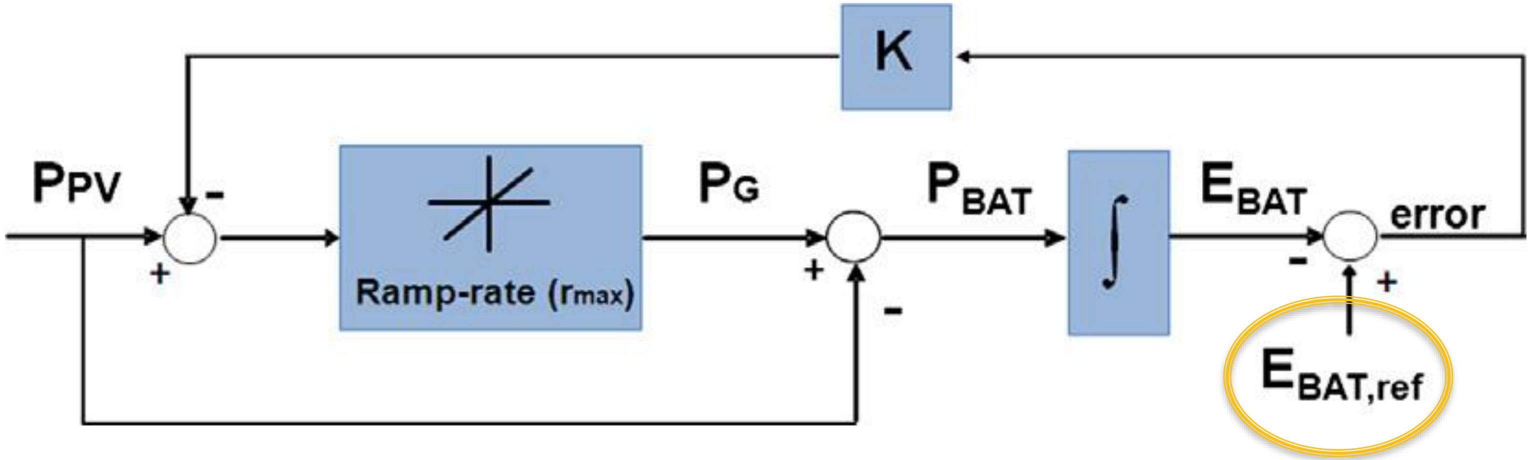
Maximum Ramp (%/min)	Battery Duration (Minutes at PV Nameplate capacity)	Battery Energy (kWh) Pn=75kW
1	81	101.2
2	41	50.6
3	27	33.8
4	20	25.3
5	16	20.3
6	14	16.9
7	12	14.5
8	10	12.7
9	9	11.3
10	8	10.1
11	7	9.2
12	7	8.4
13	6	7.8
14	6	7.2
15	5	6.8
16	5	6.3

Use NREL's SAM to Analyze Battery Degradation and Costs for Different Ramp Rate Limits



Smoothing of Power Fluctuations with Energy Storage: Daytime Charging Ramp-Rate Control Model

- **Basic Control Model**
- Energy from the sun is used to keep battery level close to the reference value (half charge $E_{BAT,ref}$)



- Value of recovery constant K: too high or too low values will increase the risk of totally discharging the battery. Values between 2 and 8 are recommended.