Assessment of Solar + Storage for Resource Adequacy and Ramp Control

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Florida Alliance for Accelerating Solar and Storage Technology Readiness

Leadership:

NHU ENERGY

OFFICE OF ENERGY
FLORIDA DEPT. OF AGRICULTURE AND CONSUMER SERVICES

Research & Analysis:

NATIONAL RENEWABLE ENERGY LAB

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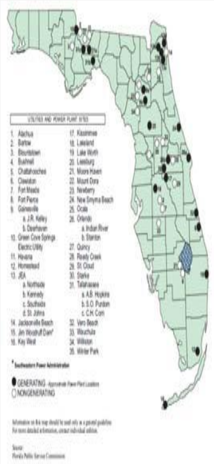
Utility Core Team

- City of Tallahassee Electric Utility
- Florida Municipal Power Agency (FMPA)
- Gainesville Regional Utilities (GRU)
- Jacksonville Electric Authority (JEA)
- Lakeland Electric
- Orlando Utilities Commission (OUC)

Advisory Board

- Utility core team representatives and other key stakeholders to provide input and guidance

All FL Municipal Utilities

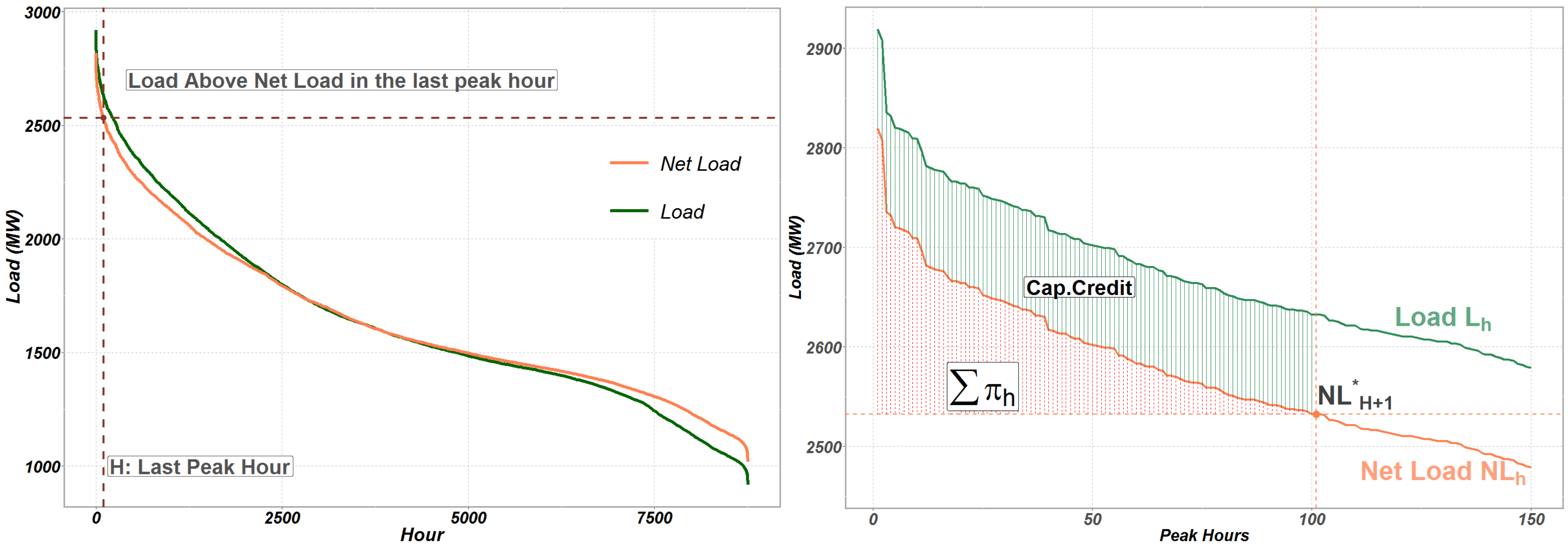


Other Stakeholders

- Industry suppliers, project developers, generation owner-operators, FL PSC, FRCC, regulated utilities, etc.

Solar + Storage for Resource Adequacy

Storage Dispatch to Maximize Capacity Credit of Storage

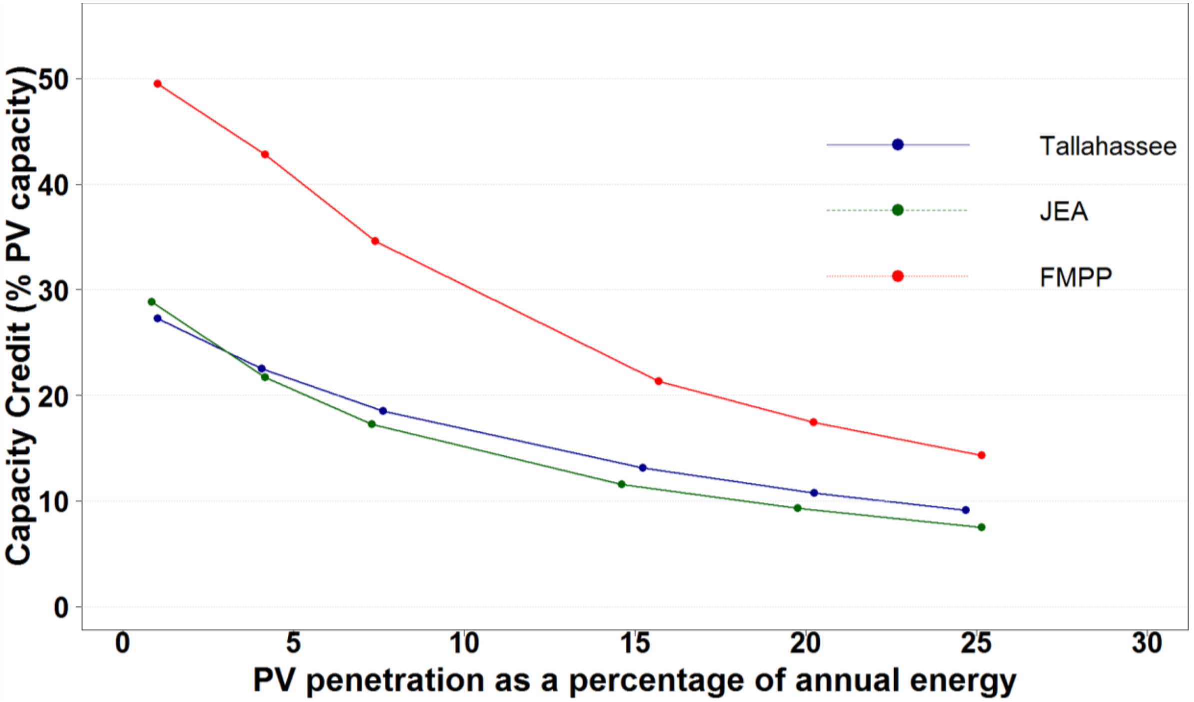


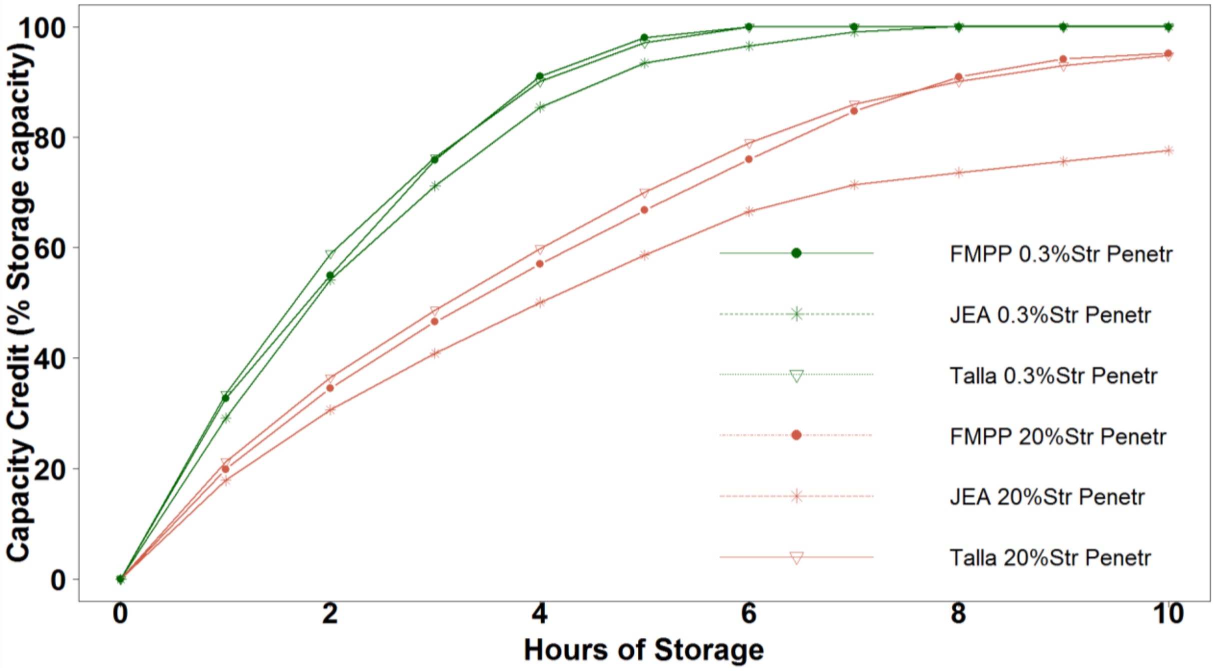
Define capacity credit similar to NREL's "Resource Planning Model": difference of the highest peak load hours and highest peak net load hours. Use a simple linear model to find the storage dispatch that maximizes this capacity credit.

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 with the size of the storage reservoir? • 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.

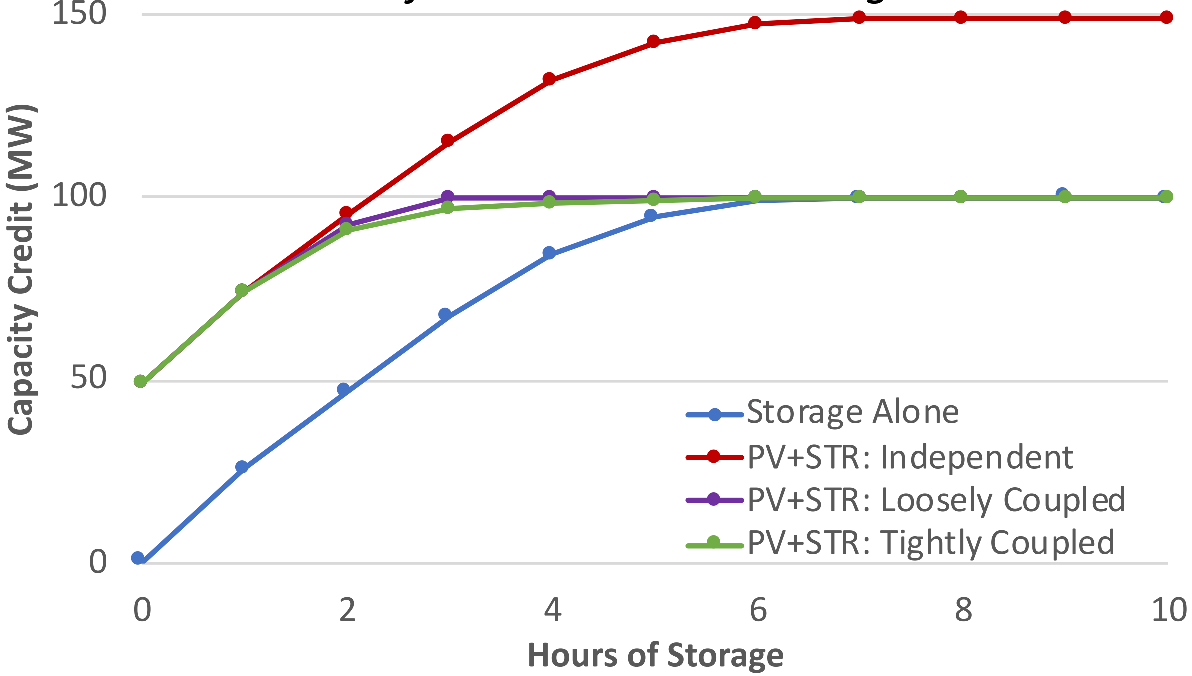
PV + Storage Configurations

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

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

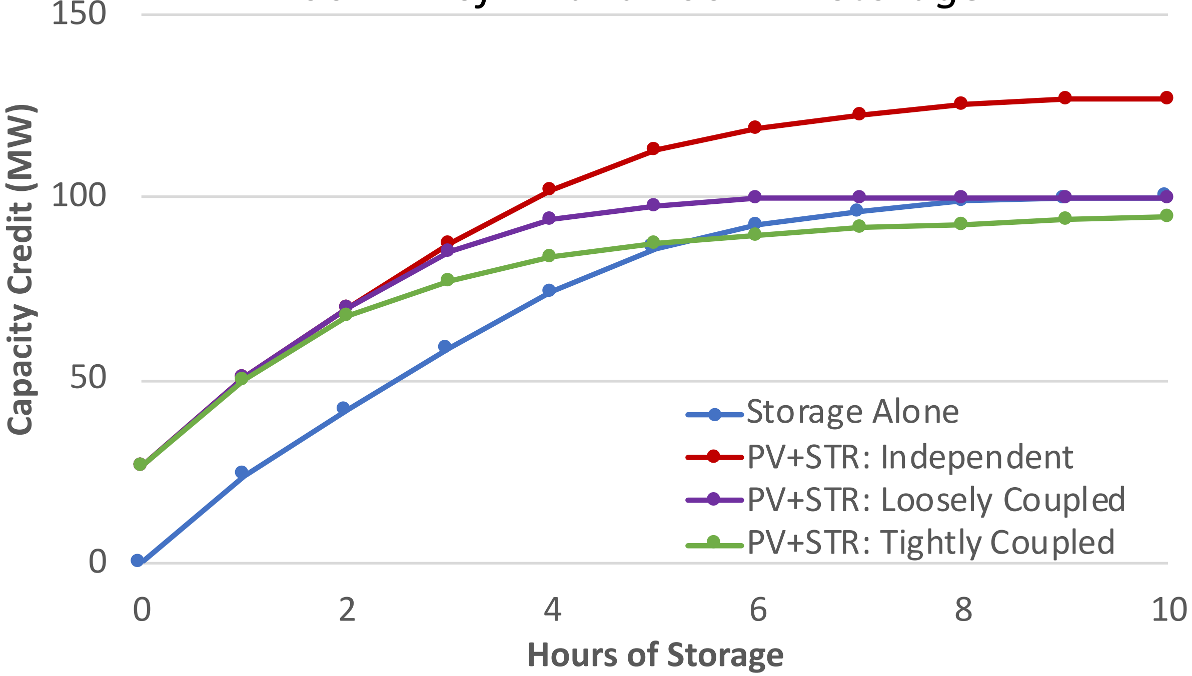
FMPP (Load has high summer peaks)

100 MW of PV and 100 MW Storage



JEA (Load has high winter and summer peaks)

100 MW of PV and 100 MW Storage

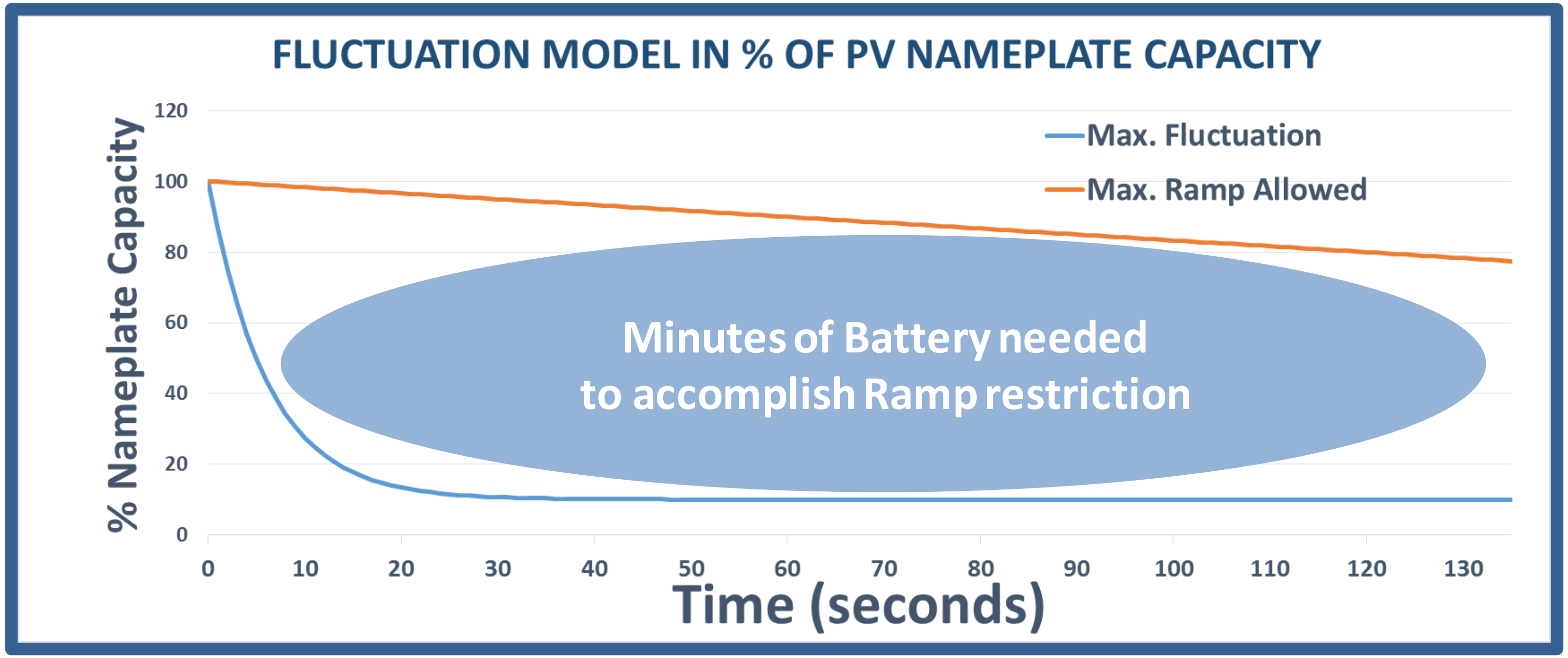


- Capacity credit of PV+Storage can be limited by the shared inverter when DC coupled
- No significant difference for loosely vs. tightly coupled

- 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

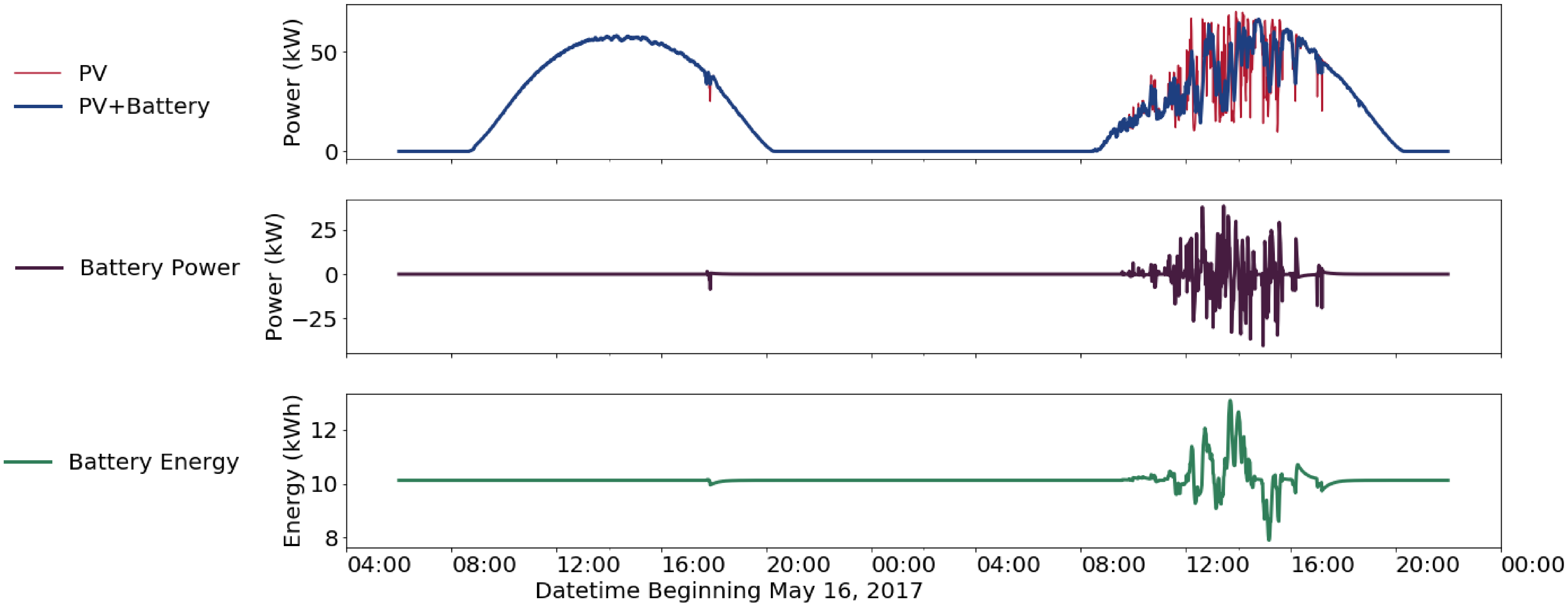
Size the Battery Using a "Worst Fluctuation" Model



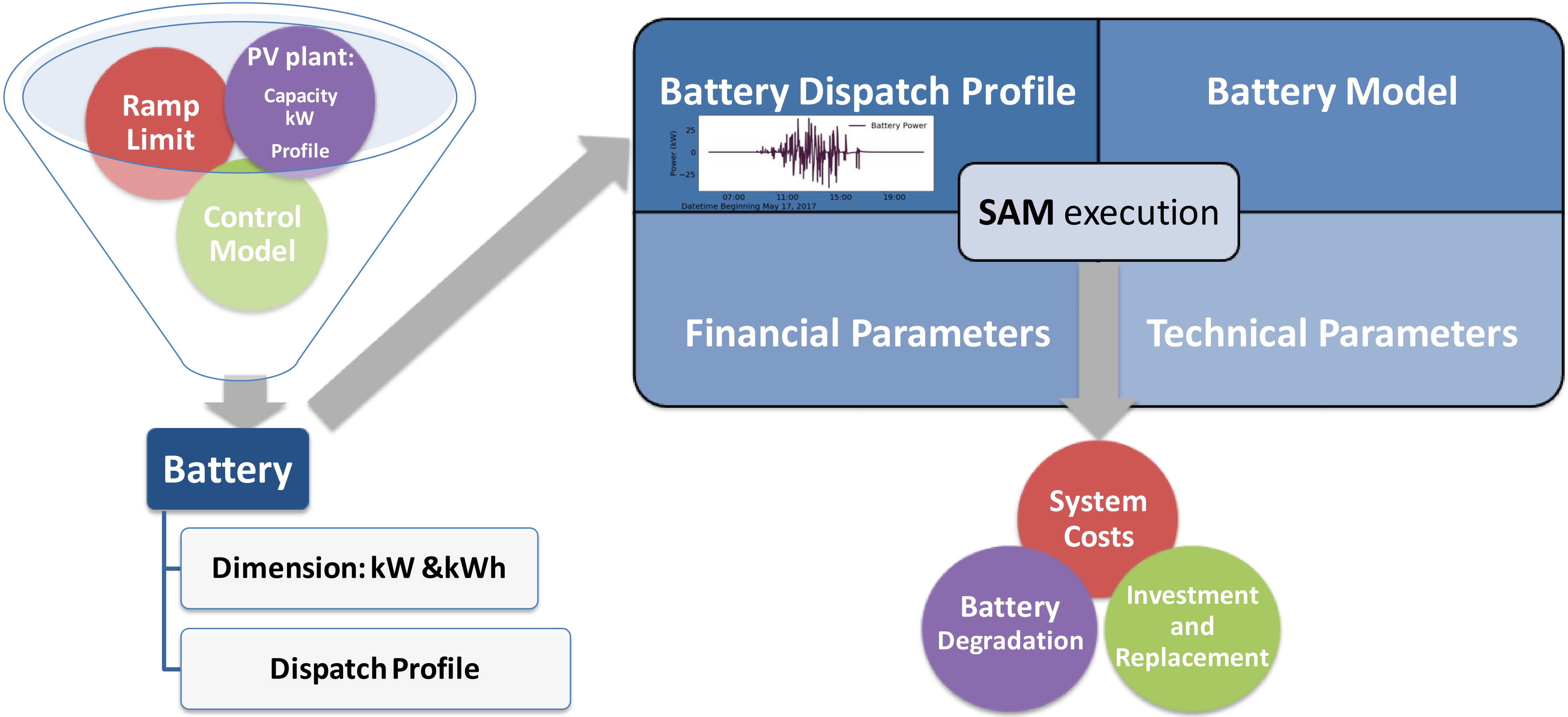
Maximum Ramp (%/min)	Battery Duration (Minutes at PV Nameplate capacity)	Battery Energy (kWh) Pn=75kW
1	81	101.2
2	41	50.6
3	27	33.8
4	20	25.3
5	16	20.3
6	14	16.9
7	12	14.5
8	10	12.7
9	9	11.3
10	8	10.1
11	7	9.2
12	7	8.4
13	6	7.8
14	6	7.2
15	5	6.8
16	5	6.3

Dispatch Battery Using a Simple Daytime Charging Ramp Control Model

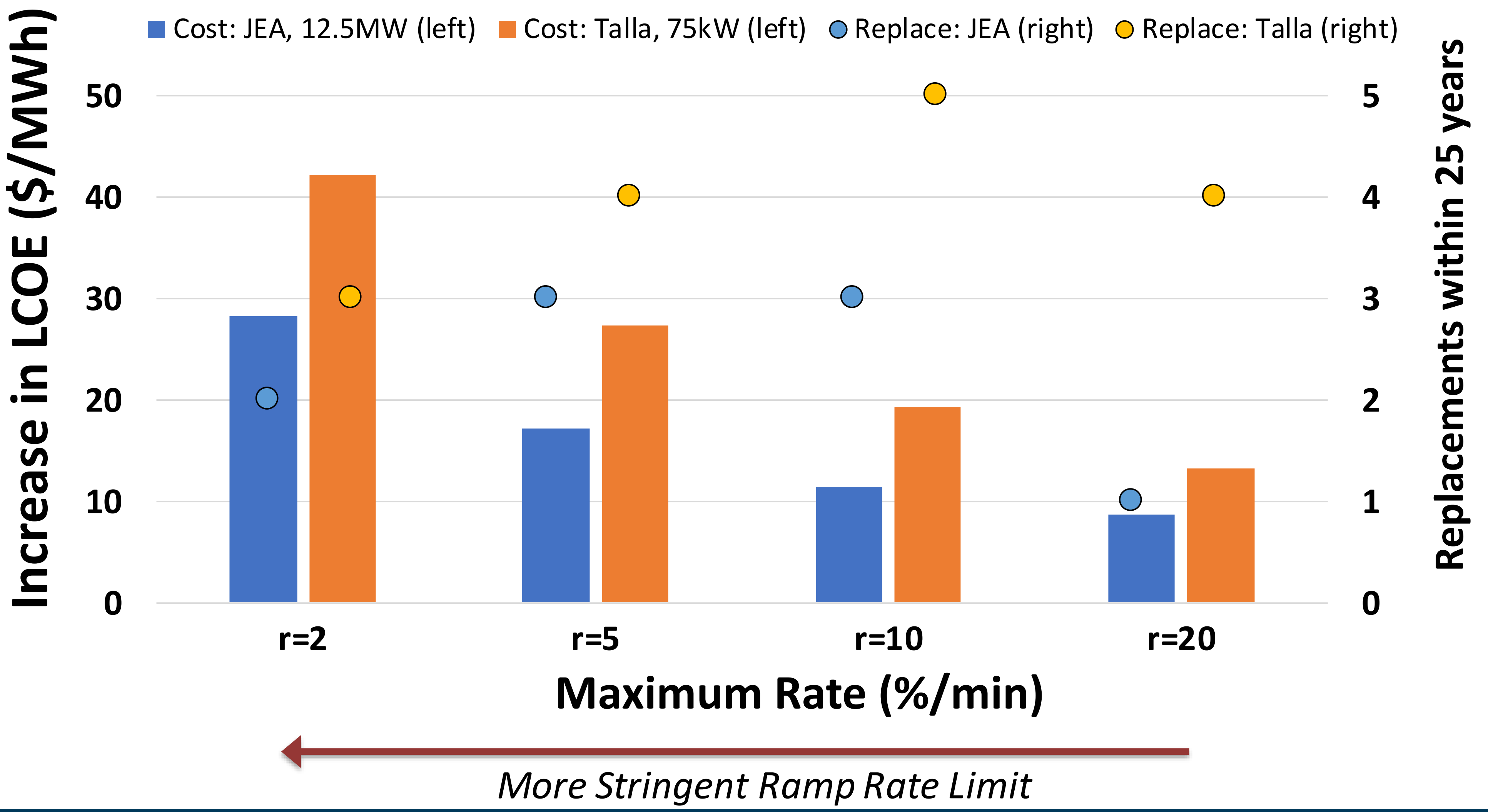
Ramp Limit = 5%/min



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



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

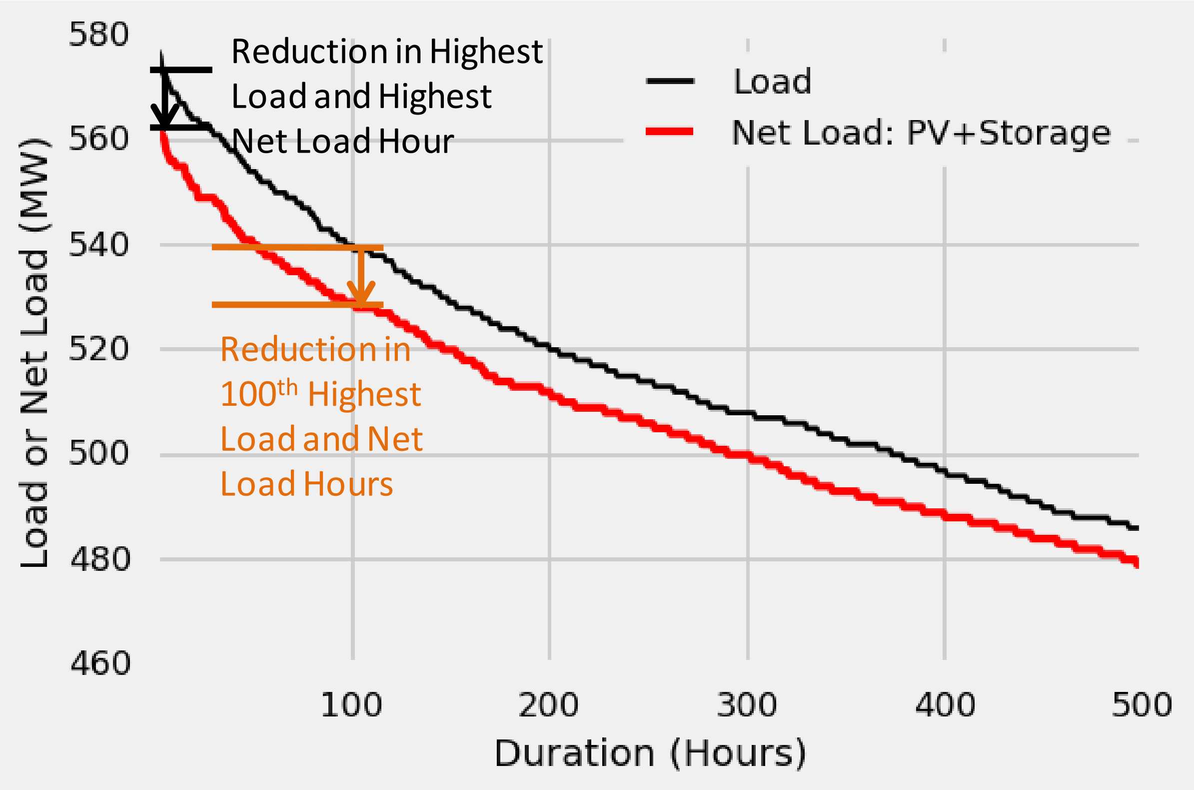
- Capacity credit of solar varies by utility; capacity credit of storage varies with storage duration
- Capacity credit of solar+storage can be limited by shared inverter when batteries are large
- Batteries can be added to solar plants to meet specific ramp-rate limitations, though there are additional 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 batteries that are experience large charge and discharge cycles

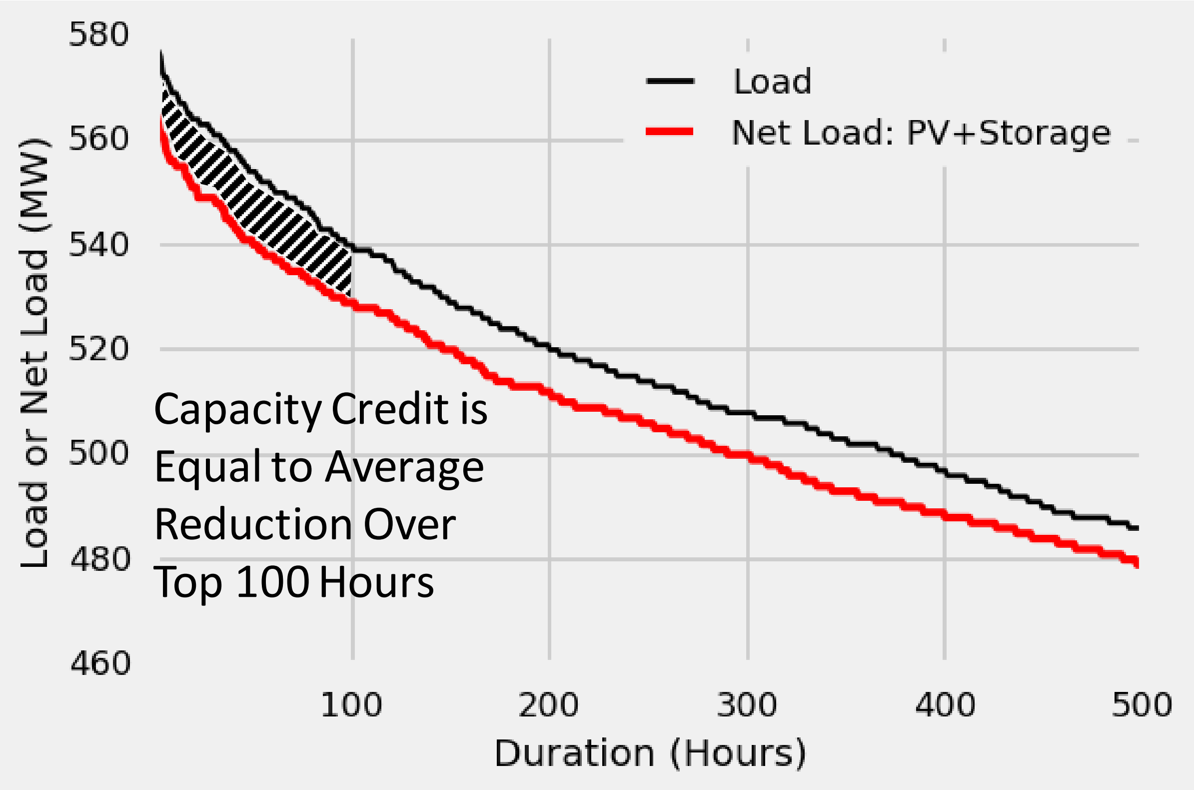
Additional Directions to Explore

- 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
- Refinement of representation of multiple services from the same battery

APPENDIX

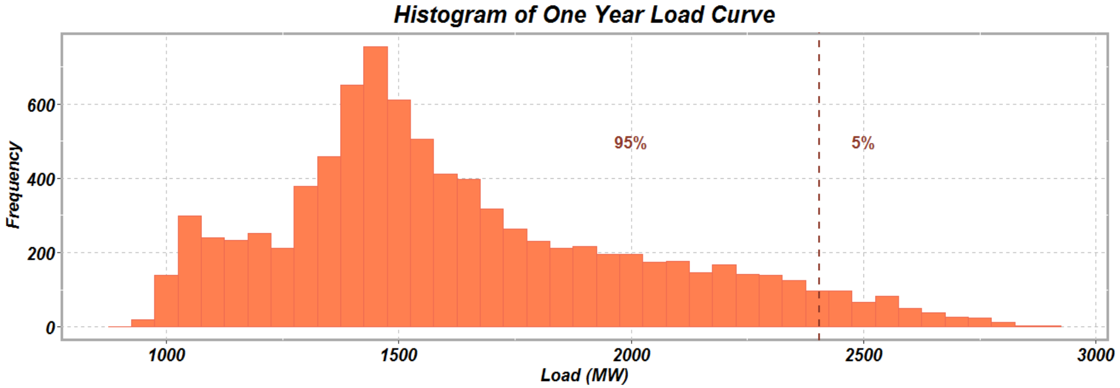
Capacity Credit Based on Method Used in NREL's Resource Planning Model

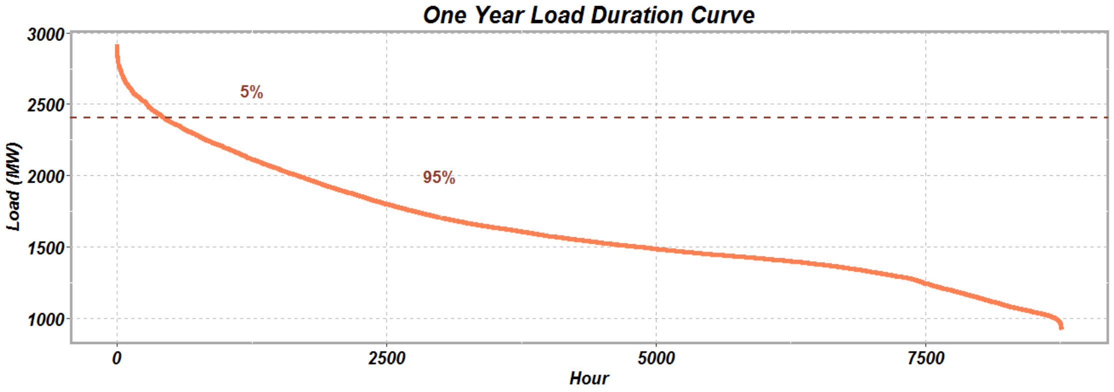




What Storage Dispatch Provides an Upper Bound on Storage Capacity Credit? Insight From CVaR

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

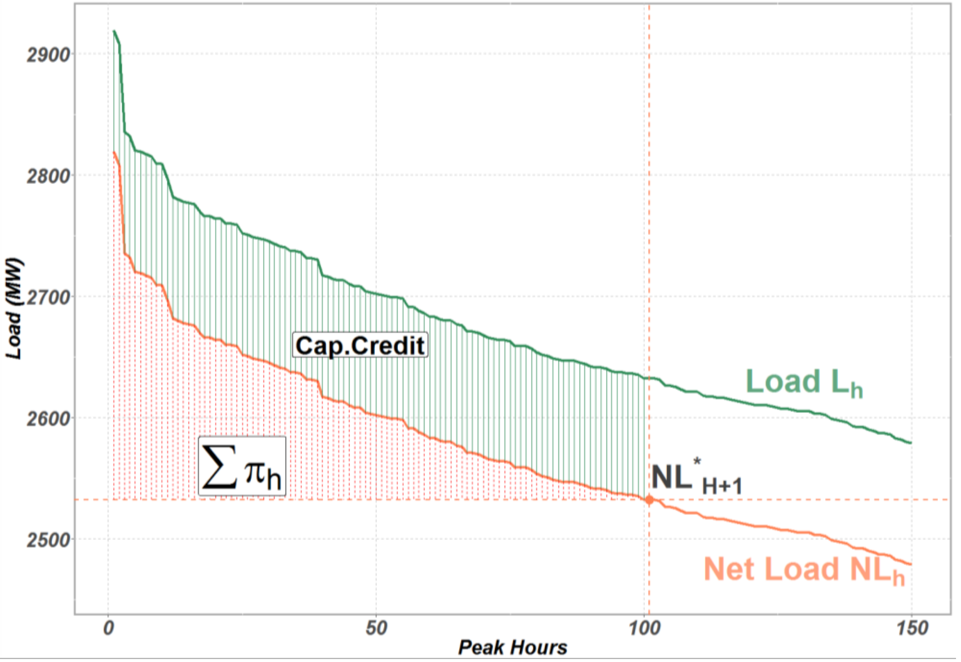




Typical CvaR Problem	Maximum Capacity Credit Dispatch of Storage
Min CVaR................................	Min average peak net load
5th Percentile	100 highest hours
Losses	Net load
Portfolio of Stocks	Storage dispatch
VaR....................................	Net Load in hour 101

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

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

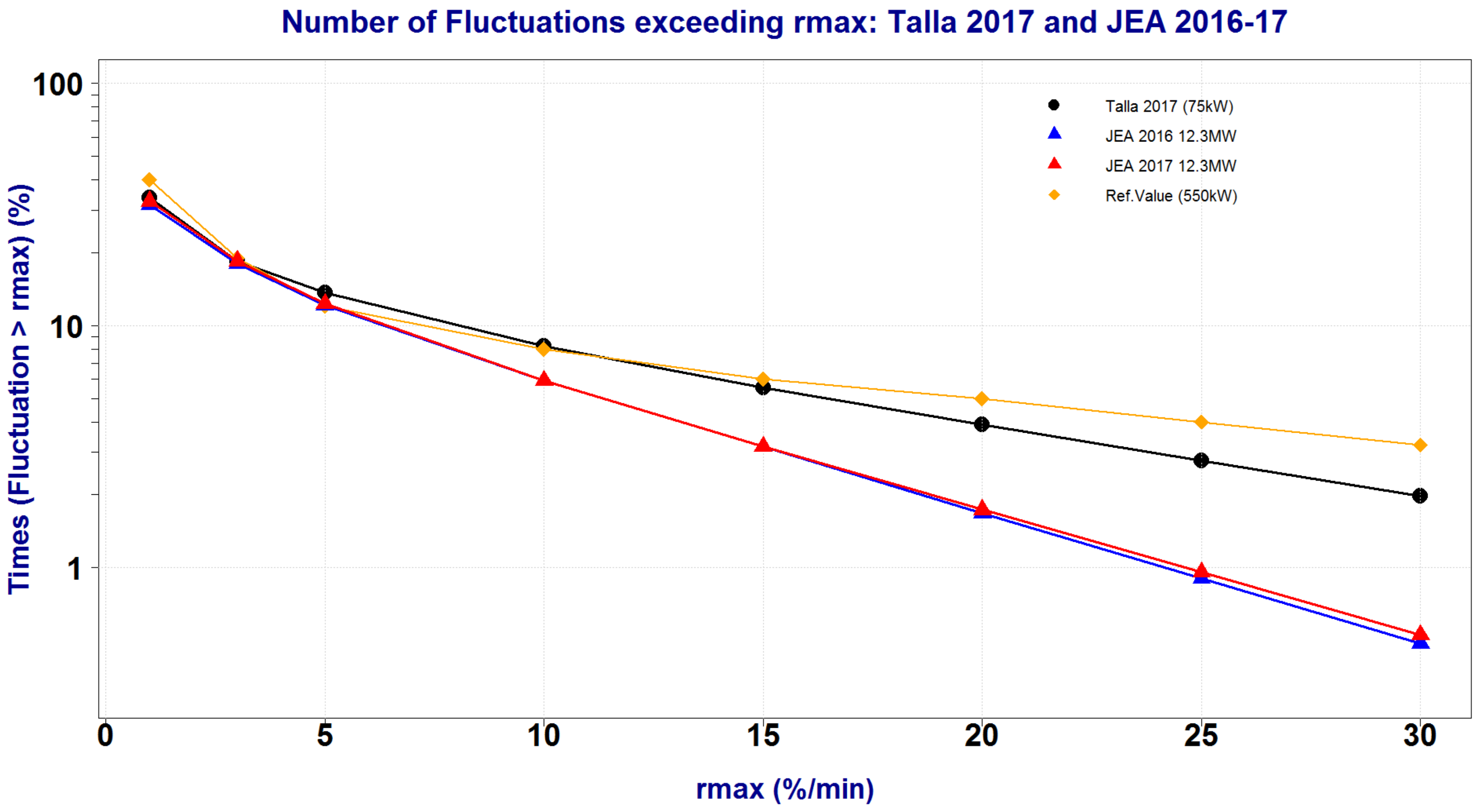
Operational Constraints

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	$0 \leq Bi_h \leq Bp_{Max}$

Emerging Applications of PV Ramp-Rate Control

- In isolated systems, where broad aggregation of multiple resources is not possible, managing the intermittent nature of solar with conventional generators is challenging.
- In some cases, system operators have implemented interconnection requirements that establish a maximum allowed fluctuation within a certain time scope. System operators in Puerto Rico, for example, imposed a 10%/min limit on PV ramps.
- Different strategies for using energy storage to limit PV fluctuations are demonstrated in the literature. Each has advantages and disadvantages:
  - Ramp-Rate control strategies: daytime charging, inverter limitation, PV plant production model, step model
  - Moving Average Model
  - Constant production

Solar Power Fluctuations Without Storage

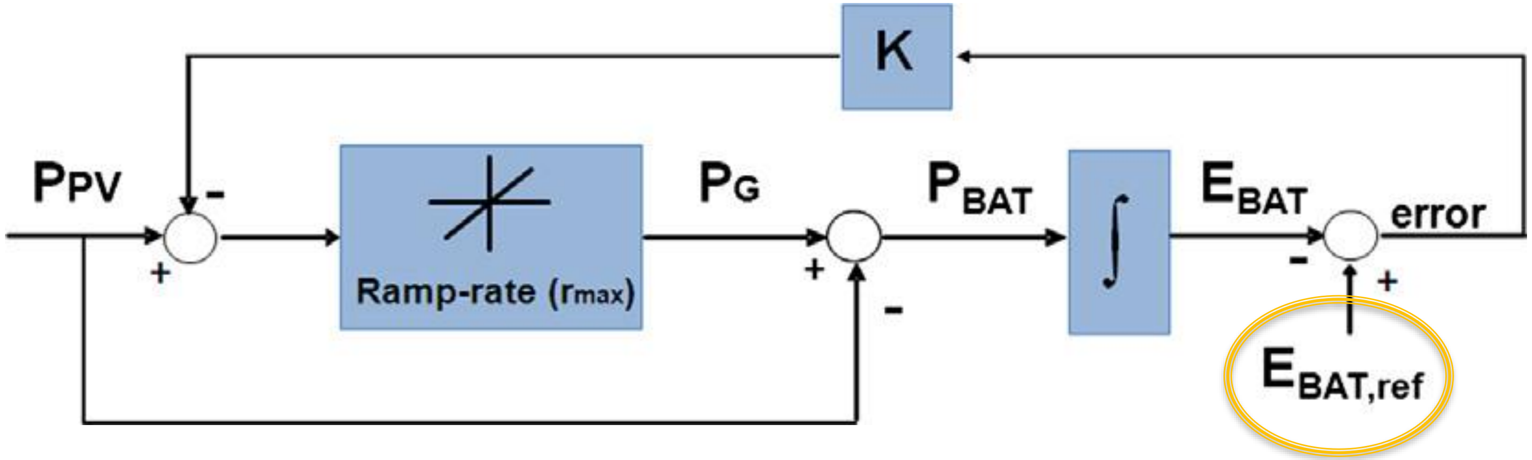


Ref. Value (550 kW) is from studies in the literature

Other values are from the 75 kW City of Tallahassee Airport Plant and 12.5 MW JEA JAX Solar Plant

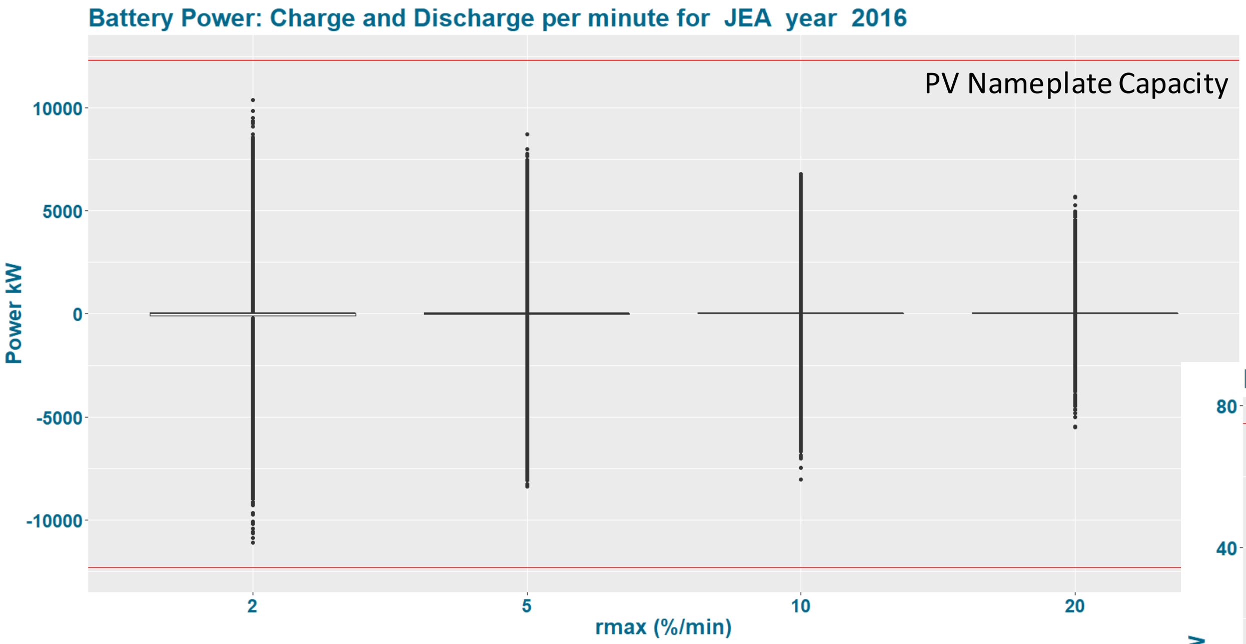
Smoothing of Power Fluctuations with Energy Storage: Daytime Charging Ramp-Rate Control Model

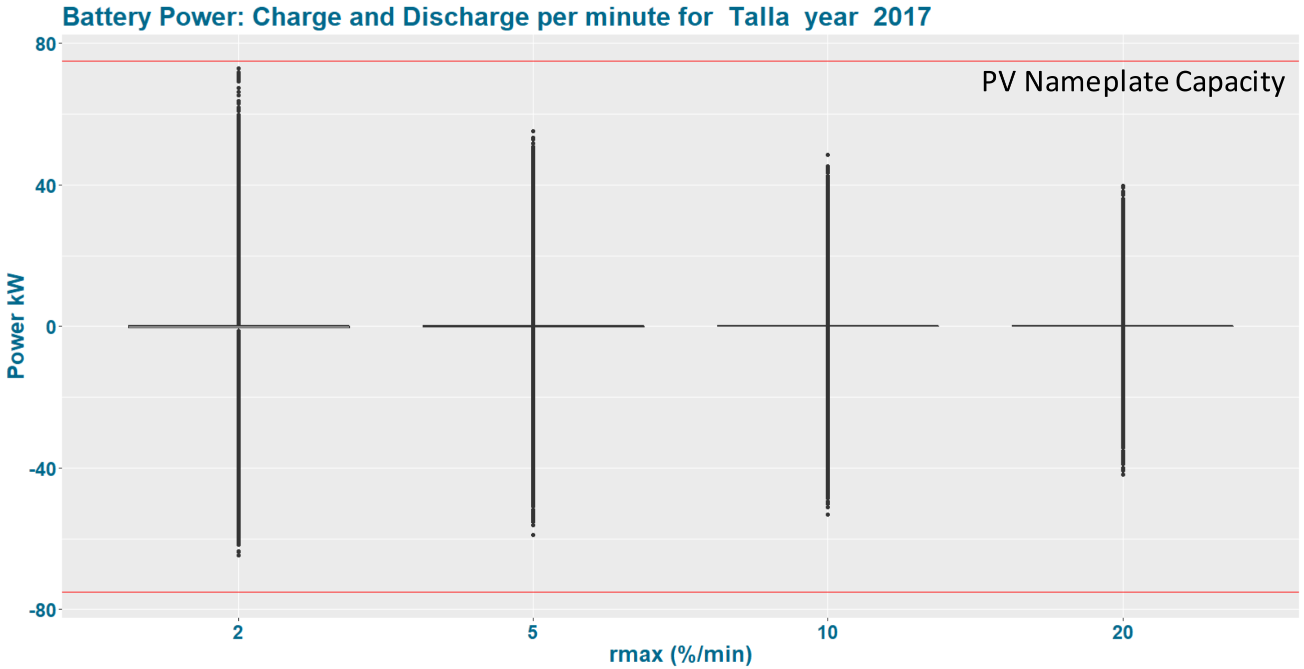
- **Basic Control Model**
- Energy from the sun is used to keep battery level close to the reference value (half charge $E_{BAT,ref}$)



- 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.

Battery Dispatch from Daytime Charging Control Model: Power to or from Battery per minute





More Stringent Ramp Rate Limit uses a greater share of the battery power rating

Maximum battery power is never quite reached to meet ramp rate limits in these two cases