Absorbing the Sun: Operational Practices and Balancing Reserves In Florida's Municipal Utilities

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Florida Alliance for Accelerating Solar and Storage Technology Readiness (FAASSTeR) Webinar

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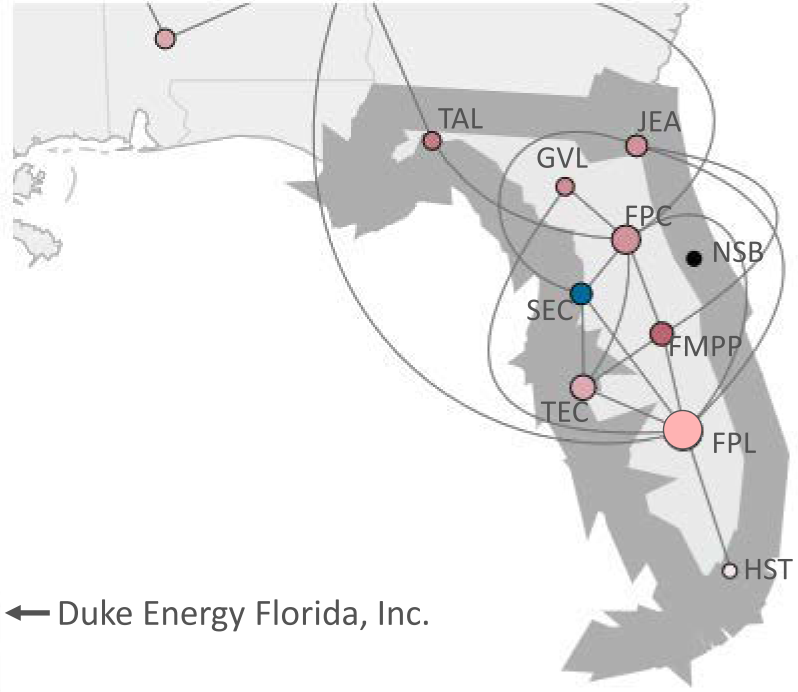
Florida Reliability Coordinating Council (FRCC) Power System

Estimates for 2024 Used in the Analysis that Follows

Compiled from 2018 SNL Plant Information, FERC 714 2015 Load, and 2019 Ten-Year Site Plans

EIA BA ID	Generation Capacity (MW)	PV Capacity (MW)	PV Capacity (%)	Annual Load (TWh)	Annual PV Generation (GWh)	PV Generation (%)
GVL	750	1.2	0.2	1.73	1.8	0.1
TAL	1,009	60.0	5.9	2.93	88.1	3.0
JEA	2,555	277.4	10.8	14.09	422.1	3.0
SEC	4,141	2.2	0.1	15.79	4.0	0.0
FMPP	5,640	244.4	4.3	16.07	374.9	2.3
TEC	7,783	626.7	8.0	21.51	1,016.2	4.7
FPC	13,175	304.0	2.3	43.32	487.0	1.1
FPL	30,915	1007.0	3.2	123.30	1,645.8	1.3



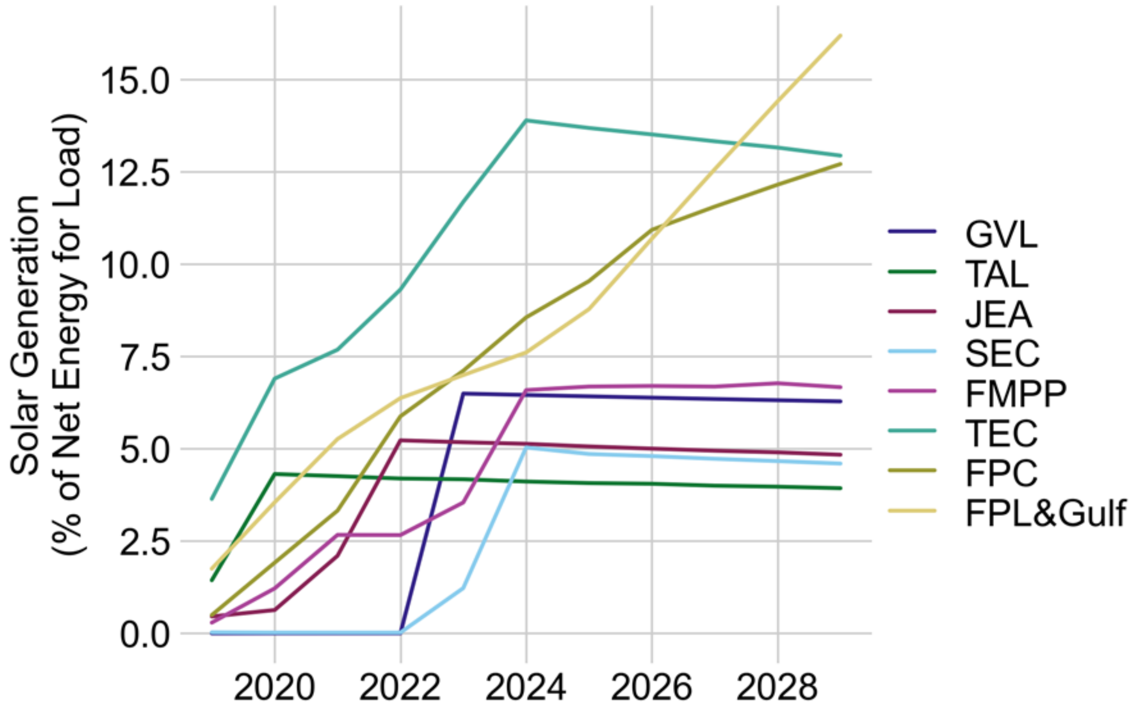
← Duke Energy Florida, Inc.

- Nameplate capacity of current generators, planned builds and retirements as represented in the SNL database (https://www.spglobal.com/marketintelligence/en/) as of October 2018, plus known planned PV builds in JEA and FMPP
- In some cases, distributed generators/co-gen units are included and assigned to the hosting BA (thus overstating BA-level generating capacity)
- Distributed PV capacity is NOT included. Consistent with that, annual load is the "net energy for load," which does not include load that is served by behind-the-meter PV on a net-energy basis.
- The BA load profiles and 2015 annual load are taken from FERC Form 714 historical data. Each year of FERC Form 714 data (2006-2015) is scaled first to match the annual load levels in 2015 and is then scaled again by the 2015 to 2024 load growth factors implied for each BA by the FRCC 2019 10-year site plans. The annual load reported for 2015 in the 10-year site plans does not always match the FERC Form 714 data—absolute relative errors range from 0.02% to 13%.
- FMPP includes FMPA, Lakeland Electric, and Orlando Utilities Commission load

eia Source: U.S. Energy Information Administration

Florida Solar Deployment Plans and Clean Energy Goals

Planned Solar Deployment per 2020 Ten-Year Site Plans



Data compiled from: http://www.psc.state.fl.us/ElectricNaturalGas/TenYearSitePlans

Orlando: 100% Renewable electricity by 2050

- 50% CO_2 reduction by 2030; 75% by 2040

Tallahassee: 100% Clean, renewable energy by 2050

- In city operations by 2035; community-wide by 2050

Gainesville: 100% Energy from renewable resources by 2045

- Net-zero greenhouse gas emissions community-wide by 2045

Other cities: Dunedin, Largo, Safety Harbor, Sarasota, Satellite Beach, South Miami, St. Petersburg

Research Questions:

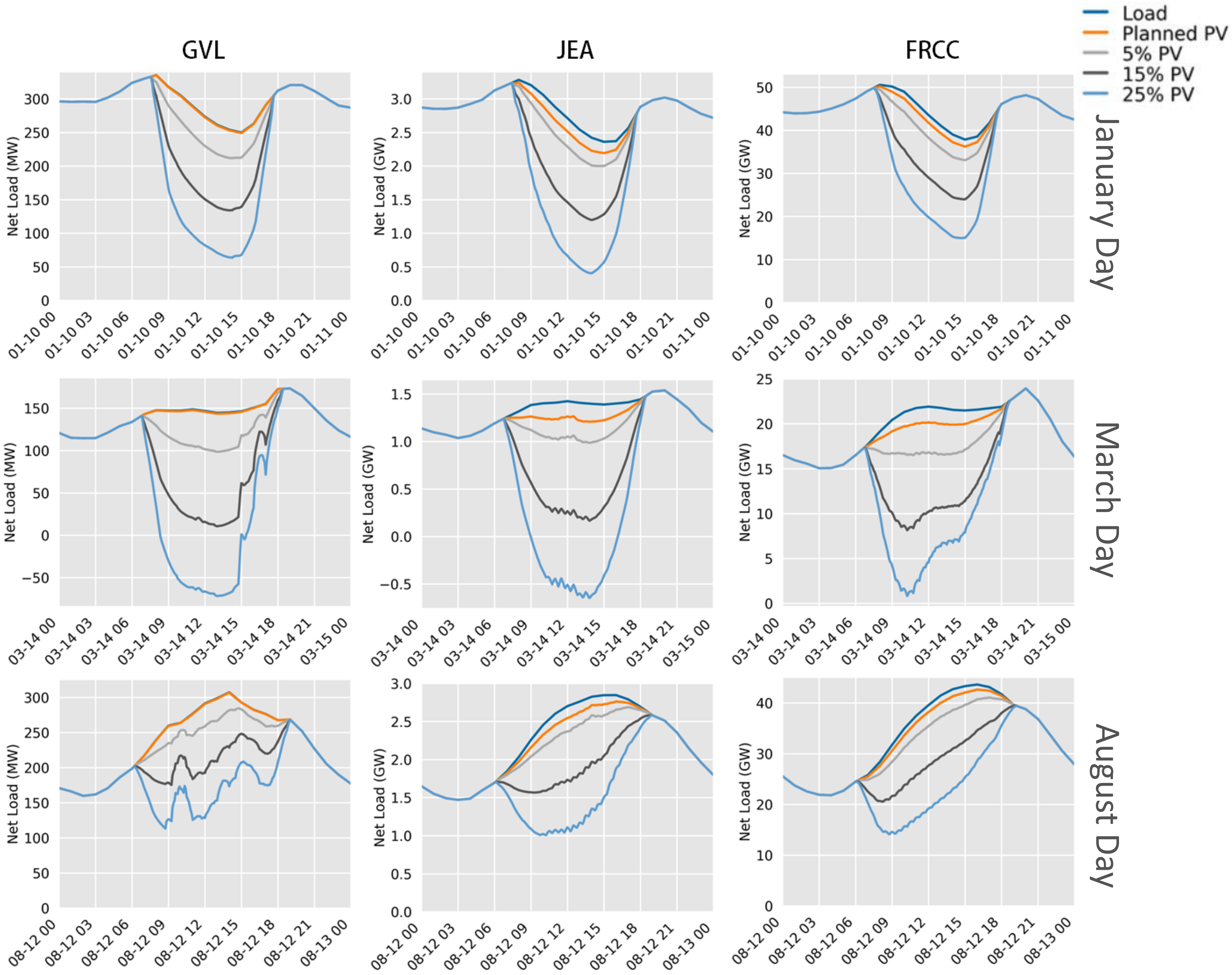
Can Florida municipal utilities' current operational practices accommodate increasing solar* deployment?

What operational changes would ease the transition from low to high solar penetrations?

*For the purposes of this presentation, solar = solar photovoltaics (PV), and we do not distinguish between utility-scale and customer-owned solar.

Solar Photovoltaic (PV) Deployment Changes the Net-Load Profile

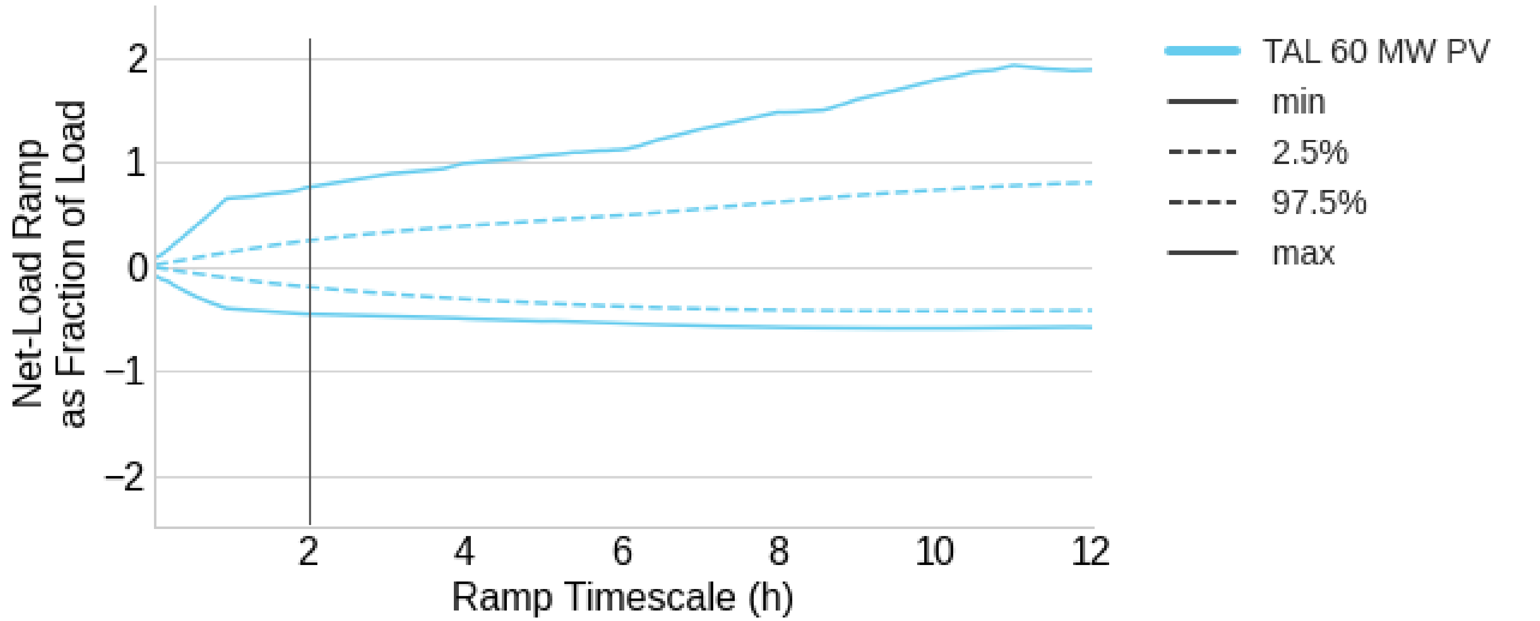
- Net-load is load minus variable generation
- Diurnal PV pattern results in low net-load mid-day and large net-load ramps when transitioning to or from daylight hours

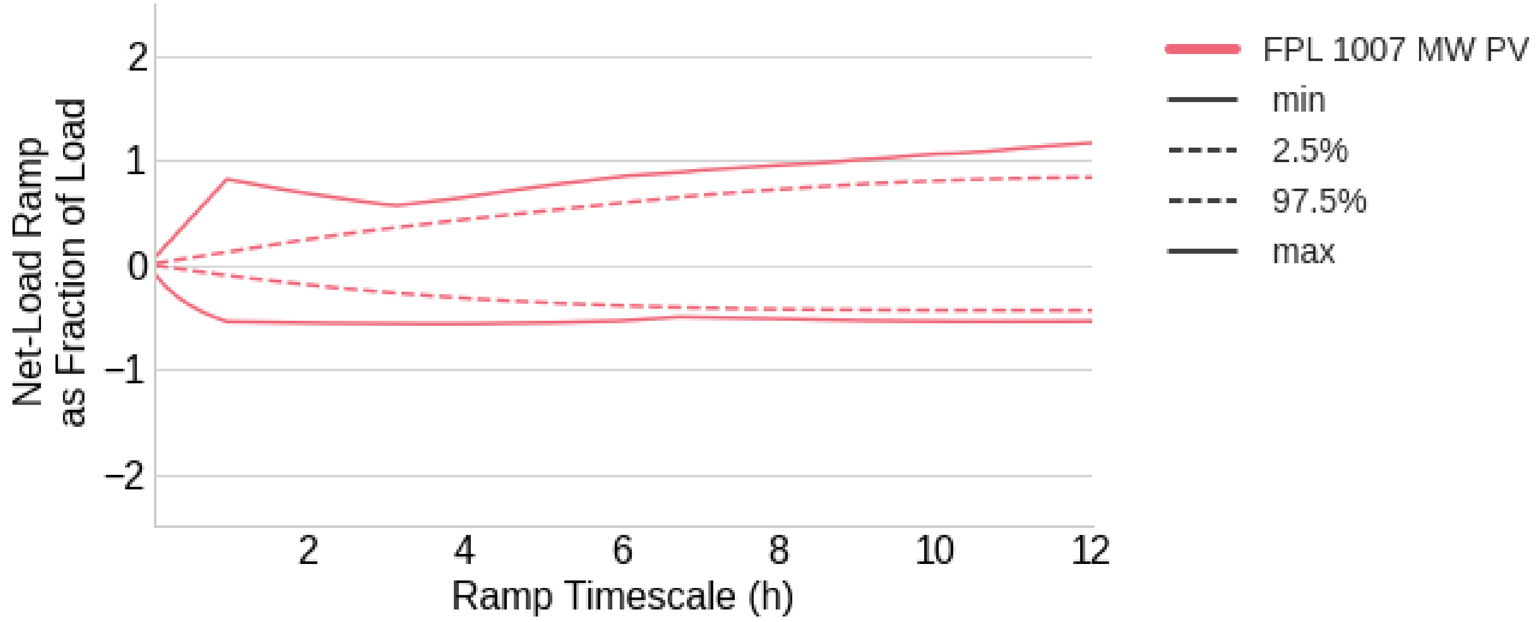


In this presentation, PV percentages are pre-curtailment PV generation divided by annual load.

Impact of Solar on Net-Load Variability

- TAL capacities correspond to 3% and 32% annual PV generation
- FPL capacities correspond to 1% and 31% annual PV generation
- Ramp distribution envelope widens with increasing PV
- Low probability events may be more severe in small utilities





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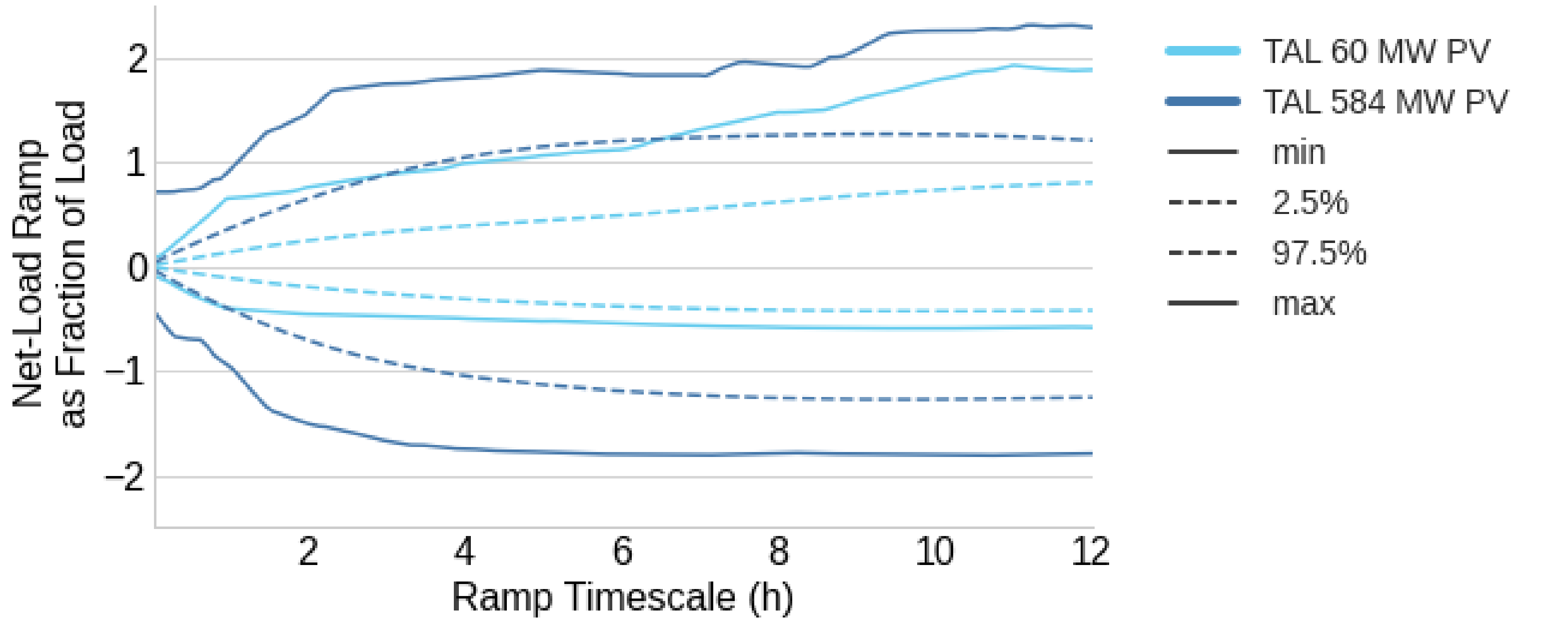
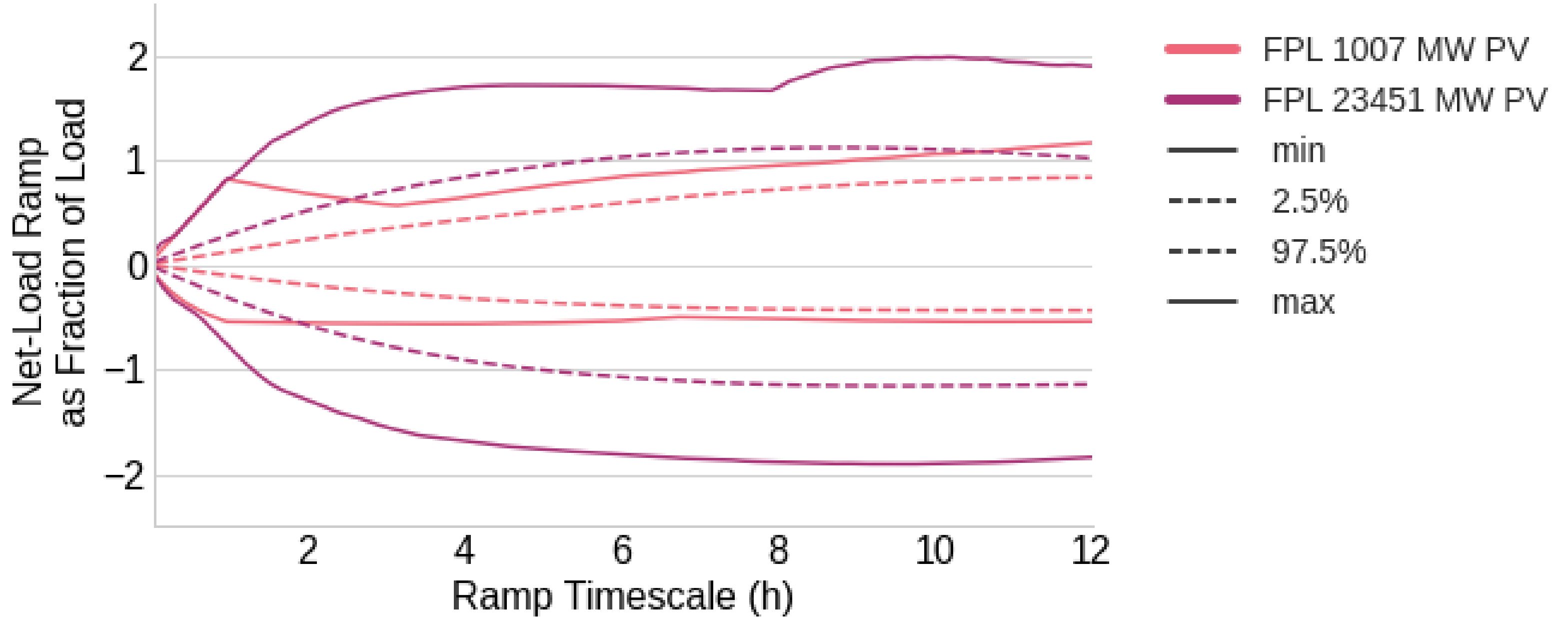




PV Forecasting without Weather Forecasts

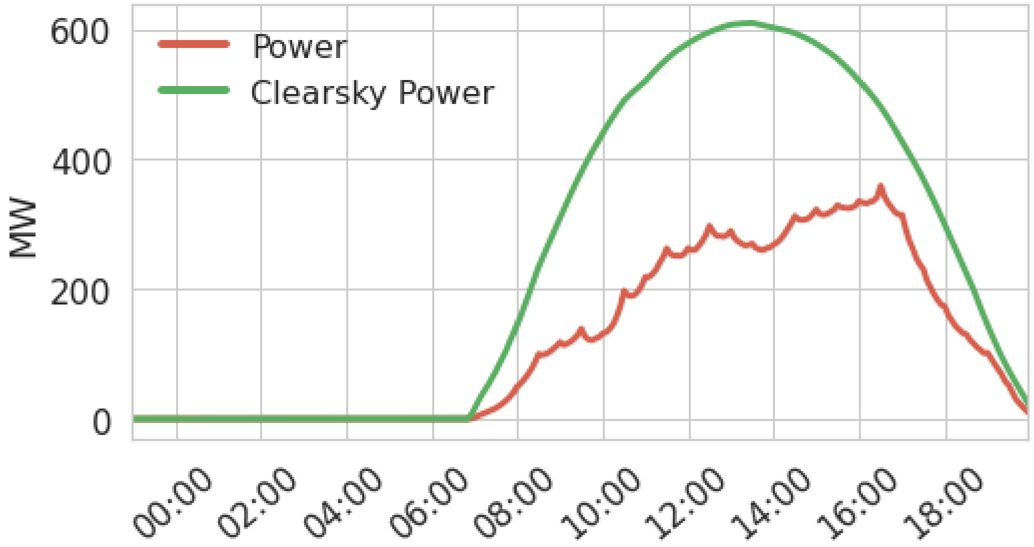
Persistence forecast

- Assume what is happening now (t) will persist (to t + Δt)
- "Forecast to beat"

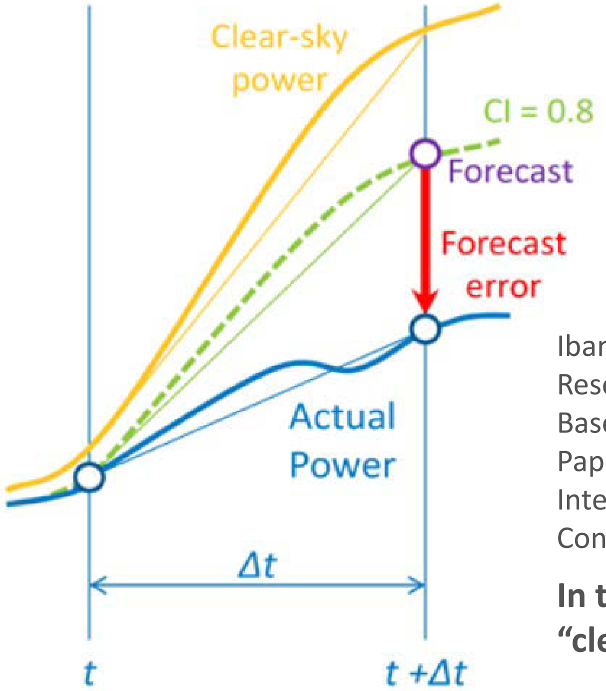
For PV, account for the movement of the sun

- Pre-compute clear-sky power
- Clear-sky Index (CI) = $\frac{\text{Actual Power (MW)}}{\text{Clearsky Power (MW)}}$
- Persist clear-sky index

Clear-sky and Actual PV Generation



Clear-sky Index Persistence Forecast



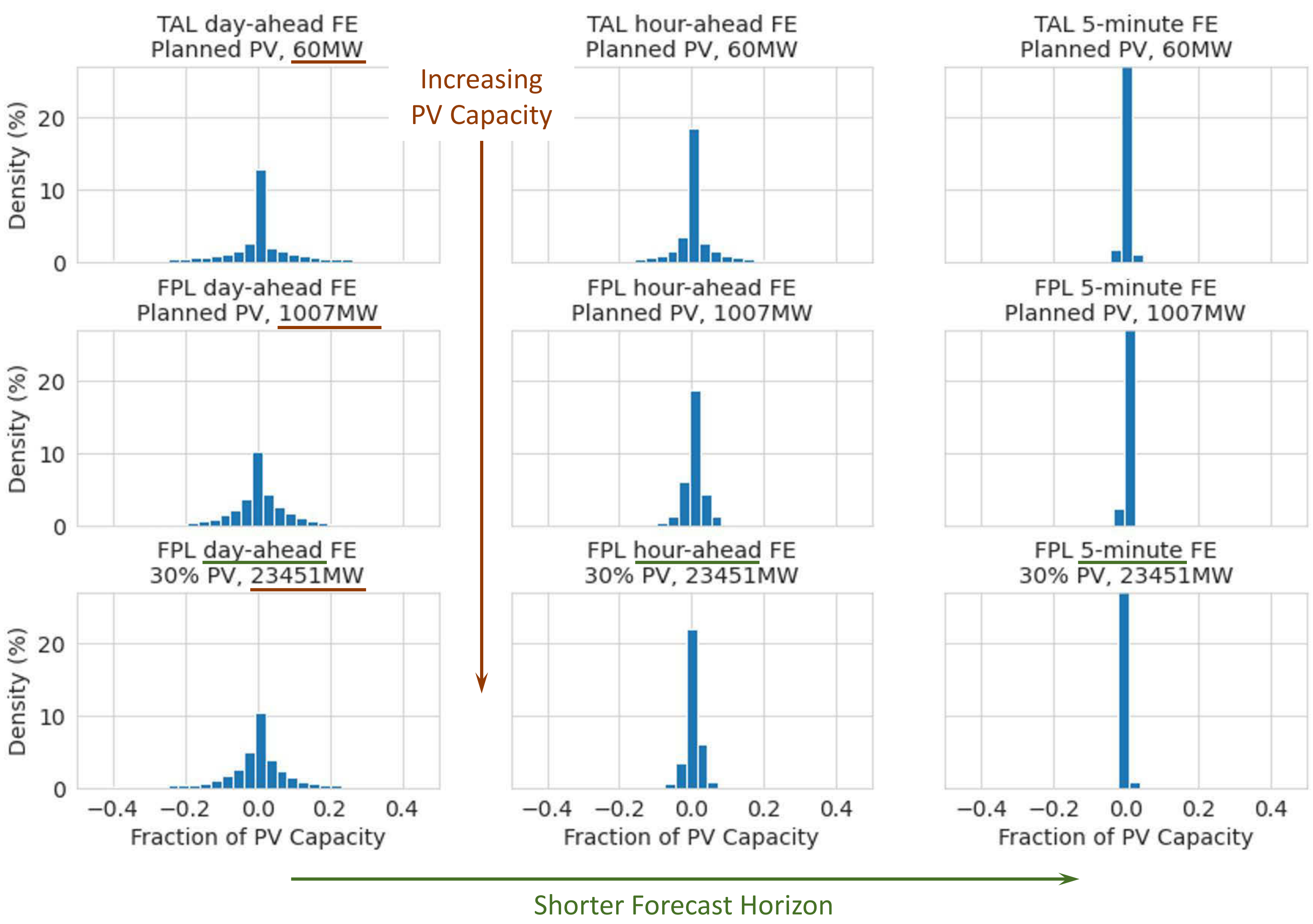
Ibanez, E., G. Brinkman, M. Hummon, and D. Lew. 2012. "Solar Reserve Methodology for Renewable Energy Integration Studies Based on Sub-Hourly Variability Analysis: Preprint." Conference Paper NREL/CP-5500-56169. Lisbon, Portugal: 2nd Annual International Workshop on Integration of Solar Power Systems Conference.

In this presentation, we use "clear-sky index" and "clear-sky fraction interchangeably.

Solar Forecast Uncertainty

- PV forecast errors (FEs) are smaller relative to nameplate capacity when there is more PV or the forecast horizon is shorter
- For the low-data forecasting methods shown here, the capacity effect is most pronounced for the hour-ahead timescale

Solar Forecast Errors for Different Timescales and Quantities of PV



Reserves: How Power Systems Cope with Variability and Uncertainty

Operating Reserves	Description
Frequency-Responsive	Services that act to slow and arrest the change in frequency via rapid and automatic responses that increase or decrease output from generators providing these services.
Regulating	Rapid response by generators used to help restore system frequency. These reserves may be deployed after an event and are **also used to address normal random short-term fluctuations in load that can create imbalances in supply and demand**.
Contingency	Reserves used to address power plant or transmission line failures by increasing output from generators.
Ramping (or Flexibility)	An emerging and evolving reserve product (also known as load-following or flexibility reserves) that is **used to address "slower" variations in net load and is increasingly considered to manage variability in net load** from wind and solar energy.

Excerpt from Table ES-1 in Denholm, Paul, Yinong Sun, and Trieu Mai. 2019. "An Introduction to Grid Services: Concepts, Technical Requirements, and Provision from Wind." Technical Report NREL/TP-6A20-72578. Golden, CO (United States): National Renewable Energy Laboratory (NREL). https://www.nrel.gov/docs/fy19osti/72578.pdf.

Reserves and Operational Practices in Florida's Municipal Utilities

Balancing Authority	Day-Ahead Forecasting		Intra-day Updates		Operating Reserves
	Load	Solar	Load	Solar	
Gainesville (GVL or GRU)	Hourly 10 day horizon	N/A	N/A	N/A	N/A[b]
Tallahassee (COT or TAL)	Hourly 16 day horizon	Hourly fixed profile	Hourly Hourly updates	N/A	+/- 16 MW
JEA	Hourly 14 day horizon	N/A	Hourly 5 min updates	N/A	+/- 50 MW
FMPP (incl. FMPA, OUC, Lakeland)	Hourly 7 day horizon	Hourly 7 day horizon	Infrequent updates as needed	Infrequent updates as needed	+50 MW[a,b] (more if no quick starts)

[a] FMPP requires 50 MW of up reserve during unit commitment, primarily to have sufficient spinning capacity to meet Florida Reserve Sharing Group obligations. As such, this does not represent "regulation reserves" per se.

[b] Although Gainesville and FMPP do not have precise regulation reserve requirements, during real-time operations they have significant capacity following AGC and continuously monitor both ACE and their ability to meet Florida Reserve Sharing Group obligations.

Detailed Questions and Brief Answers about FRCC Balancing Authorities:

What operational reserves are currently needed?

As a fraction of load, reserve needs vary with system size and operational practices

How do those needs change with increasing solar?

Reserve needs increase with increasing solar

Would more frequent load and solar forecasts reduce reserve needs?

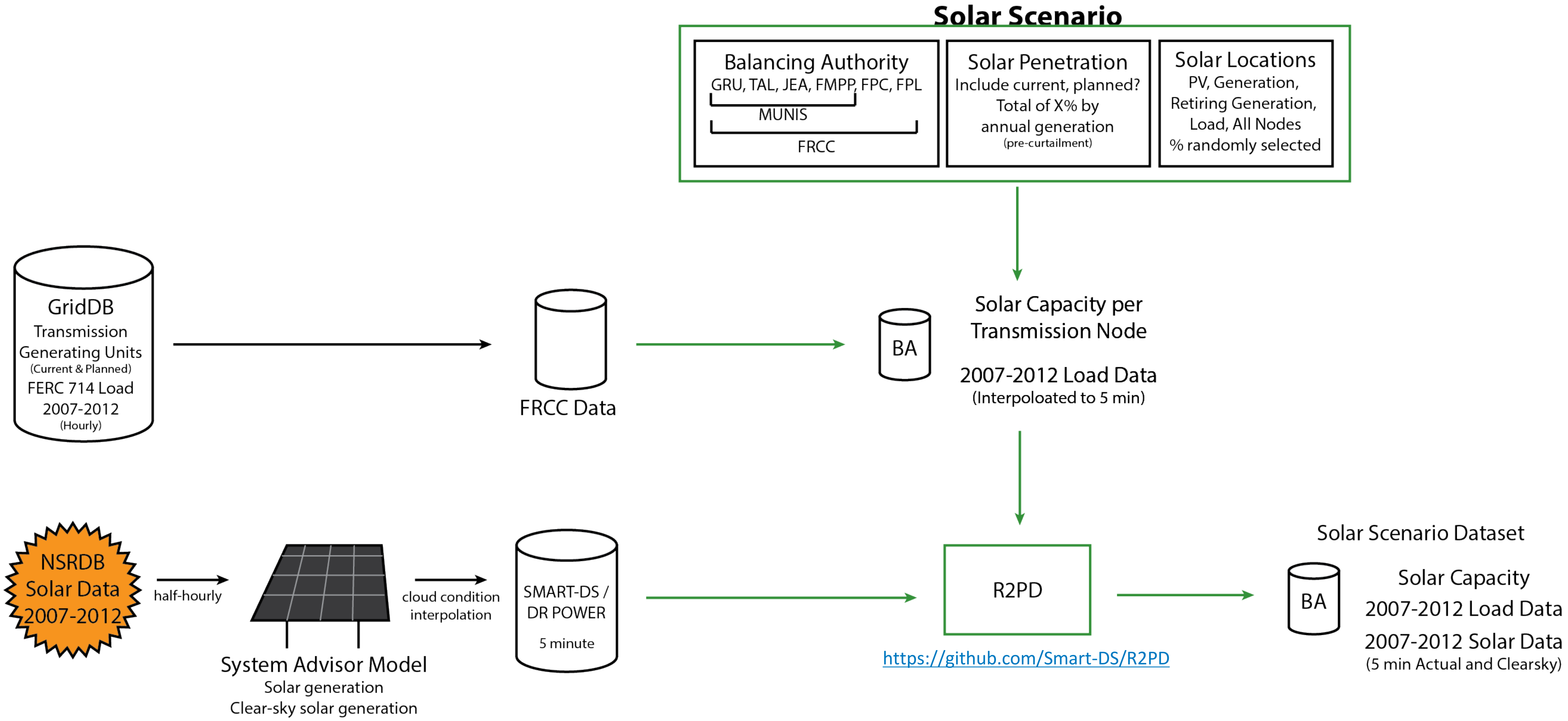
Yes

Would collective procurement of reserves (e.g., the formation of reserve sharing groups) reduce reserve needs?

Yes

But how do we know?

Time-Synchronized Solar and Load Data



Operational Practices

Day-ahead dispatch (e.g., GVL)

- Sufficient generation capacity following AGC signal to balance out differences between day-ahead forecast and actual net-load (load minus solar)

Hourly dispatch (e.g., TAL, JEA)

- Sufficient generation capacity following AGC signal to balance out differences between hour-ahead forecast and actual net-load

Sub-hourly dispatch (e.g., FPL)

- Sufficient generation capacity following AGC signal (regulation reserves) to balance out differences between 5 to 10-minute ahead forecast and actual net-load
- Sufficient generation capacity reserved at the 1-4 hour timescale and available at the sub-hourly timescale to follow net-load ramps (flexibility reserves) to cover differences between hour-ahead forecast and actual solar generation

Operational Practices

Day-ahead

– Suf
diff
sola

Hourly disp

– Suf
diff

Sub-hourly

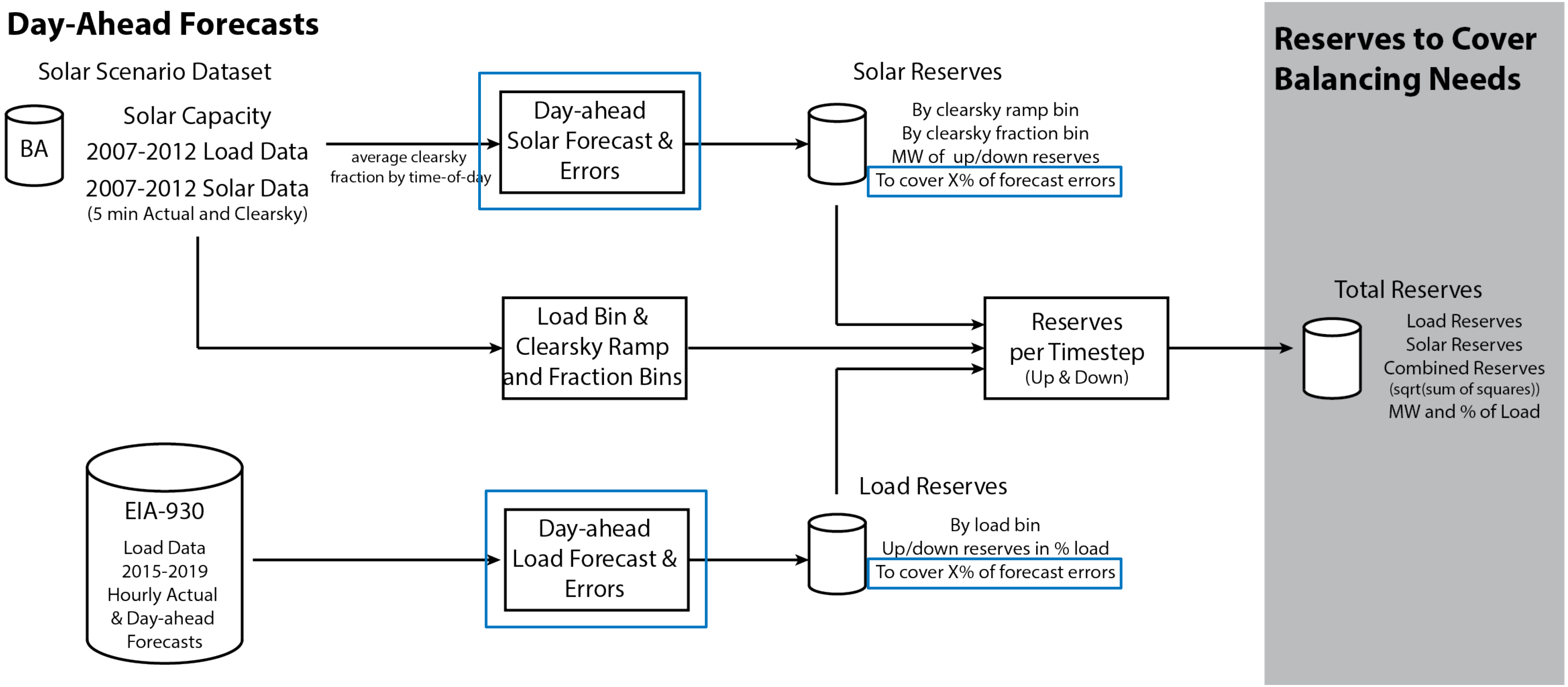
– Suf
bala
net

– Suf
ava
reso
sola

From forecast errors …

… to reserve requirements

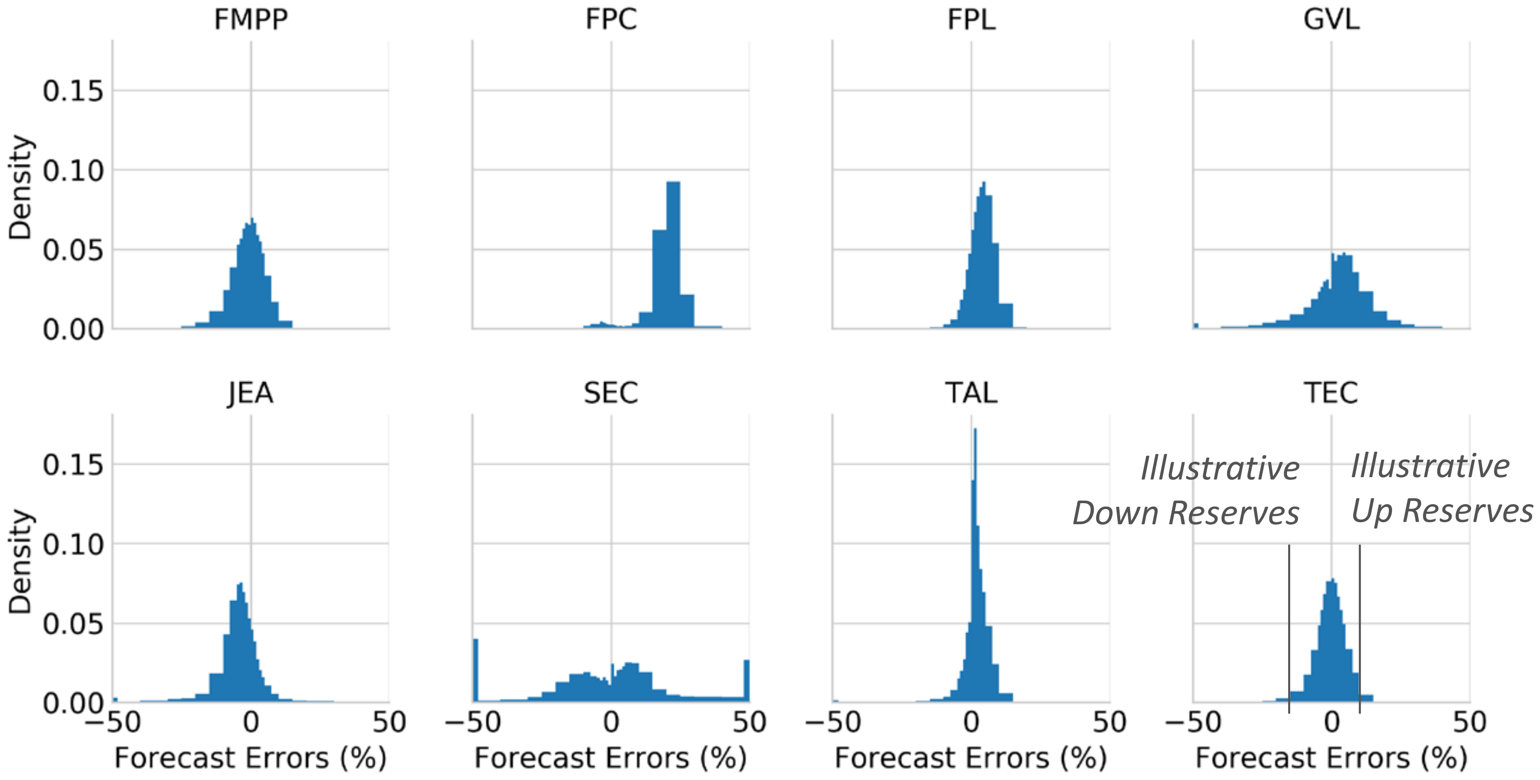
Day-Ahead Reserve Requirements



Day-ahead Load Forecast Errors (Historical)

- Actual day-ahead hourly forecast errors reported by the BAs to EIA
- BAs can have very different forecast error distributions

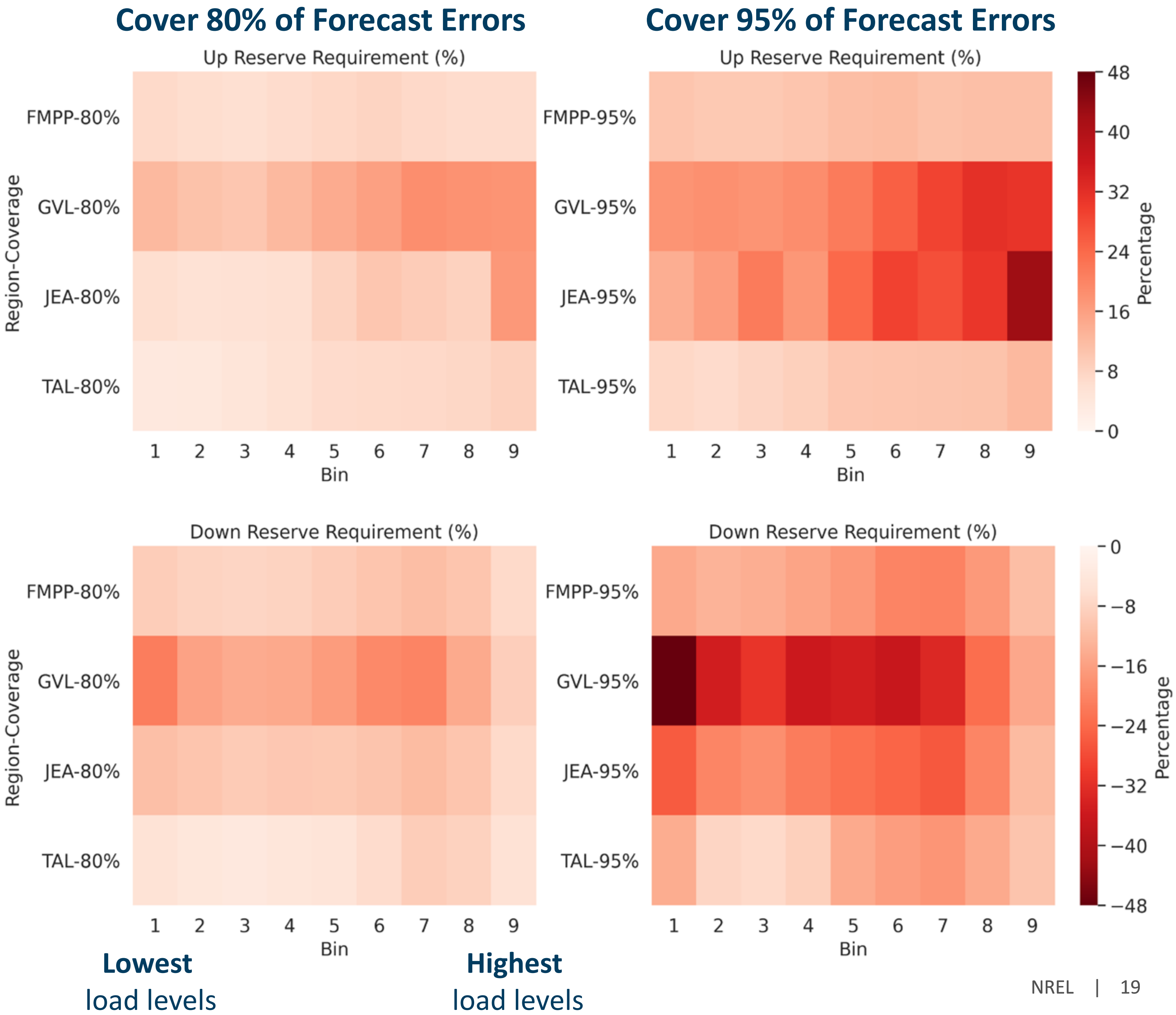
Histograms of "Total Day Ahead Forecast Error" = (Actual – Forecast) * 100 / Actual from EIA-930 1/1/2016 through 9/9/2018



Forecast errors outside of limits shown are placed in first (FE < -50%) or last (FE > 50%) bins.

Reserve Requirements Implied by Day-ahead Load Forecast Errors

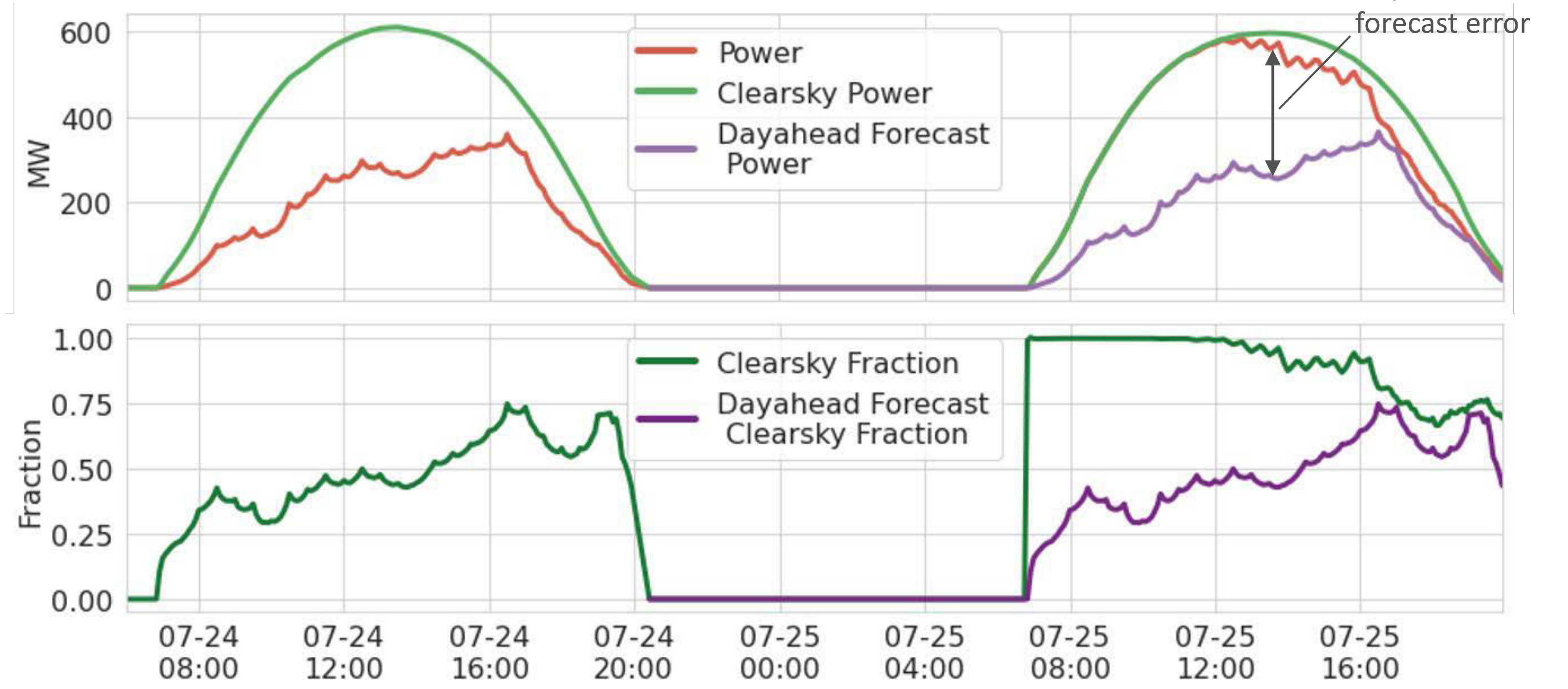
- Load reserve requirement for day-ahead only operational practices set by covering X% of historical load forecast errors
- Percent of load to cover for up- and down-reserves specified per load bin



Day-ahead Solar Forecast Method

- Assume that today's clear-sky index pattern will repeat tomorrow
- This is a worst-case, persistence forecast
  - Only clear-sky and actual generation data are required
  - No weather forecast information is used
- Yields conservative reserve estimates

Forecast Process for One Day



In this example

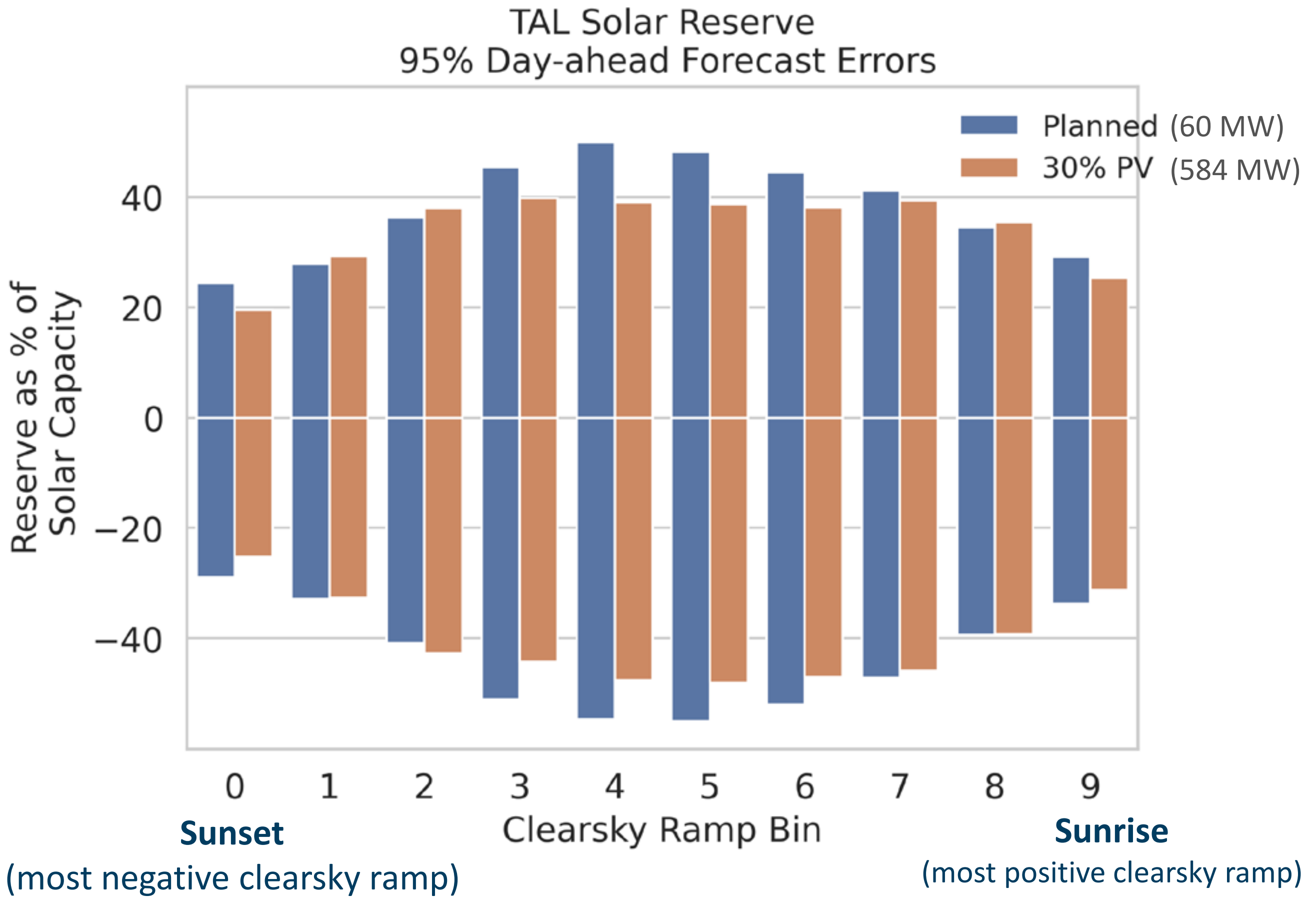
- The afternoon/evening cloud patterns are similar on the two days
- But the second day's morning and midday hours are much sunnier, leading to large forecast errors

In our analysis

- This process was repeated for 2,192 days for each BA

Reserve Requirements Implied by Day-ahead Solar Forecast Errors

- If only day-ahead solar forecasts are used, a significant fraction of PV capacity may need to be held in reserve to cover forecast errors
- The amount of up and down reserves needed varies with time of day



In our analysis

- Day-ahead solar forecasts were computed for 2,192 days
- Resulting in 52,608 hours of day-ahead forecast errors for each BA
- Each hour was placed in a clearsky 1-hour ramp bin
- And a number of MW of up- and down- reserves was specified to cover 80%, 95%, or 99% of the observed forecast errors

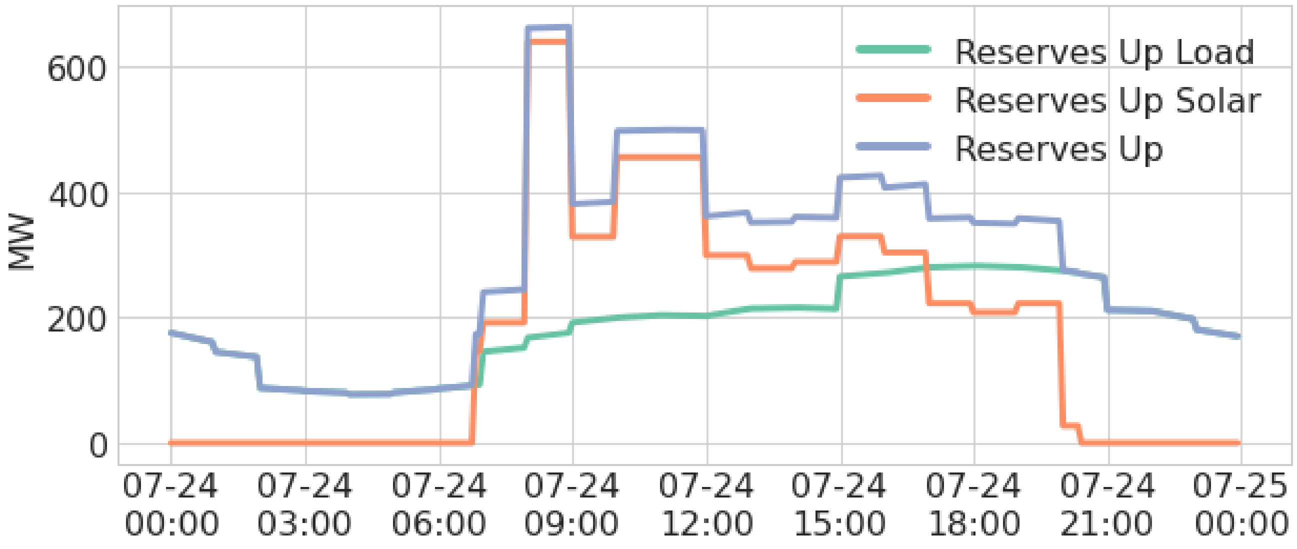
Combining Load and Solar Reserves

Because reserves cover forecast errors, they are combined like standard deviations, not means. Thus, under an assumption of no correlation

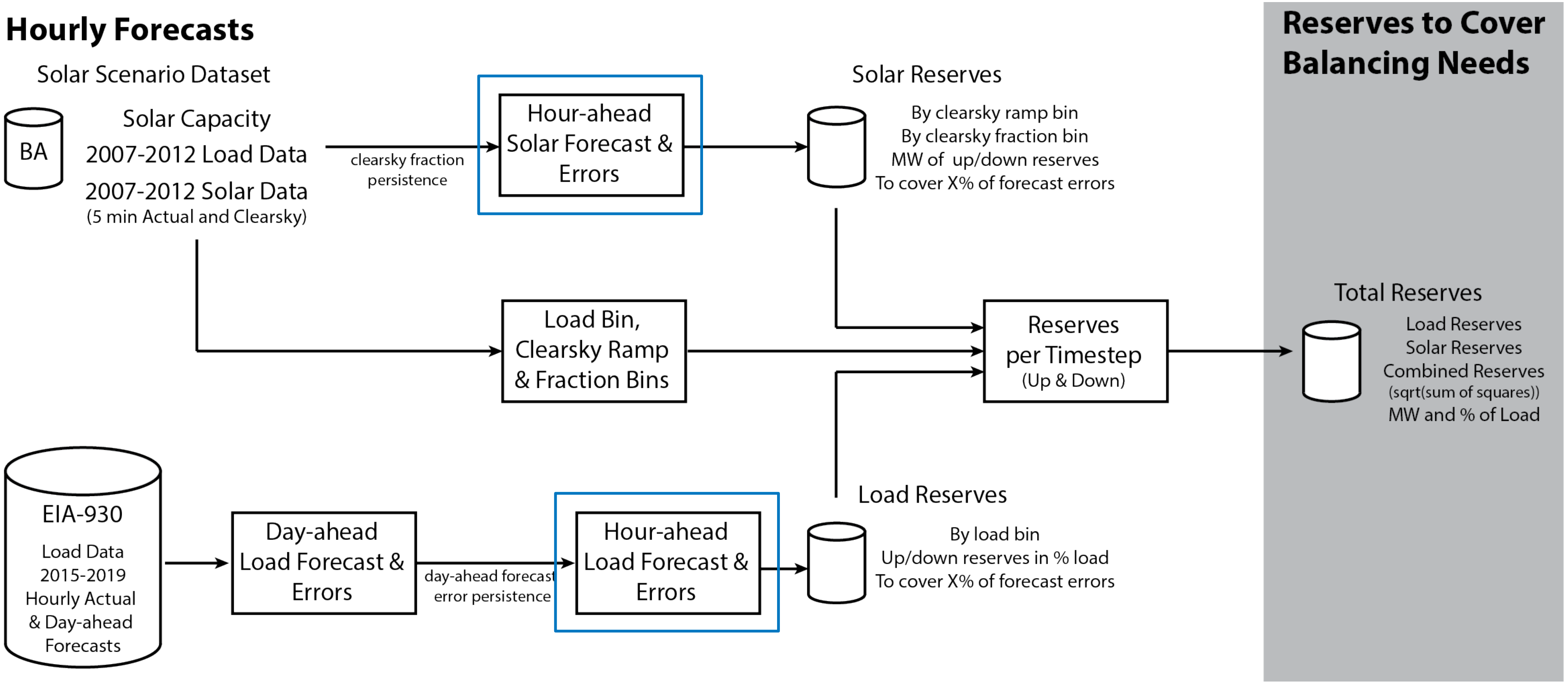
$$\sigma_{total} = \sqrt{\sigma_{load}^2 + \sigma_{solar}^2}$$

(based on variance of the sum of two random variables). For example, if $\sigma_{load} = \sigma_{solar} = 10$ MW then $\sigma_{total} = 14.1$ MW.

Example of day-ahead up reserves for load, solar, and combined



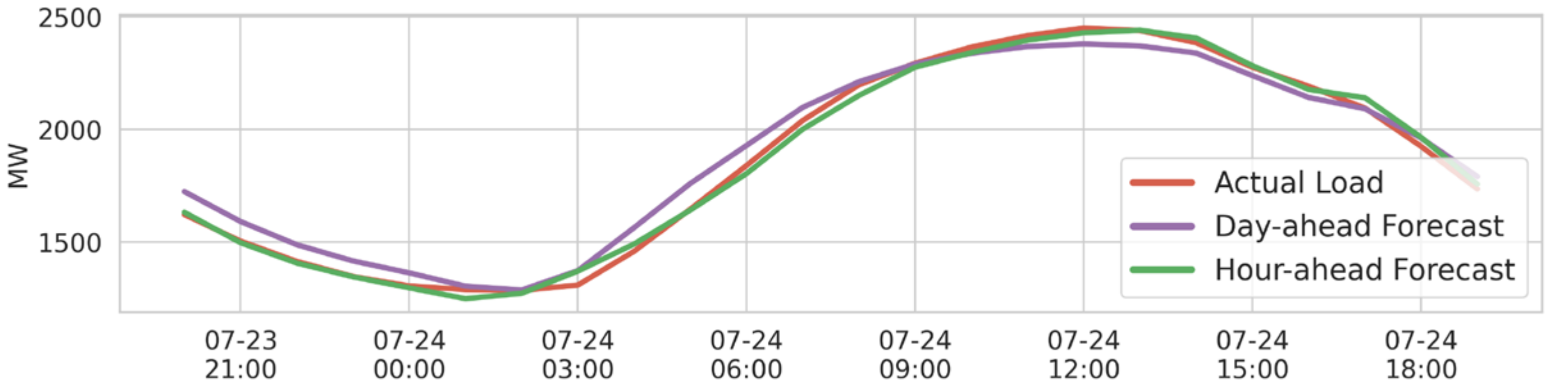
Hour-ahead Reserve Requirements



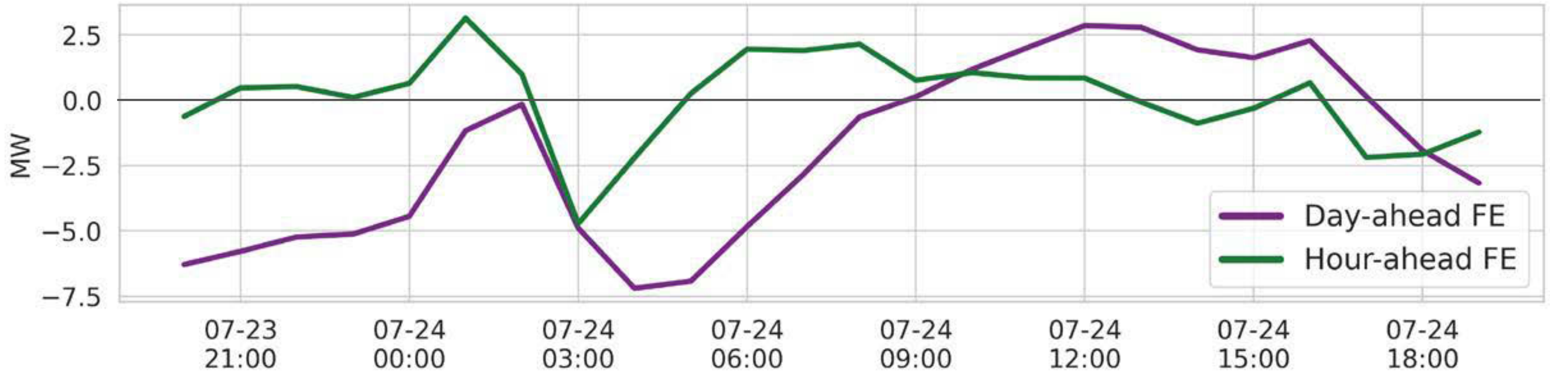
Hour-Ahead Load Forecast Method

- Hour-ahead forecasts computed for the EIA-930 2015-2018 data set
- Assume the next hour's day-ahead forecast error will be the same as this hour's

Hour-Ahead Load Forecast Example Day



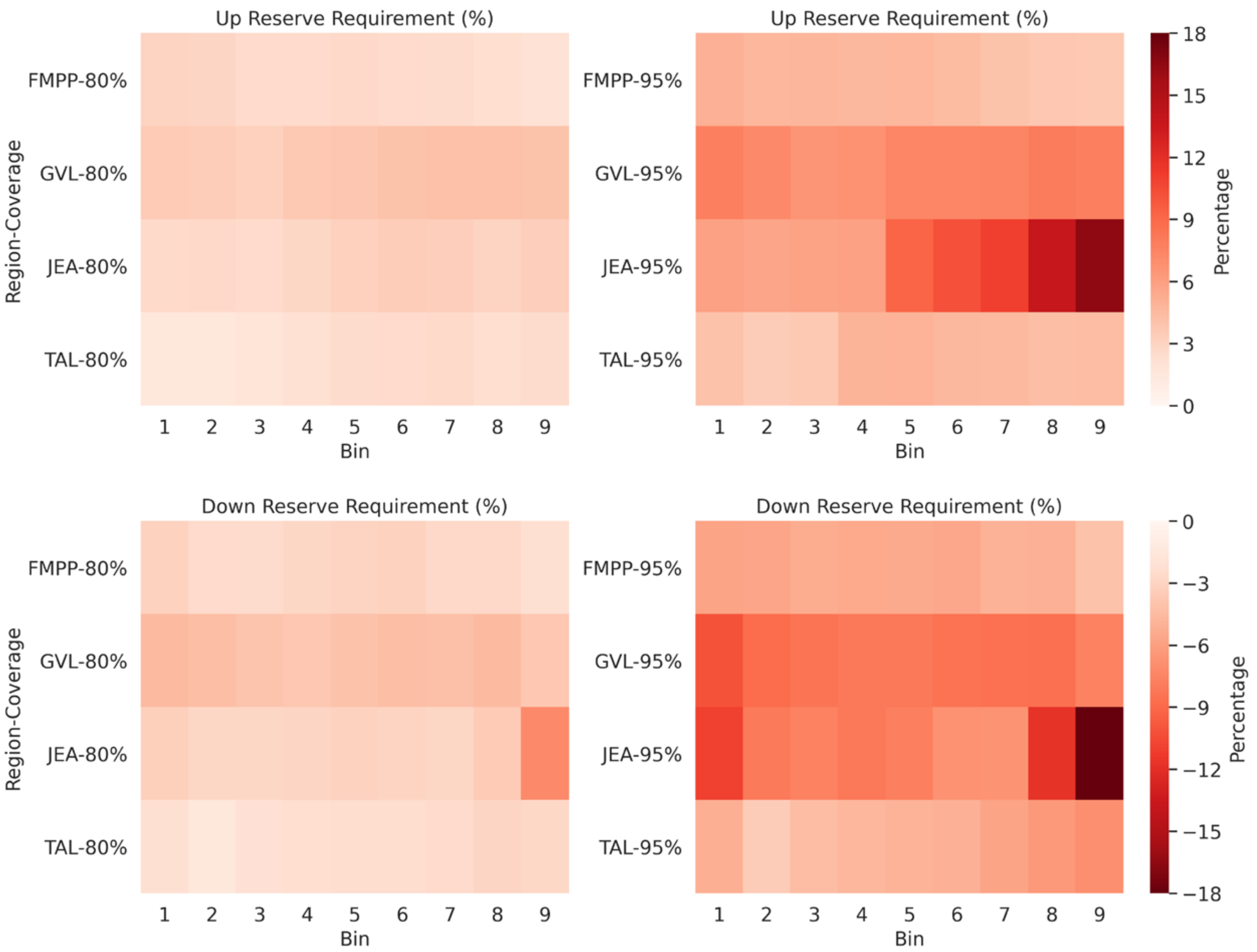
Resulting Hour-Ahead Forecast Error Compared to Day-Ahead Forecast Error



Reserve Requirements Implied by Hour-ahead Load Forecast Errors

- Hour-ahead forecast errors are significantly smaller than day-ahead forecast errors (compare this scale to Slide 18’s)

Cover 80% of Forecast Errors | **Cover 95% of Forecast Errors**

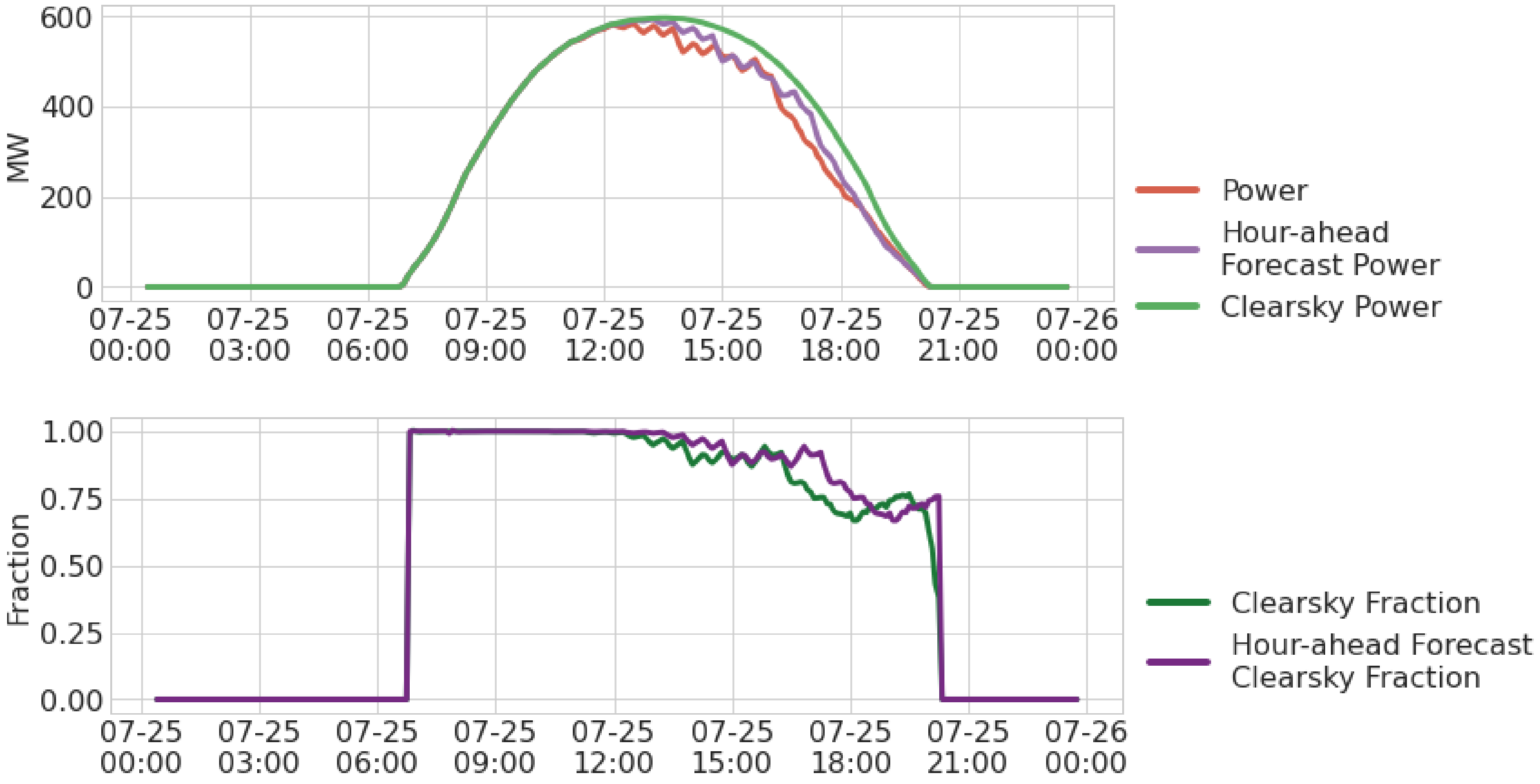


Lowest load levels | **Highest** load levels

Hour-ahead Solar Forecast Method

- Assume that this hour's clear-sky index will persist to the next hour
- This is a worst-case, persistence forecast that yields conservative reserve estimates

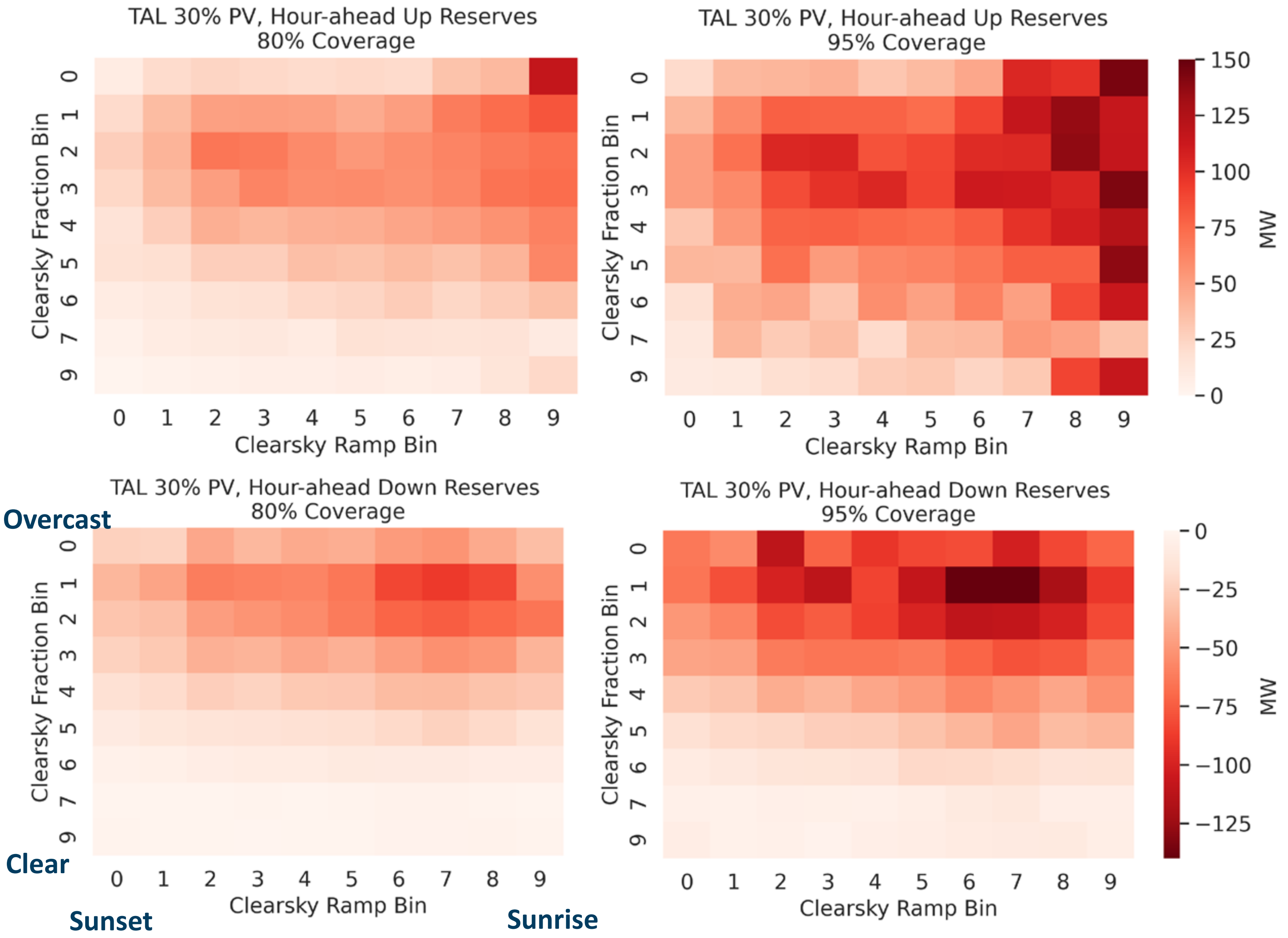
Forecast Process for One Day



Reserve Requirements Implied by Hour-ahead Solar Forecast Errors

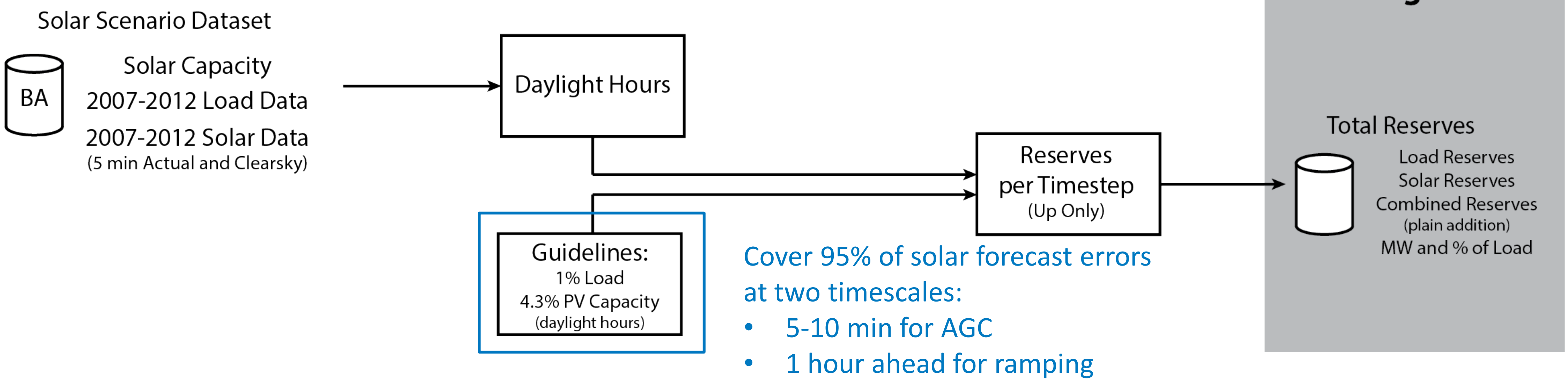
- In this case we bin by clear-sky ramp (i.e., time of day) and clear-sky fraction (i.e., cloudiness)
- More up- and down-reserves are needed in cloudy conditions

Solar Reserve Requirements to Cover Hour-Ahead Forecast Errors



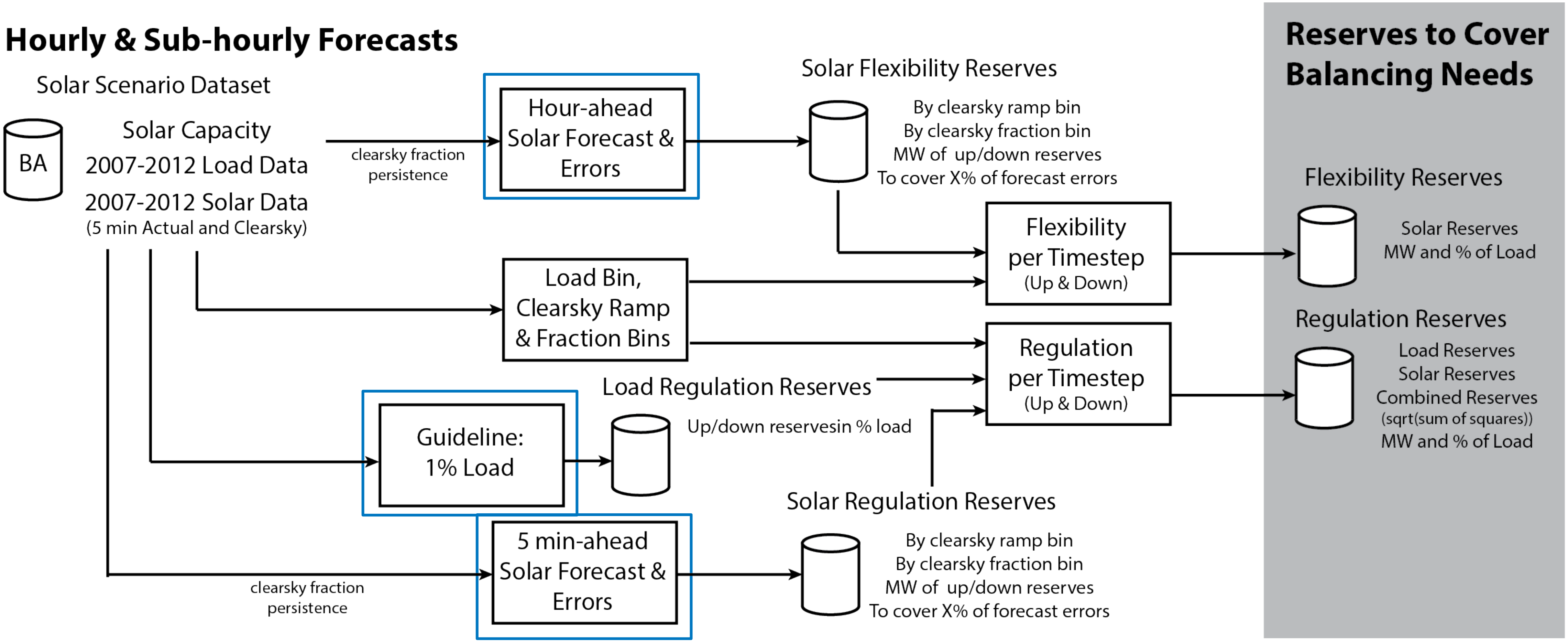
Capacity Expansion Model (CEM) Reserve Requirement Assumptions

Large System, Sub-Hourly Dispatch



Product	Load Reqt	Wind Reqt	PV Reqt	Timescale	Extra Cost
Reg	**1%**	0.5% of Generation	**0.3% of PV Capacity (daytime)**	**5-10 min**	Table from Hummon et al. (2013)
Flex	-	10% of Generation	**4% of PV Capacity (daytime)**	**60 min**	-

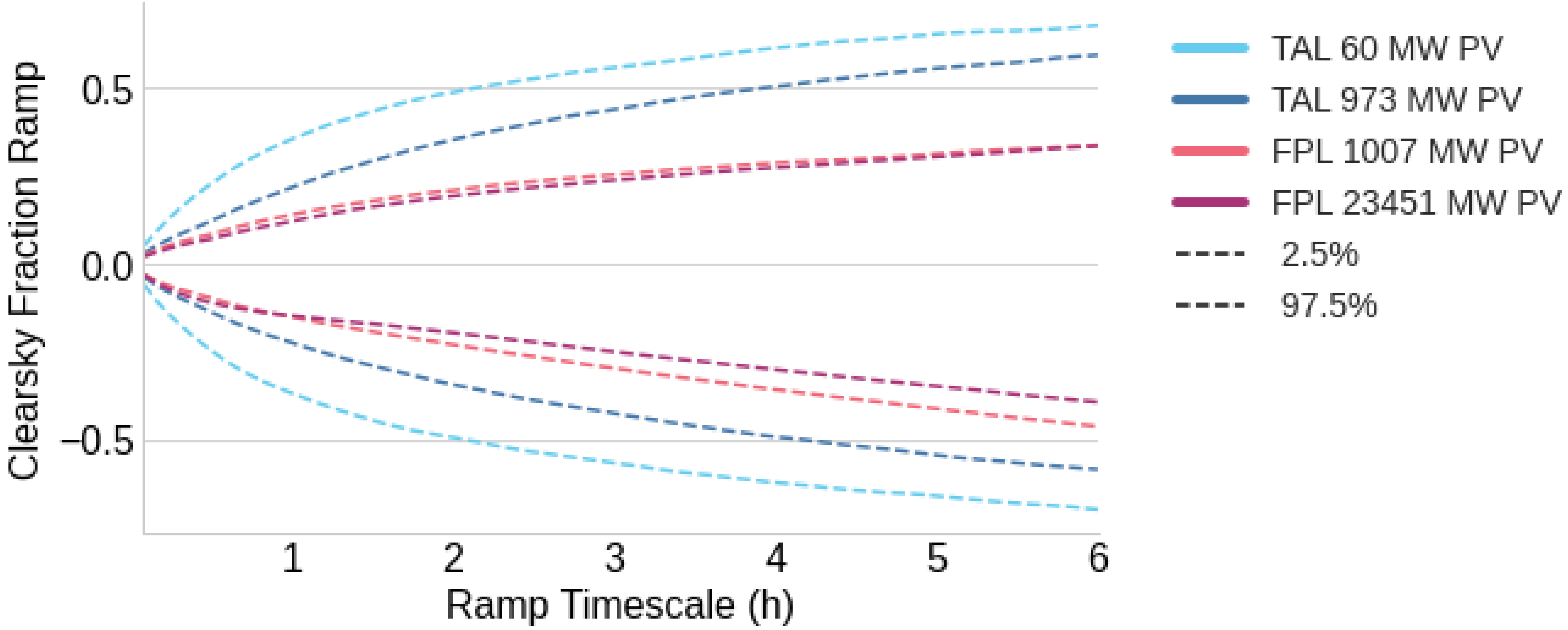
Sub-hourly Operations Reserve Requirements



Analysis Scenarios

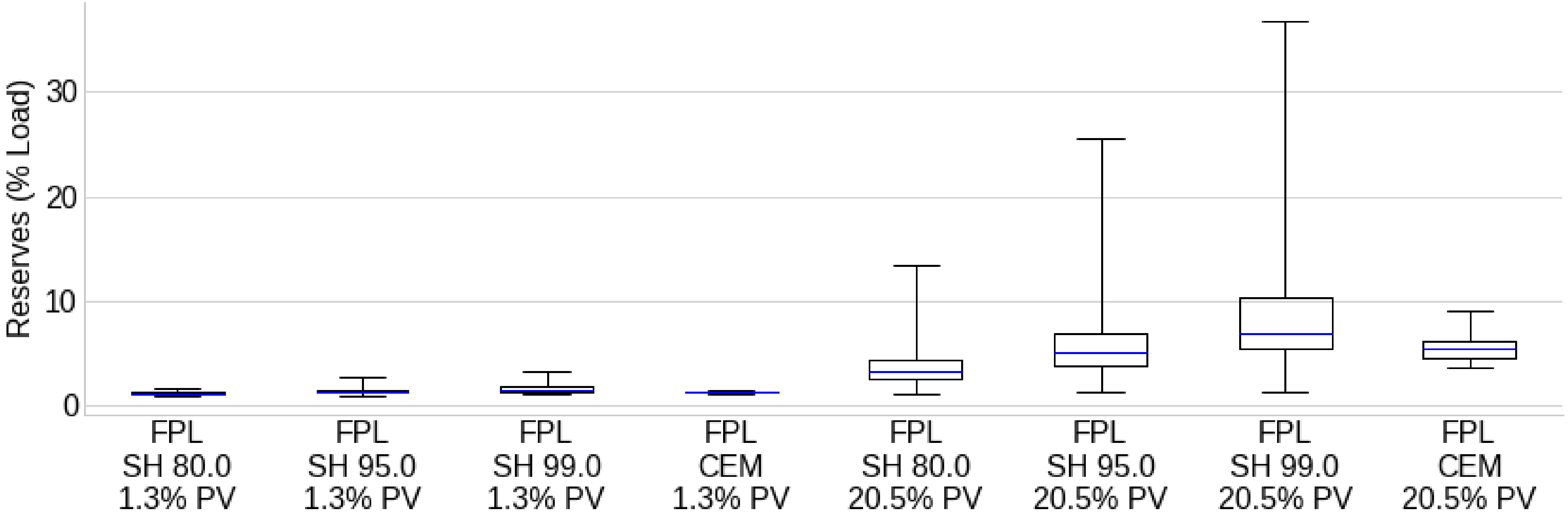
- Balancing authority
  - **GVL**, **TAL**, **JEA**, SEC, **FMPP**, TEC, FPC, or FPL
  - MUNIS (GVL, TAL, JEA, & FMPP)
  - FRCC (all BAs except SEC)
- PV penetration
  - "Planned," 5%, 10%, …, 50%
- PV placement
- Operational practice
  - Day-ahead (DA), hour-ahead (HA), or sub-hourly (SH)
- Percent of forecast errors to cover with reserves

Reserve Methods Parameters: PV Placement



- Smaller, geographically concentrated quantities of PV have more variable generation profiles.
- Although variability depends on PV capacity and total geographic area, **we found that it did not matter how we placed the same quantity of PV within the same BA**.
- For example, clear-sky ramp envelopes for TAL and FPL 30% PV cases were nearly indistinguishable if PV was placed at 2 vs. 20 (for TAL) or 17 vs. 581 (for FPL) nodes.
- ***In what follows, we show results in which PV is placed at a randomly selected 50% of a BA's nodes***

Reserve Methods Parameters: Percent of Forecast Errors



Blue lines show medians, whiskers cover full range.

- Our CEM assumptions are based on covering 95% of large balancing authority wind and solar forecast errors, 10-minute ahead errors for regulating reserves, 1-hour ahead errors for flexibility reserves (Ibanez et al. 2012)
- But many other variants can be found in the literature—50%, 70%, 99.9%, 3σ, 5σ
- ***In what follows, we mostly present reserve quantities that cover 95% of forecast errors. In a few places we present sensitivities on this assumption, showing the change when we cover 80% or 99% of forecast errors***

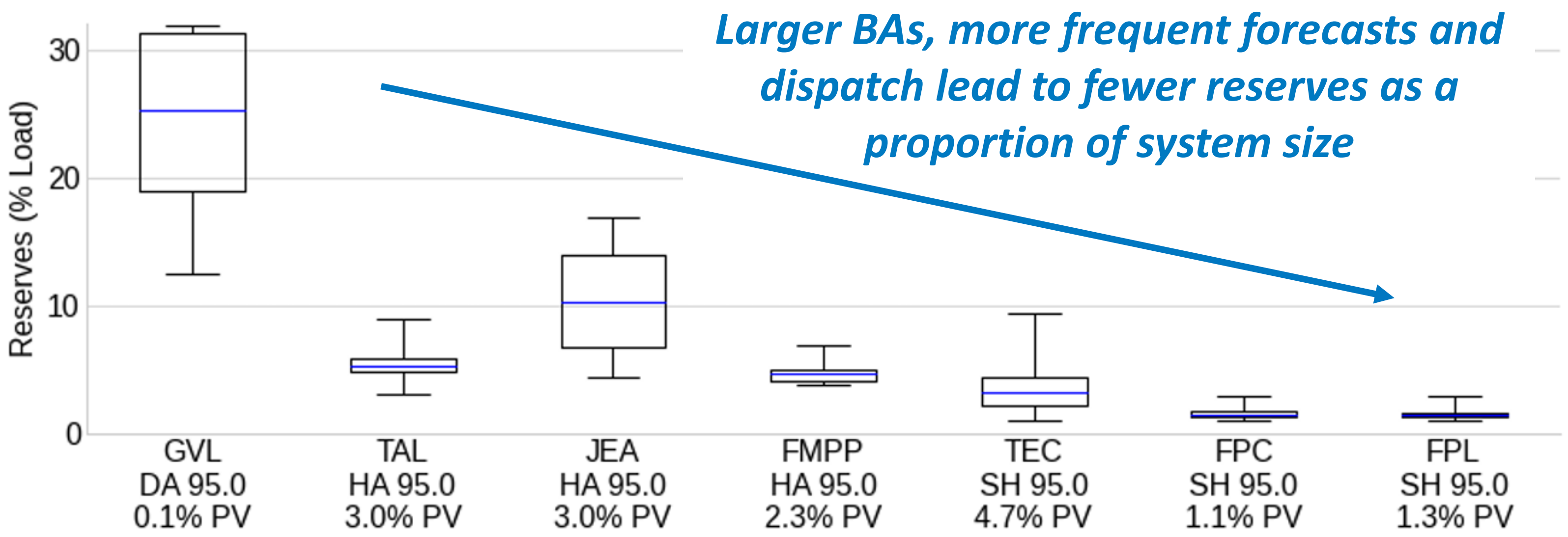
Ibanez, E., G. Brinkman, M. Hummon, and D. Lew. 2012. "Solar Reserve Methodology for Renewable Energy Integration Studies Based on Sub-Hourly Variability Analysis: Preprint." Conference Paper NREL/CP-5500-56169. Lisbon, Portugal: 2nd Annual International Workshop on Integration of Solar Power Systems Conference.

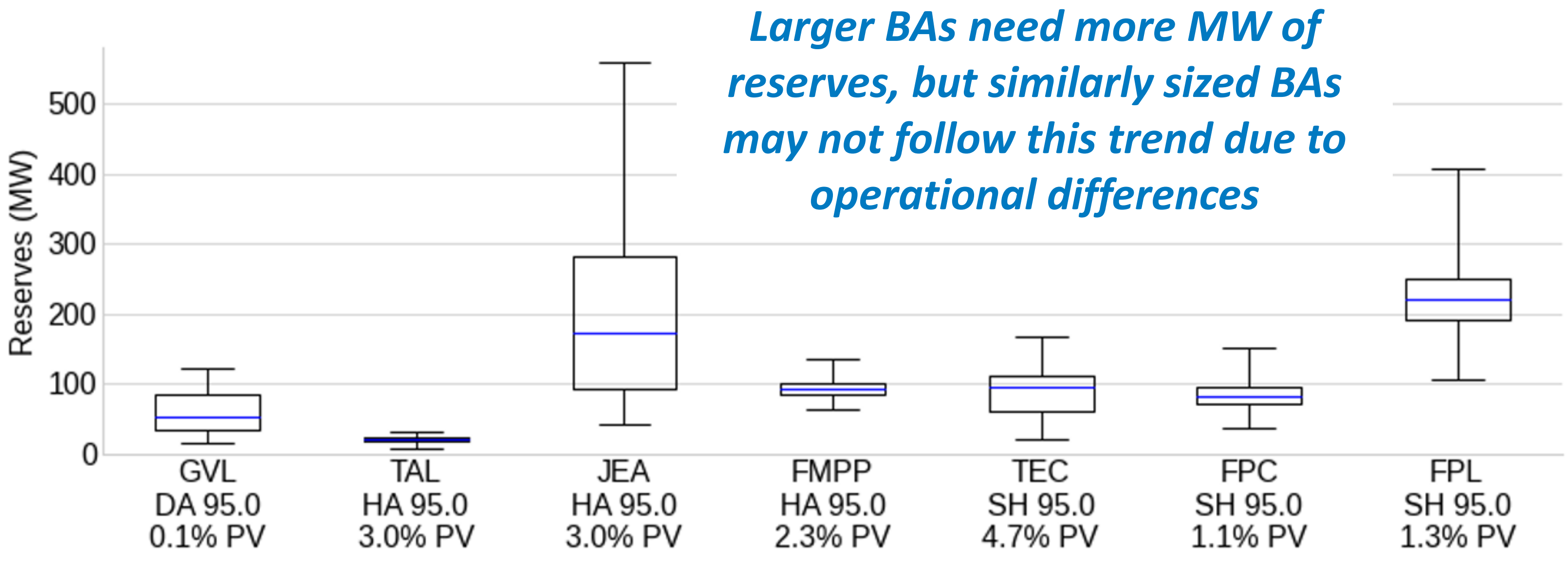
What more can we say?

Reserve estimates for current operational practices, planned PV

- Gainesville (GVL) uses day-ahead forecast only (DA)
- Tallahassee (TAL), JEA, and FMPP make hourly updates (HA)
- We assume TECO (TEC), Duke Energy Florida (FPC), and FPL do sub-hourly dispatch

Up reserves needed to provide regulation and flexibility services
(contingency / Florida Reserve Sharing Group obligations not included)





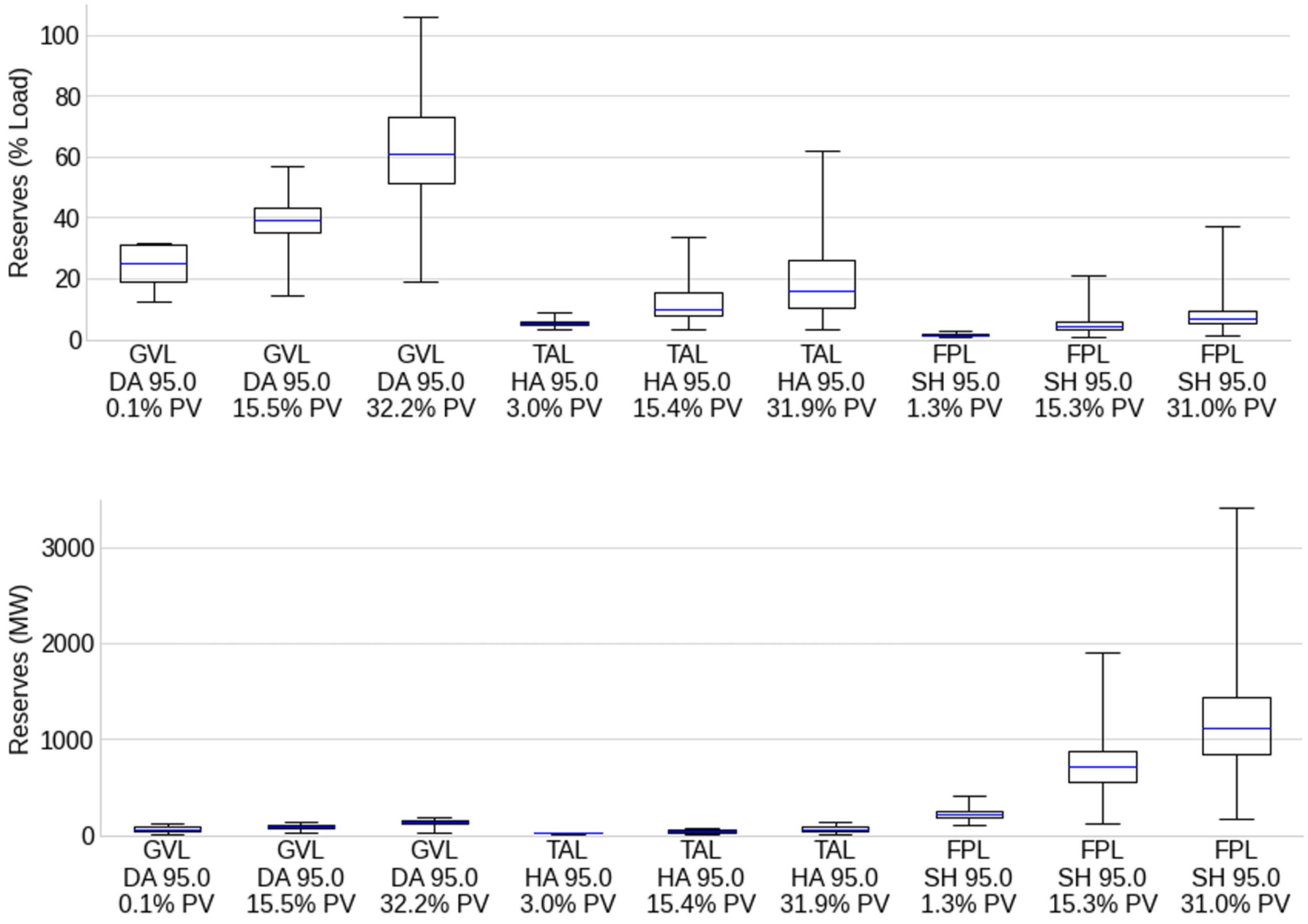
Blue lines show medians, whiskers cover full range.

Reserve estimates for different amounts of solar PV

- All BAs face more variability and uncertainty as they integrate more PV
- Small BAs need to hold more reserves as a % of load; Large BAs need to hold more reserve capacity (in MW)
- More frequent forecasts and dispatch reduce the amount of reserves required (compare GVL and TAL)

Up reserves needed to provide regulation and flexibility services

(contingency / Florida Reserve Sharing Group obligations not included)

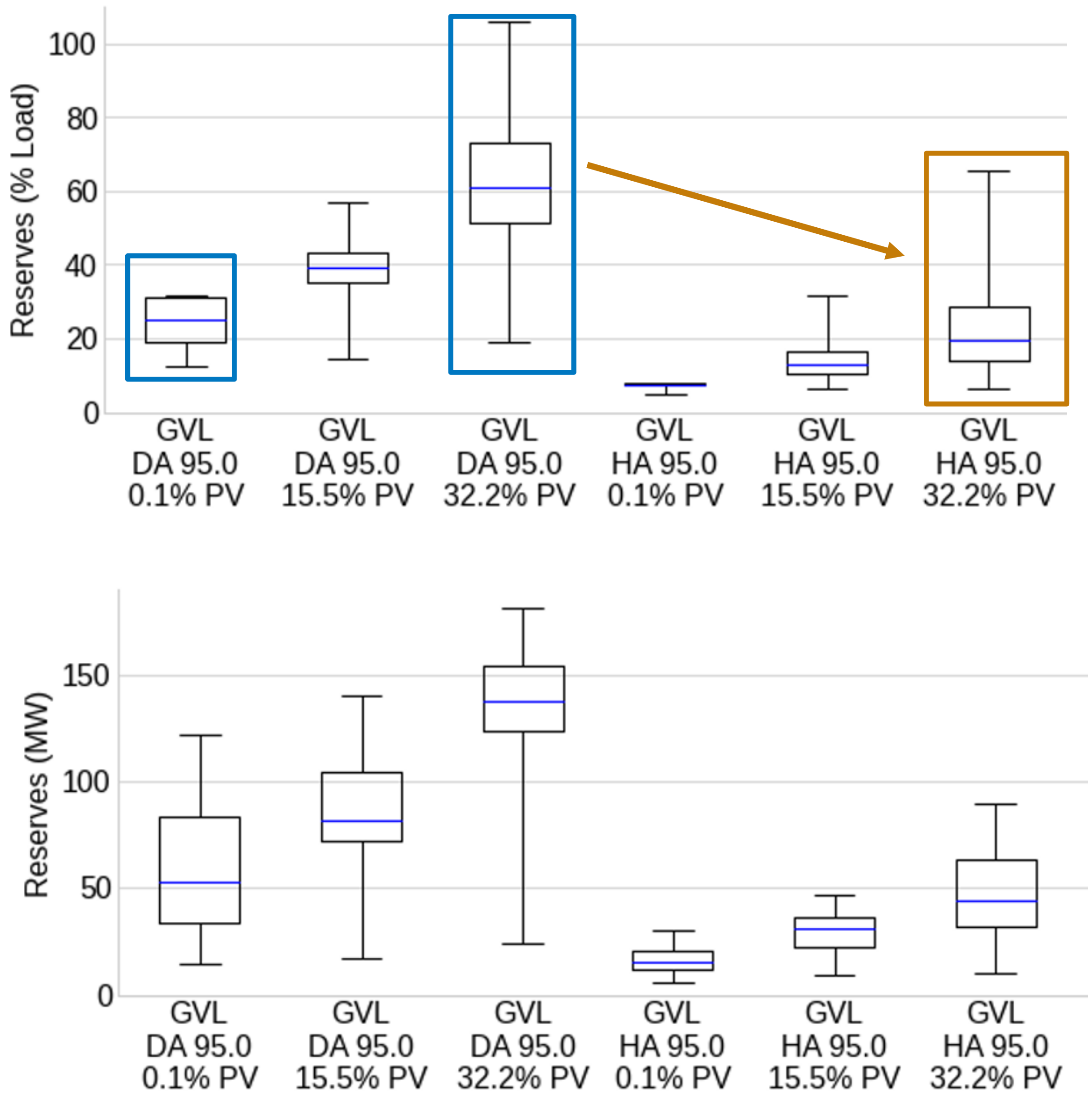


Blue lines show medians, whiskers cover full range.

Reserve estimates for Gainesville with day-ahead or hourly operations, different amounts of solar PV

Integration Option 1:
Increase frequency of operational practices

Up reserves needed to provide regulation and flexibility services
(contingency / Florida Reserve Sharing Group obligations not included)

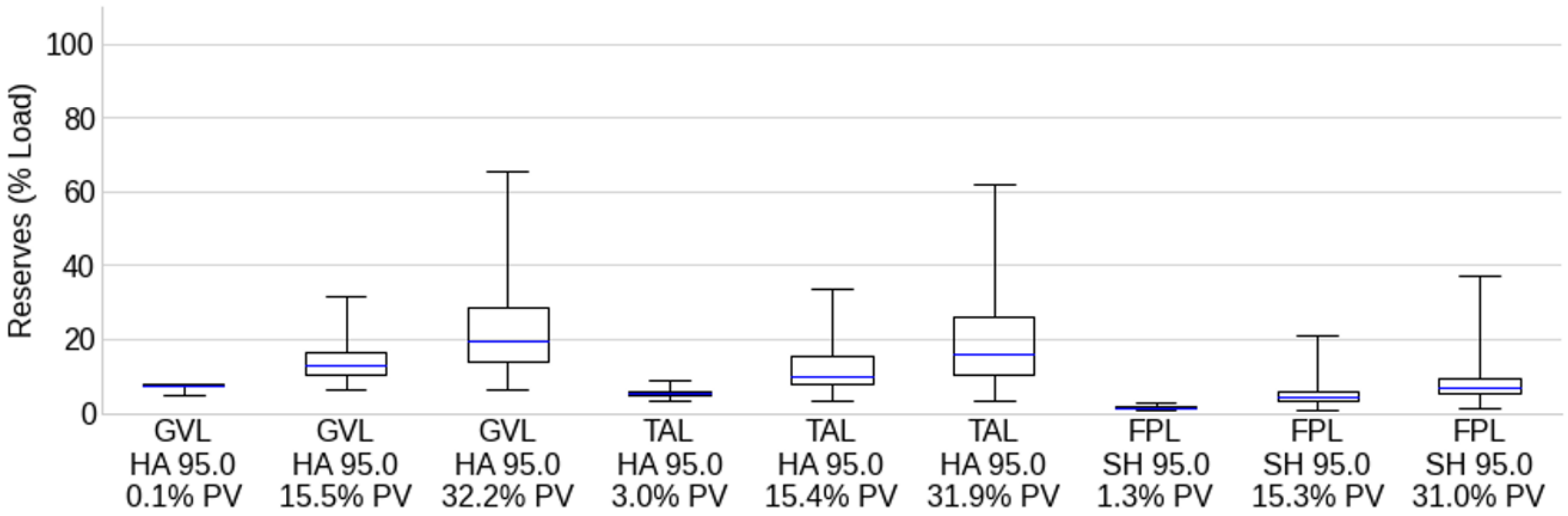


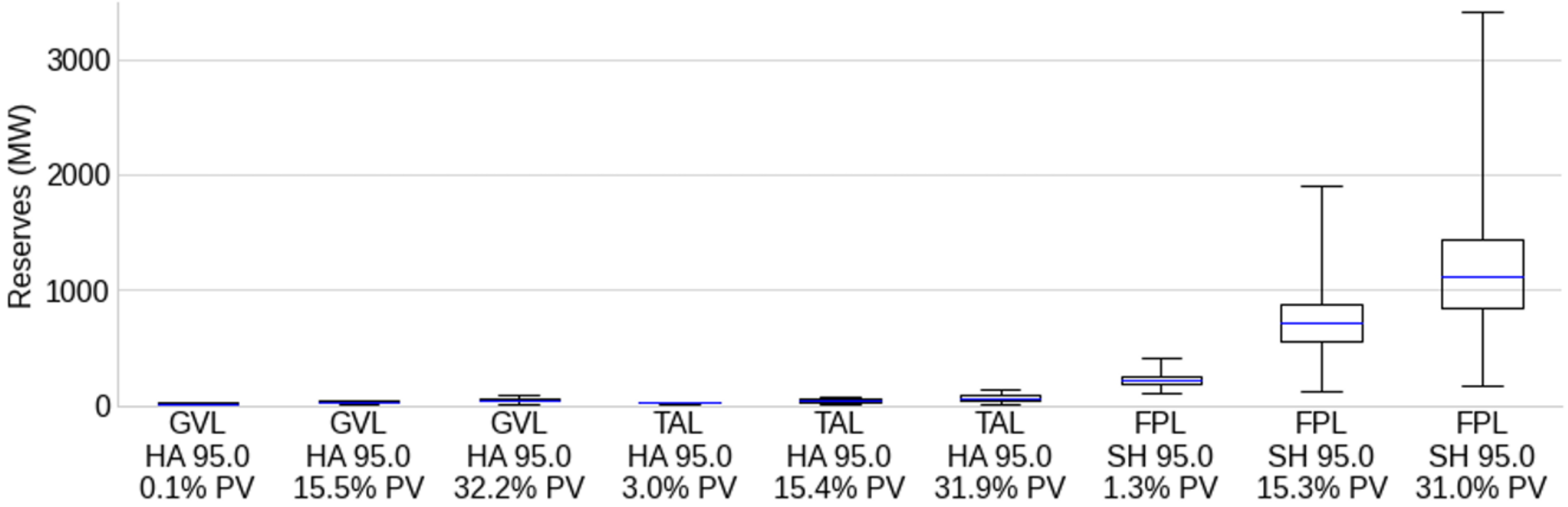
Blue lines show medians, whiskers cover full range.

Reserve estimates for different amounts of solar PV: Reprise

- Increasing GVL dispatch frequency from day-ahead to hourly brings its reserve needs in line with TAL, a similar-sized BA

Up reserves needed to provide regulation and flexibility services
(contingency / Florida Reserve Sharing Group obligations not included)





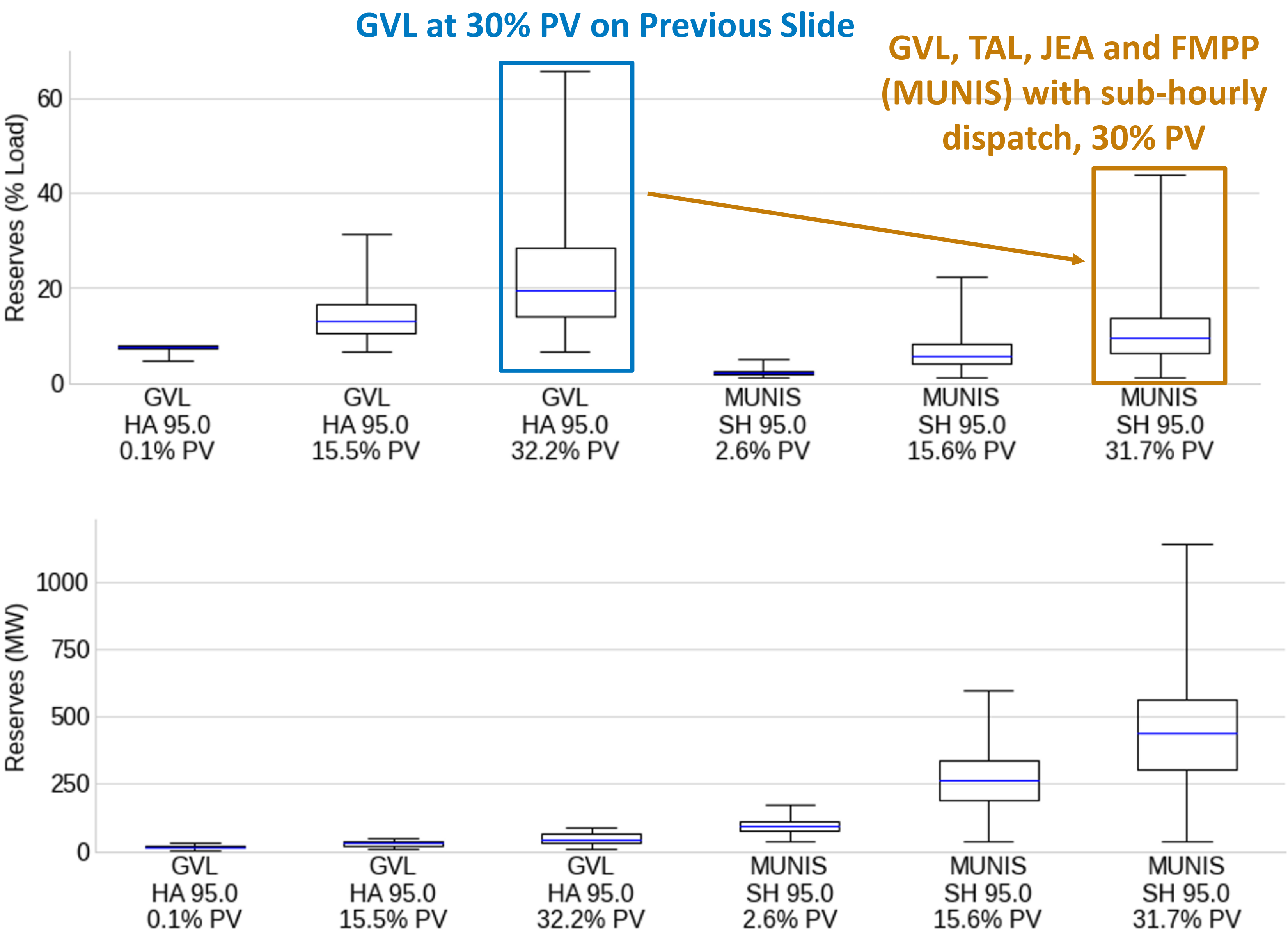
Blue lines show medians, whiskers cover full range.

Reserve estimates for Gainesville and a “MUNIS” reserve sharing group, different amounts of solar PV

Integration Option 2:

An operational reserve sharing group could pool load and resources to improve short-term forecasting and dispatch

Up reserves needed to provide regulation and flexibility services
(contingency / Florida Reserve Sharing Group obligations not included)

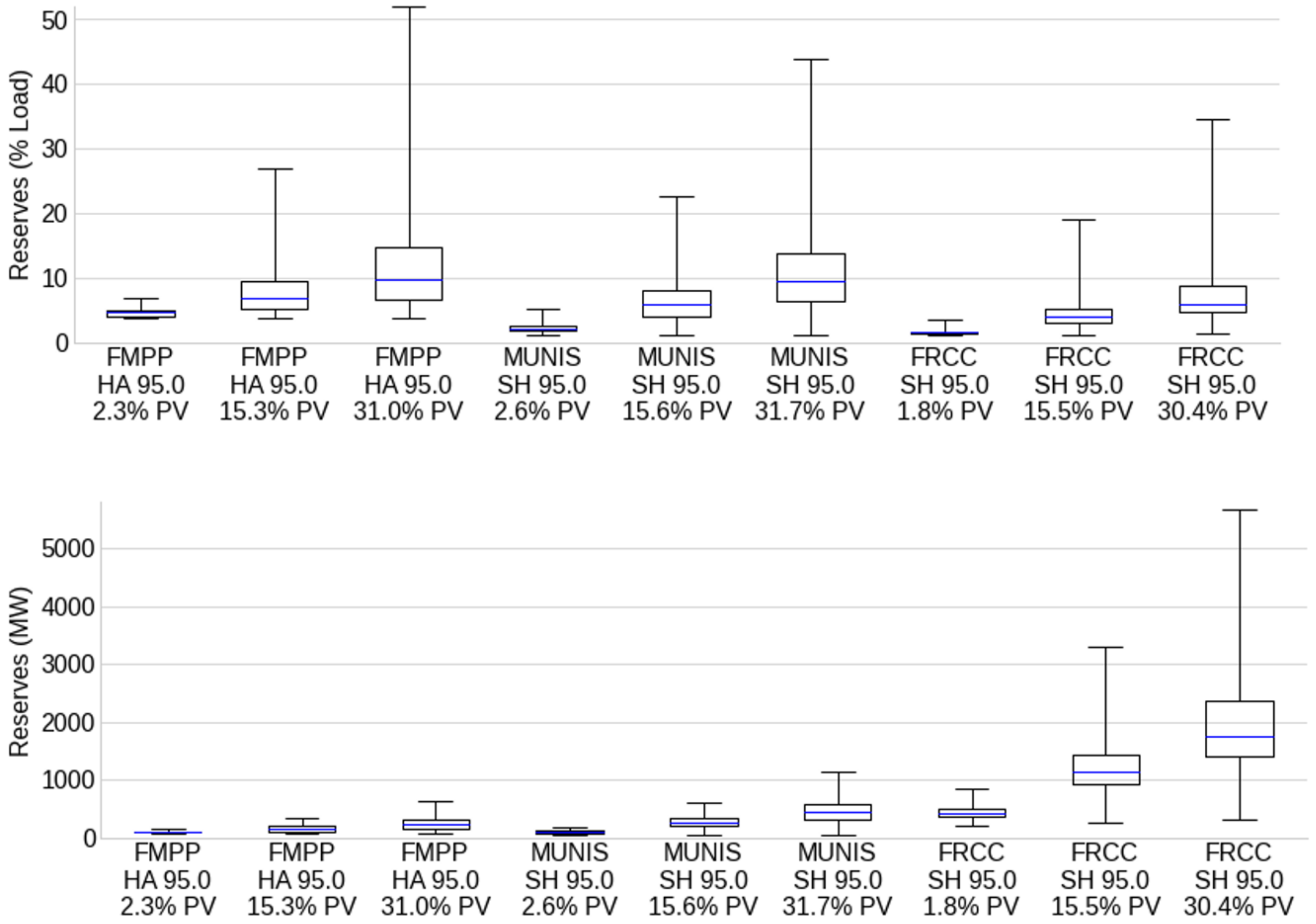


Blue lines show medians, whiskers cover full range.

Reserve estimates for different amounts of solar PV: Reprise

- FMPP hourly vs. MUNIS hybrid shows the potential impact of sub-hourly dispatch
- MUNIS v. FRCC shows the impact of a very large coordinating region

Up reserves needed to provide regulation and flexibility services
(contingency / Florida Reserve Sharing Group obligations not included)



Blue lines show medians, whiskers cover full range.

Sensitivity to Percent of Forecast Errors Covered

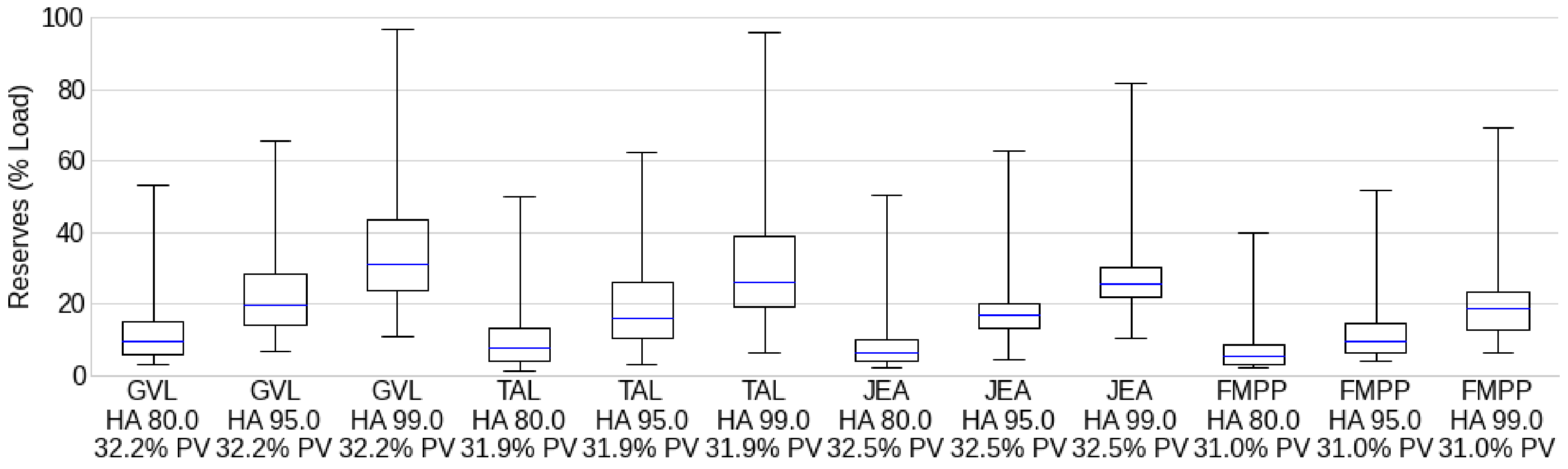
"Reserve strategies are typically developed in response to operating challenges in a given footprint, which has led to a lack of industry-wide standards regarding the calculation of operating reserve requirements and the effect that variable generation (VG) has on them. This is true for both contingency and, especially, regulation reserves." (Krad et al. 2016)

Krad, Ibrahim, David Wenzhong Gao, Eduardo Ibanez, and Erik Ela. 2016. "Three-Stage Variability-Based Reserve Modifiers for Enhancing Flexibility Reserve Requirements under High Variable Generation Penetrations." *Electric Power Systems Research* 141 (December): 522–28. https://doi.org/10.1016/j.epsr.2016.08.021.

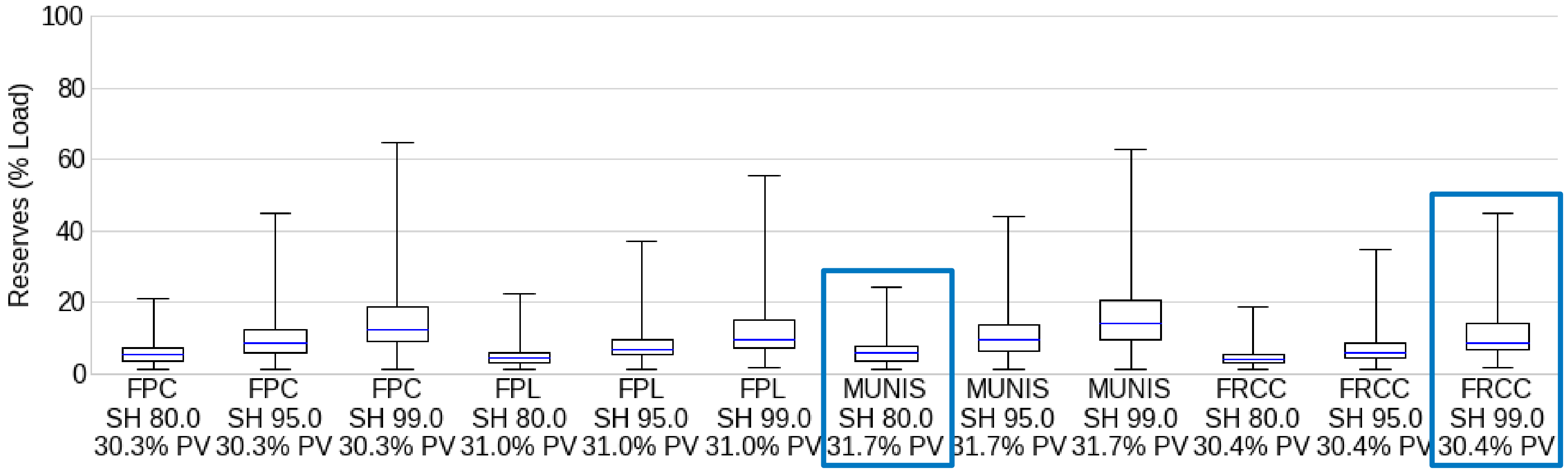
Up reserves needed to provide regulation and flexibility services

(contingency / Florida Reserve Sharing Group obligations not included)

Smaller BAs, 30% PV, Hourly Operations



Larger BAs, 30% PV, Sub-hourly Operations



Blue lines show medians, whiskers cover full range.

Key Findings

- FRCC balancing authorities' reserve needs currently depend on system size and operational practices. All else equal, smaller balancing authorities and less frequent forecasts lead to greater reserve requirements (measured as a fraction of load).
- Increasing solar deployment increases reserve requirements for all balancing authorities. For the same PV penetration, the reserve requirements (measured as a fraction of load) are less for larger balancing authorities with more frequent forecasts and dispatch.
- Moving from day-ahead to hour-ahead load and solar forecasting could enable FRCC's smallest municipal balancing authority, GRU, to incorporate about 30% solar generation with median reserves around 20% instead of 60% of load.
- If all Florida municipal utilities collectively procured operational reserves, this could again halve GRU's reserve requirements at 30% solar generation, reducing the median requirements to about 10% of load. For comparison, the median reserve needs of an "FRCC" reserve sharing group at 30% PV would be about 6% of load (all else equal).
- Reserve needs vary greatly depending on how much forecast uncertainty is covered. For example, if all Florida municipal utilities collectively procured operational reserves and had a PV penetration of about 30%, the median reserve requirements could be anywhere from 5.5% to 14% of load assuming the "right" level of uncertainty to cover falls between 80% and 99%. This range overlaps with the analogous range for all of FRCC analyzed together, which is 3.5% to 9.0% of load.

Thank you

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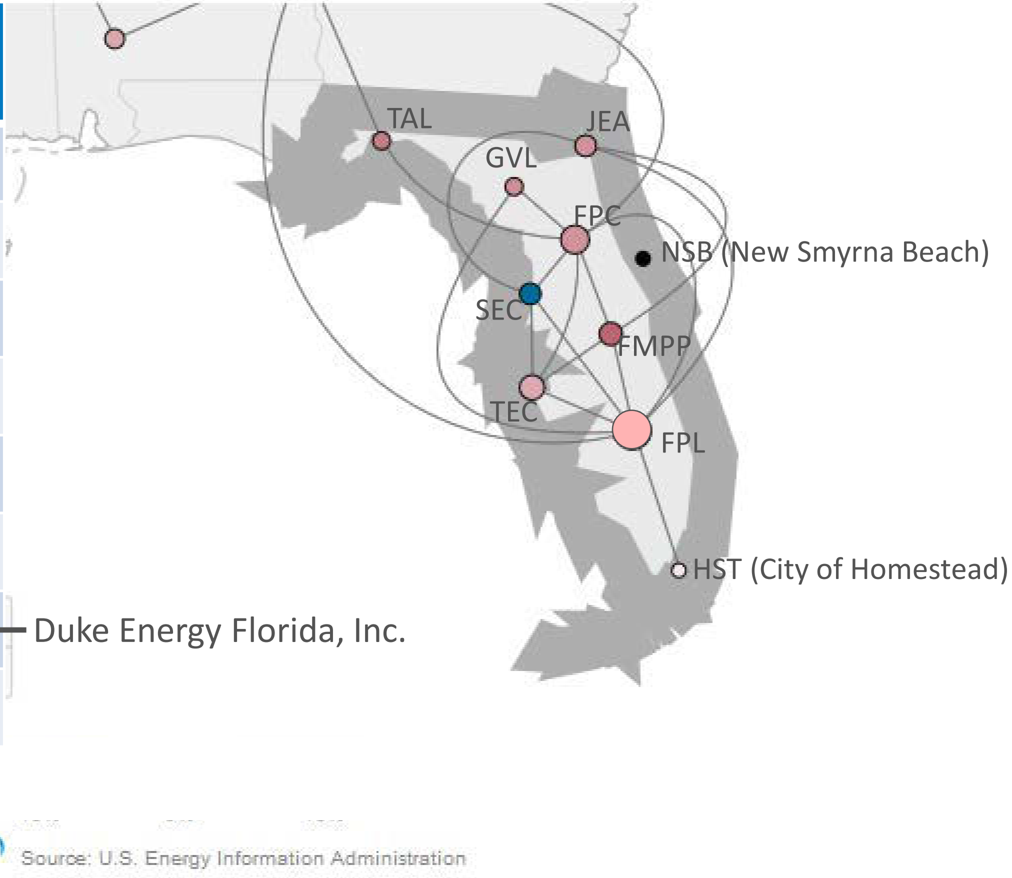
Backmatter

Florida Reliability Coordinating Council Power System

Load Region	EIA BA ID	2015 FERC (TWh)	2015 Site Plan (TWh)	2024 Site Plan (TWh)
Gainesville Regional Utilities	GVL	1.82	2.02	1.92
City of Tallahassee	TAL	2.77	2.78	2.94
JEA	JEA	13.90	12.87	13.05
Seminole Electric Cooperative, Inc.	SEC	14.19	14.10	15.69
Florida Municipal Power Agency[1]	FMPP	15.28	17.29	18.18
Tampa Electric Company	TEC	20.11	20.10	21.50
Progress Energy (Florida Power Corp.)	FPC	40.87	42.28	44.81
Florida Power & Light Company	FPL	122.26	122.76	123.80

← Duke Energy Florida, Inc.

[1] Report here for FMPA is FMPA load plus OUC and Lakeland.



For this analysis, FERC load profiles were scaled to match annual energy use obtained by growing 2015 FERC load by the 2015 to 2024 percentages implied by the 2019 10-year site plans.