QUANTA TECHNOLOGY

November 14, 2024

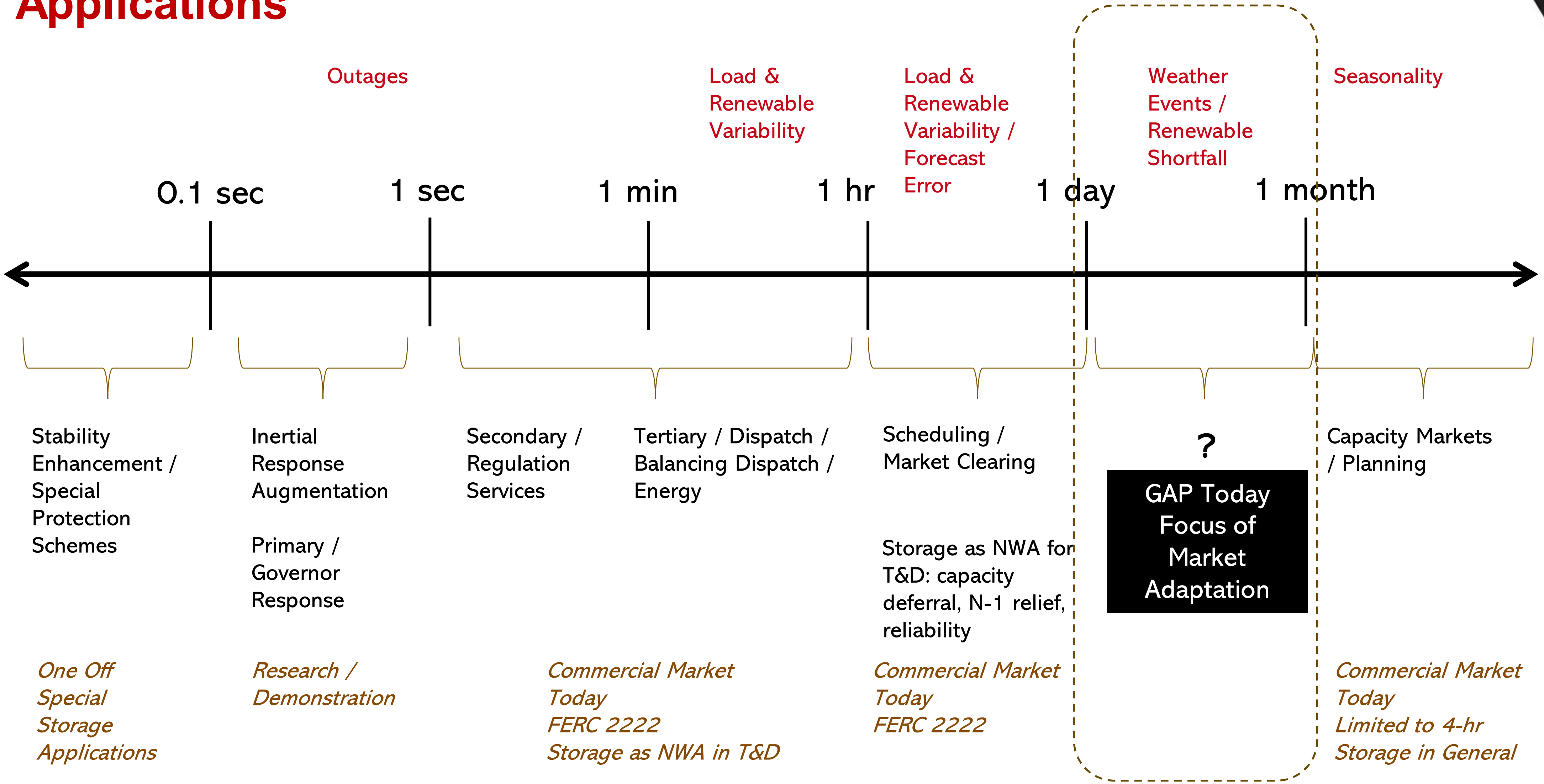
Adapting Markets to Utilize Long Duration Storage

Roles of Storage in Commodities & Energy

Roles of storage:	Common to all other commodity storage:
• Buffer Supply & Demand Imbalance over Different Time Frames. • Levelized Utilization; Production & Transportation / Delivery. • Reserve against Supply & Delivery Disruptions. • Avoid Delivery Delays; Instant Gratification.	• Amount in Storage – Inventory Level – is Key Parameter. • Monitoring, Reporting, Decision Making • Storage Technology, Novelty, & Cost are not Concerns. • Equity in Stored Commodity, not the Storage Asset, is Key. • Storage/Inventory Levels Factor into Financial Commodity Trading.

Electric Energy Storage has been forced into Existing Asset Categories: Generation, Load, and T&D to comply with existing regulatory, planning, operations policies and practices.

Time Domains, Electric Power Phenomena, and Storage Applications

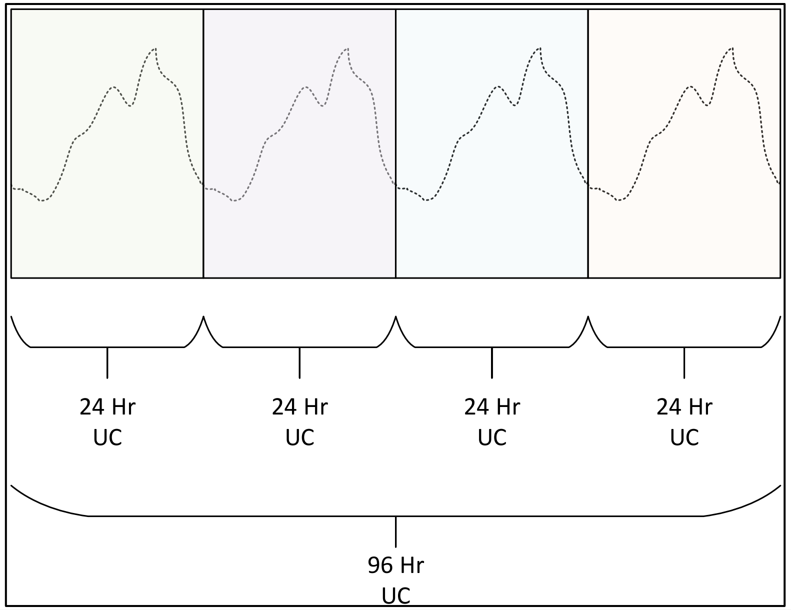


Why Markets & Integrated Resource Planning Should Adapt to LDES

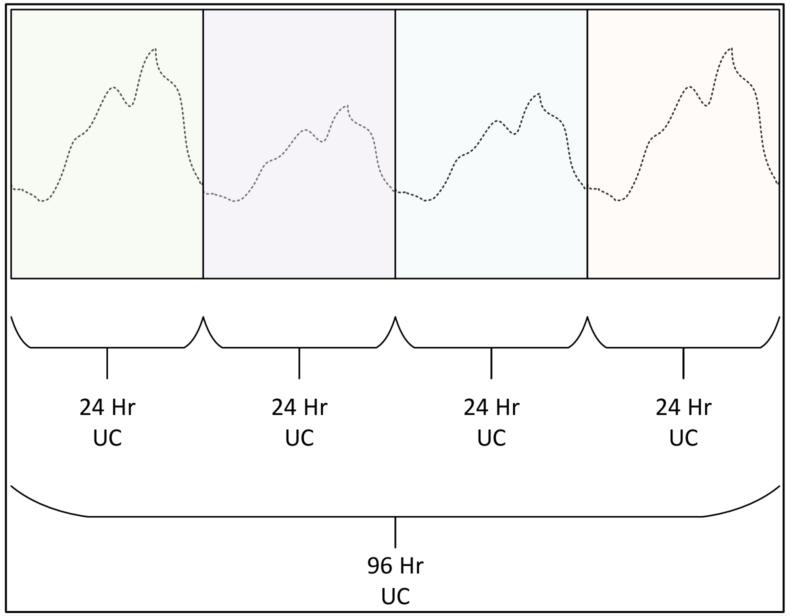
- ISO markets today are "day-ahead": Resources are bid and scheduled daily with a 24-hour horizon for optimization.
- Cannot take account of LDES with durations greater than 24 hours.
- Ability of LDES to shift energy from low net demand days to high is **not** exploited by market.
- It is left to storage operator to structure bids for charge and discharge to earn greater revenue by "Day Shifting" energy.
- Futures (financial) markets exist for future months, but no formal financial or physical market exists for current month beyond next day spot market; bilateral transactions are all that exist.
- Planning has to recognize how assets will be operated.

Illustration

- Identical days
- If everything else (boundary conditions, state of charge limits), 24-hr and 96-hr results are identical.

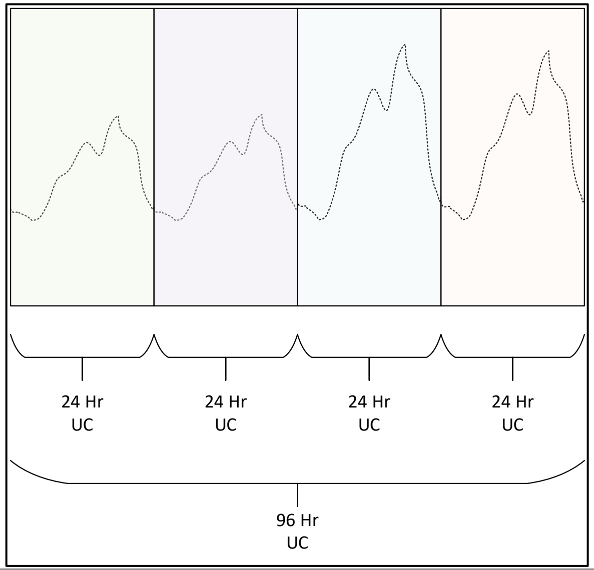


- All days are not the same
- 96-hr UC will “know” to save some stored energy for day 4, assuming the marginal production cost is higher on the day 4 peak than on the day 2-3 peaks.
- Determining the correct end state of charge can be done with a 96-hr optimization horizon.
- Individual storage operators likely won’t “get this right”.

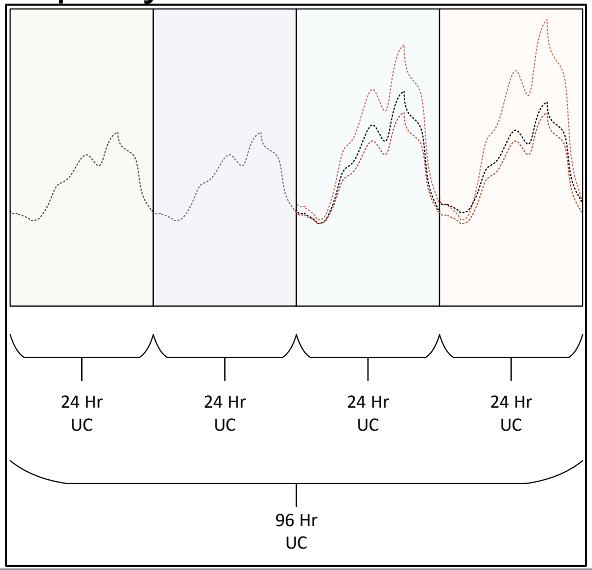


Illustration

- Adverse weather reduces PV production and increases net load.
- LDES should be used to shift some energy from the sunny days to the stormy ones.
- 96-hr UC is the straightforward way to allow the market operator to optimize "reserve energy" in storage and to co-optimize charging.



- Forecast error increases significantly with horizon especially when Severe Weather / Changes Are anticipated.
- How to Incorporate Forecast Uncertainty into the UC?
  - Larger reserve constraints?
  - Scenarios and multiple UC solutions?
  - Probabilistic UC with constraints on likelihood of outcome
- ISO Will require a formal process for determining stored energy and capacity reserves in such cases.

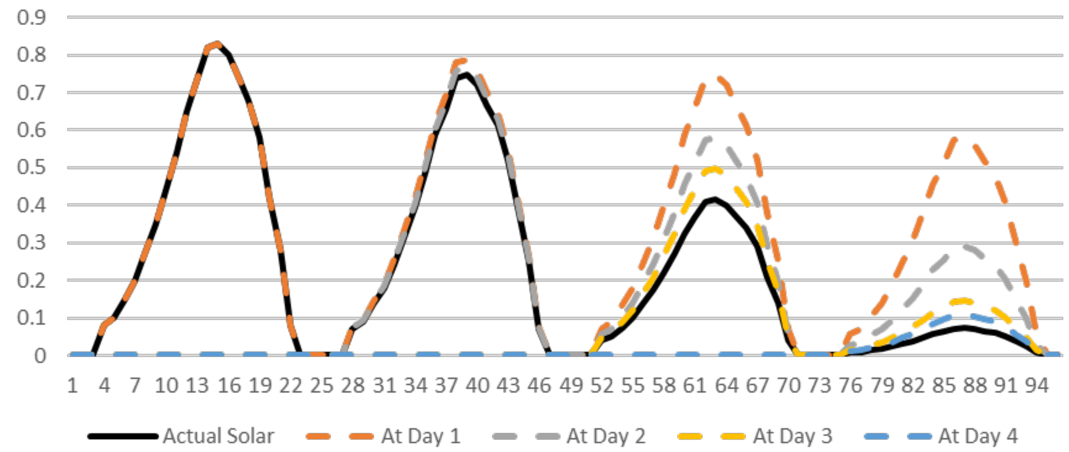


4 cases are shown with forecast uncertainty around solar only

- Case 1: Perfect forecast / next 96 hours → 1 X Multiday UC & Forecast = Actual
- Case 2: Perfect forecast / next 24 hours → 4 X single day UC & Forecast = Actual
- Case 3: Error in forecast / multiple UC (96-, 72-, 48- and 24-hr) → 4 X Multiday UC & Forecast ≠ Actual
- Case 4: Error in forecast / multiple single day UC (24-hr) → 4 X single day UC & Forecast ≠ Actual

Case 3

Forecast v.s. Actual - Longer Horizon



Forecast next 96 hours @ day 1

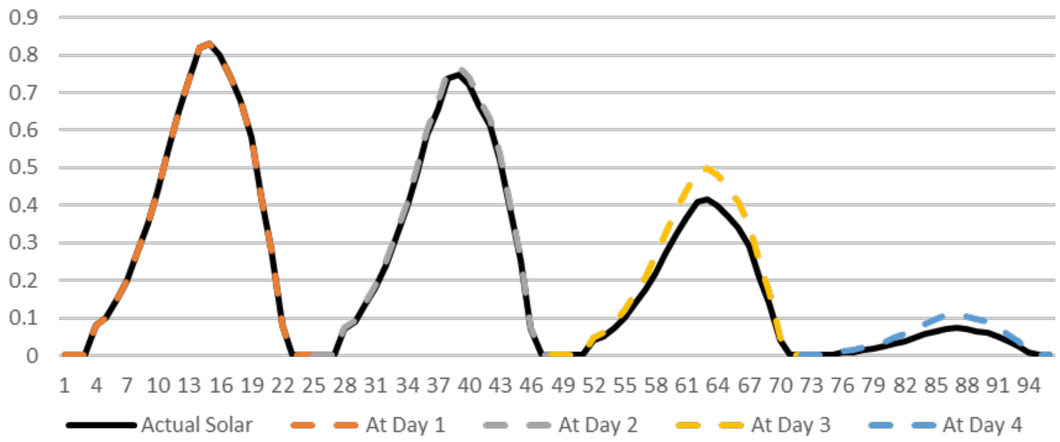
Forecast next 72 hours @ day 2

Forecast next 48 hours @ day 3

Forecast next 24 hours @ day 4

Case 4

Forecast v.s. Actual - Shorter Horizon



Forecast next 24 hours @ day 1

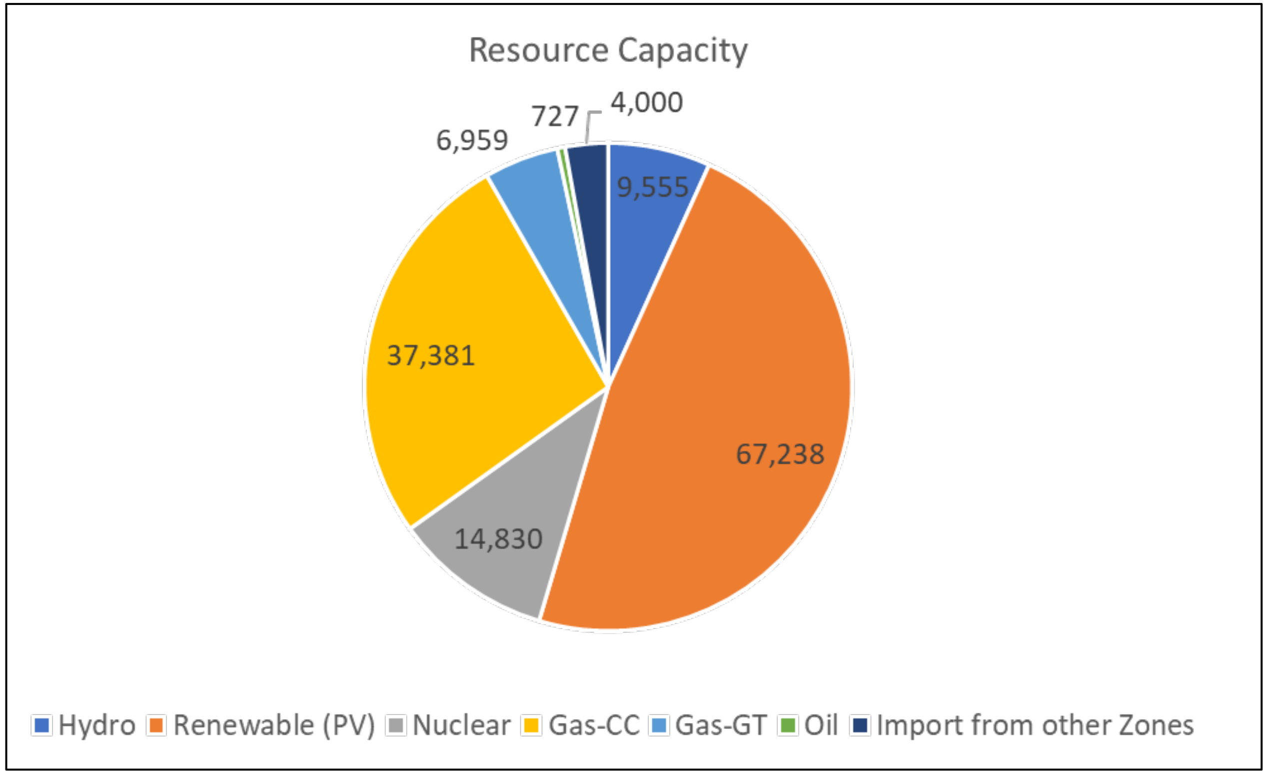
Forecast next 24 hours @ day 2

Forecast next 24 hours @ day 3

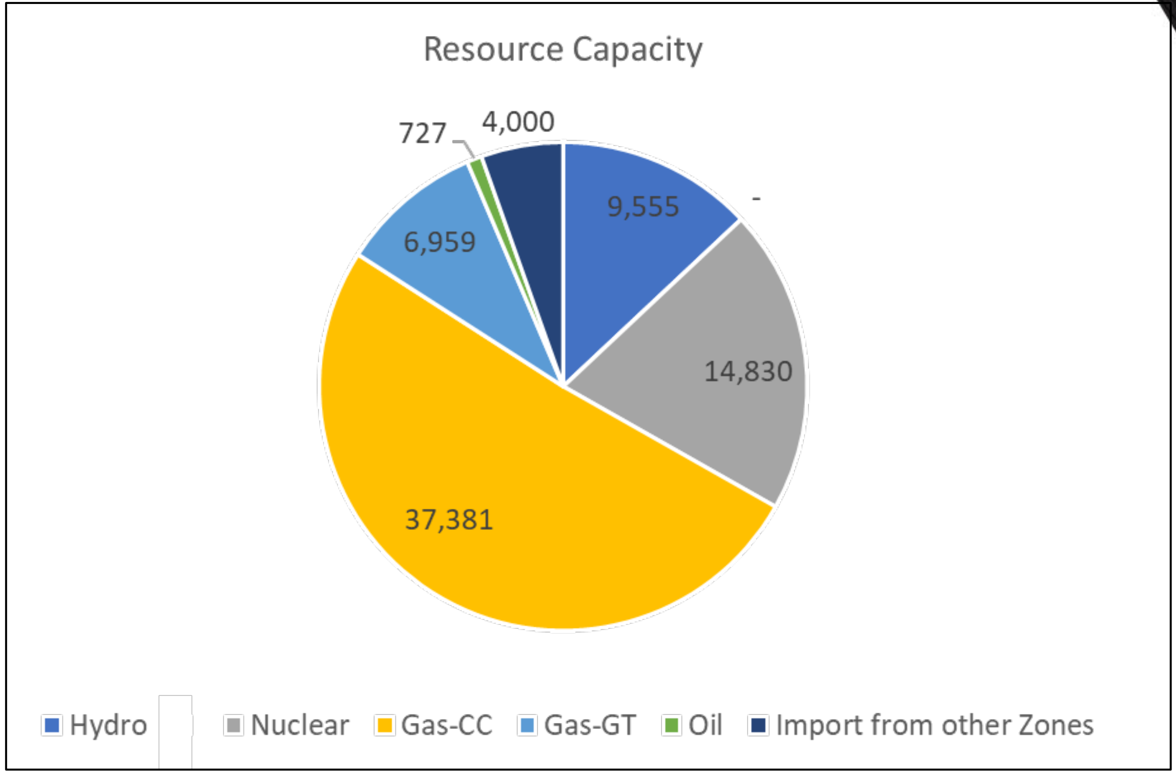
Forecast next 24 hours @ day 4

Resource Portfolio for Case Studies of LDES & Markets

With PV=60% peak load



Without PV

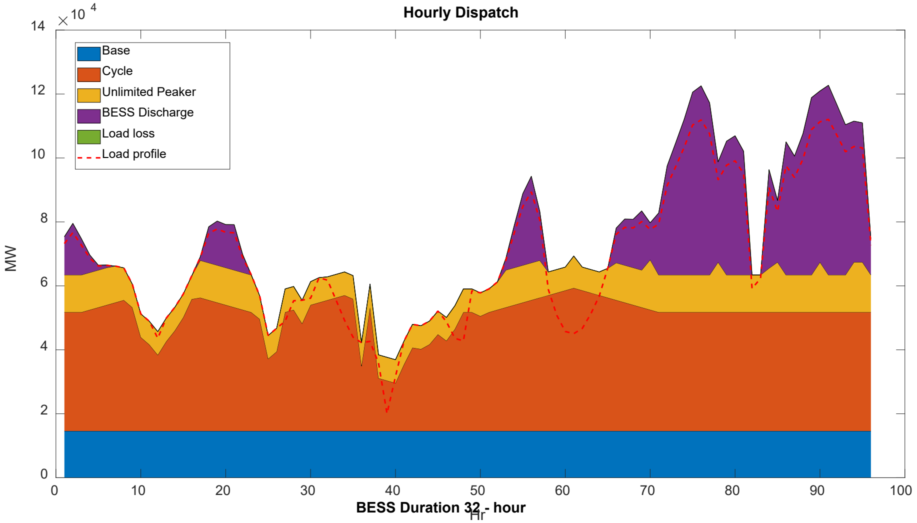


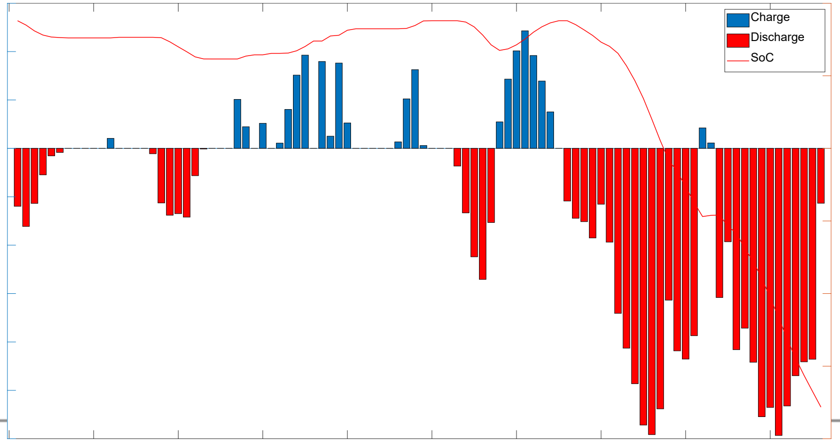
Cases with Perfect Forecast

Parameter	Day 1	Day 2	Day 3	Day 4	Total
Production Cost (M$)	$67.90	$57.61	$72.46	$76.32	**$274.3**
VOLL (M$)	0	0	0	0	**0**

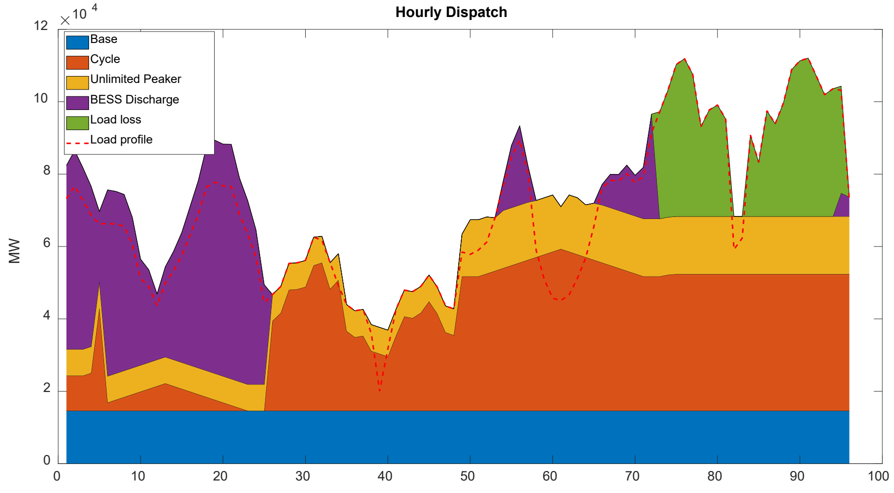
Parameter	Day 1	Day 2	Day 3	Day 4	Total
Production Cost (M$)	$28.49	$51.64	$82.73	$85.76	**$248.63**
VOLL (M$)	0	0	0	$689.41	**$689.41**

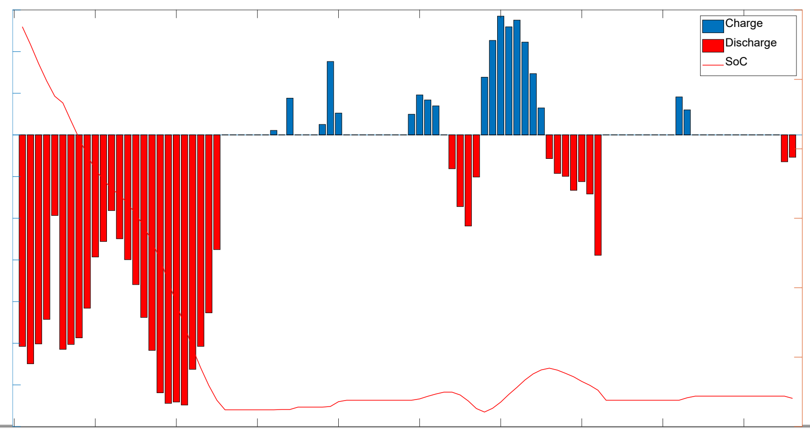
4-Day UC





4 x 1-Day UC



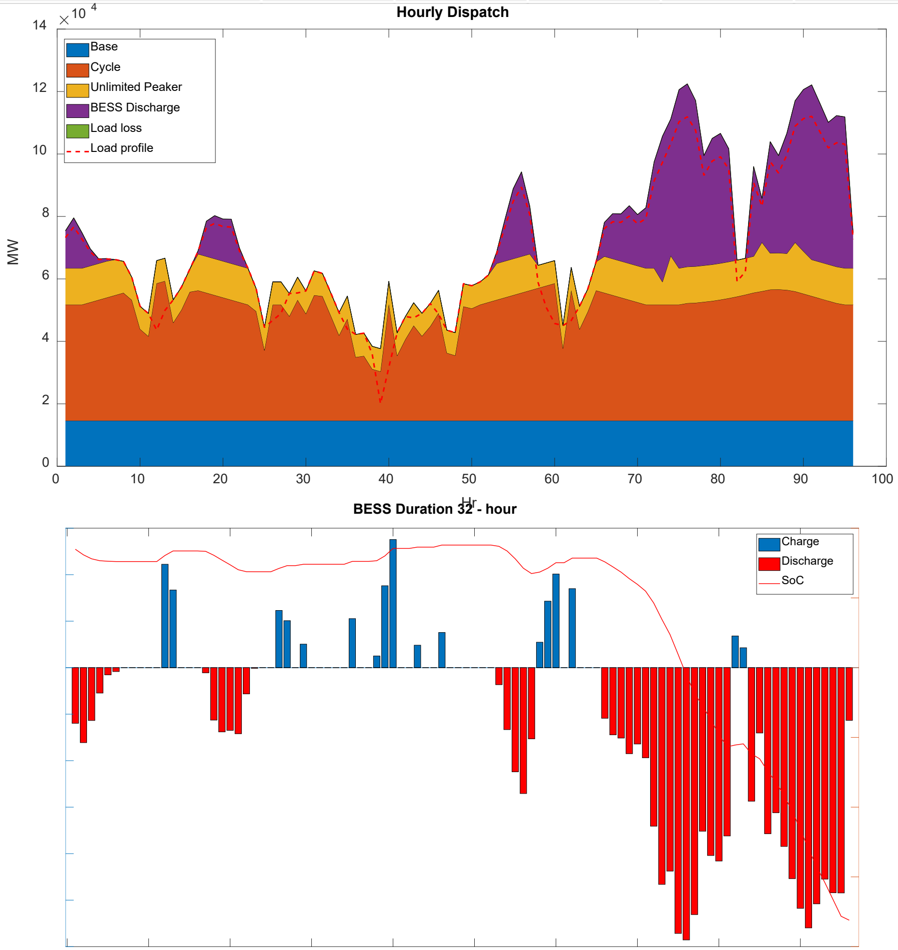


Cases with Forecast Error

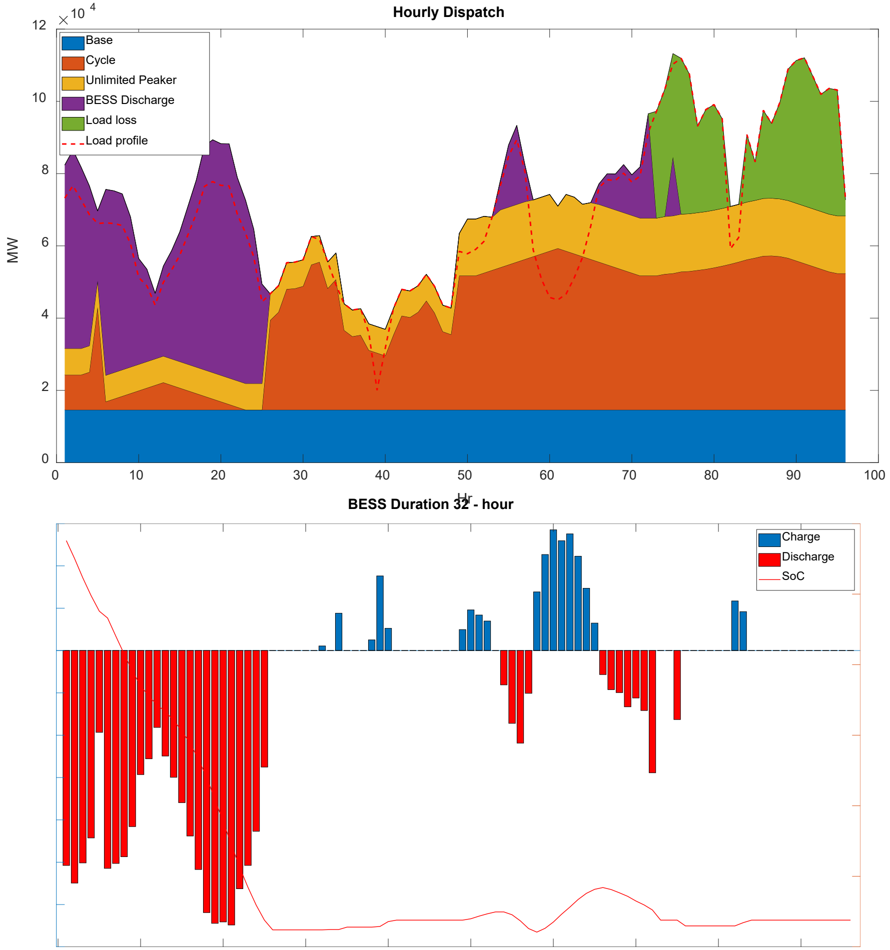
Parameter	Day 1	Day 2	Day 3	Day 4	Total
Production Cost (M$)	$67.90	$57.81	$72.86	$76.78	**$275.35**
VOLL (M$)	0	0	0	0	**0**

Parameter	Day 1	Day 2	Day 3	Day 4	Total
Production Cost (M$)	$28.49	$51.64	$82.73	$86.01	**$248.88**
VOLL (M$)	0	0	0	$689.41	**$689.41**

4-Day UC

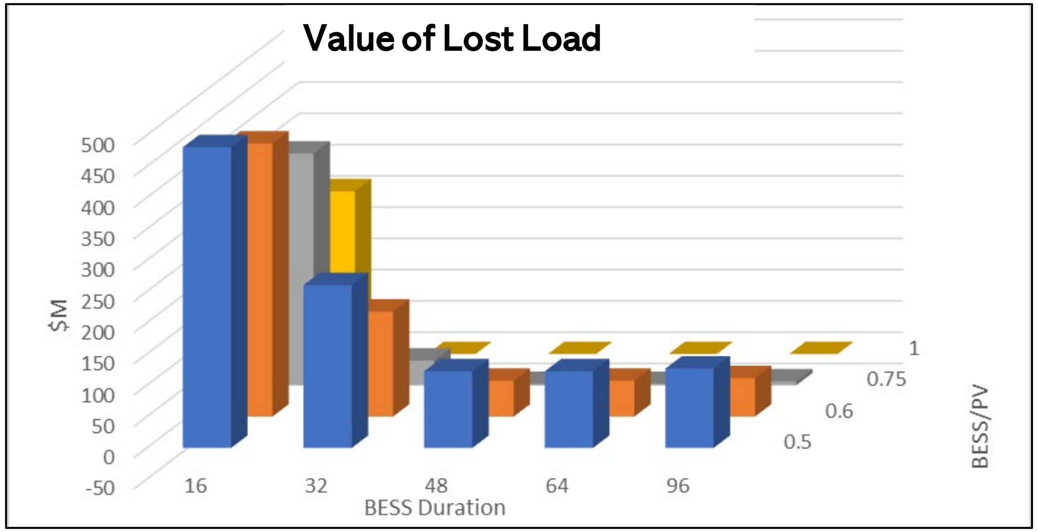


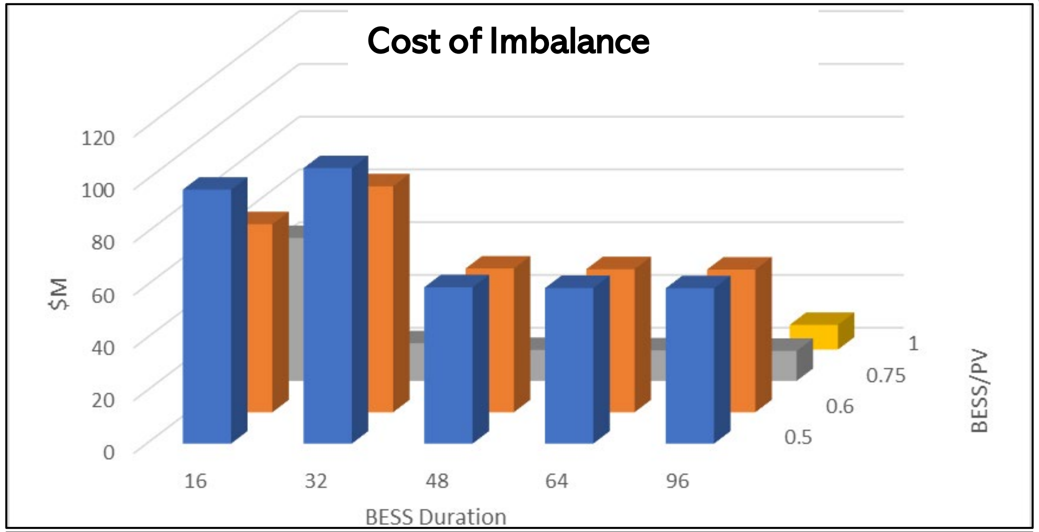
4 x 1-Day UC



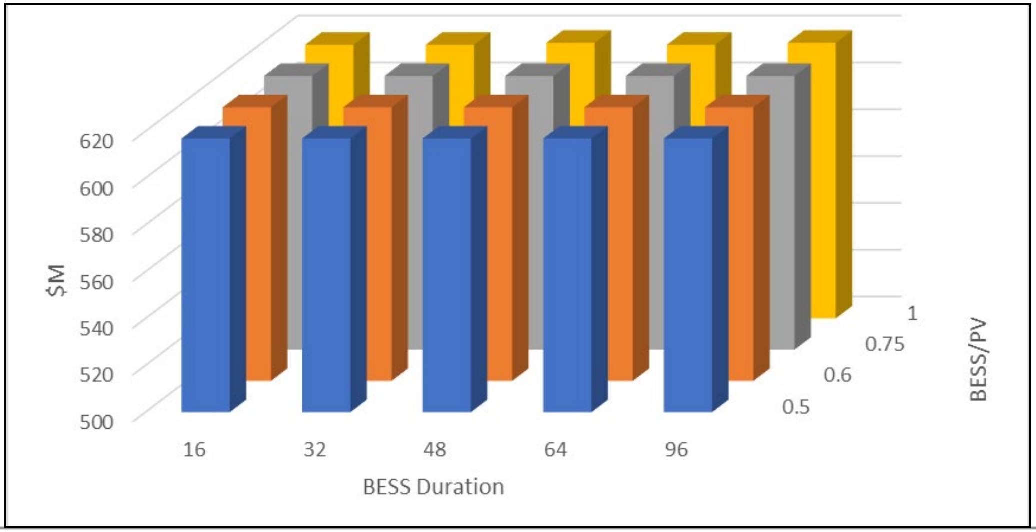
4 x 1-Day has higher lost load by far and sufficient LDES eliminates lost load with 4-day scheduling

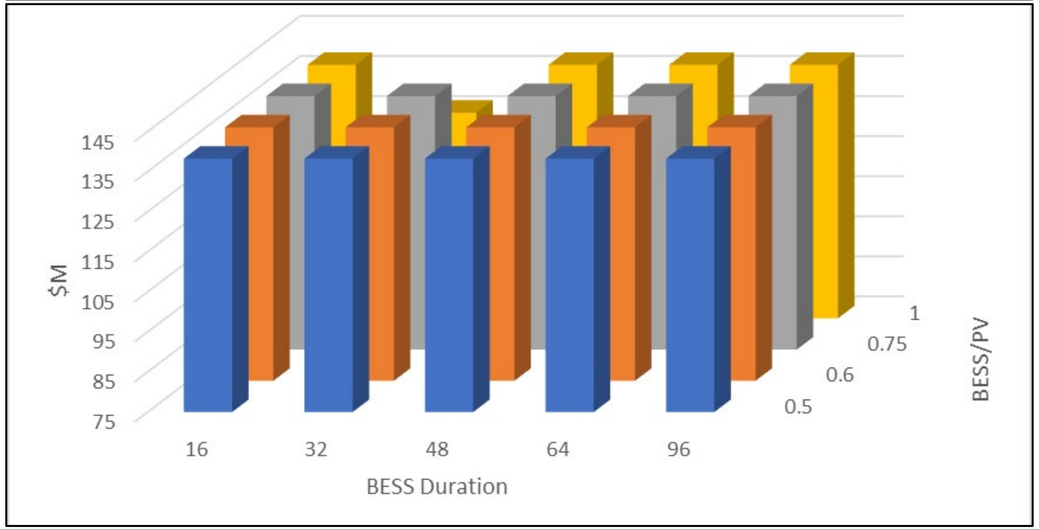
4-Day UC





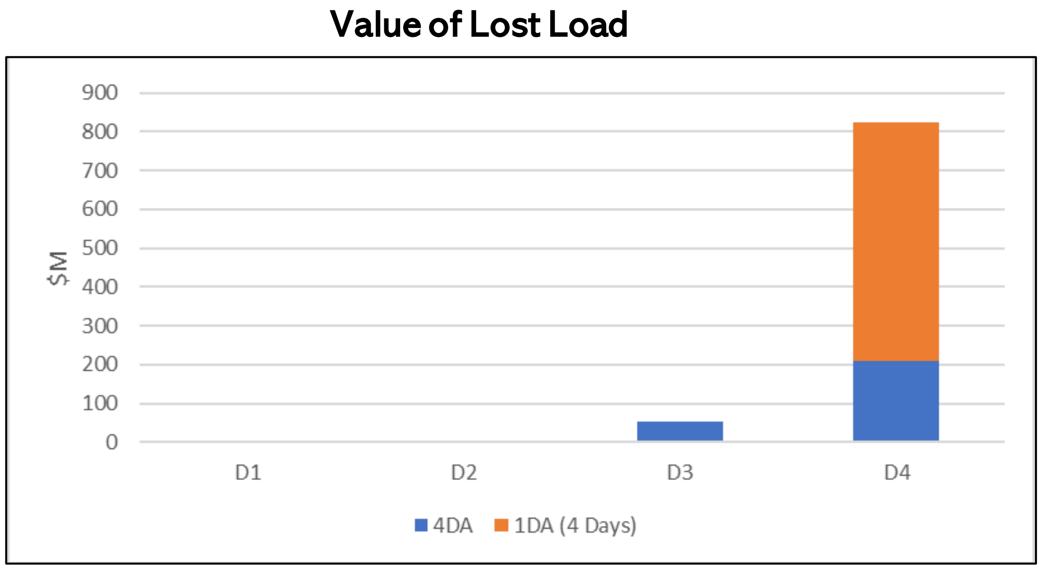
4 x 1-Day UC

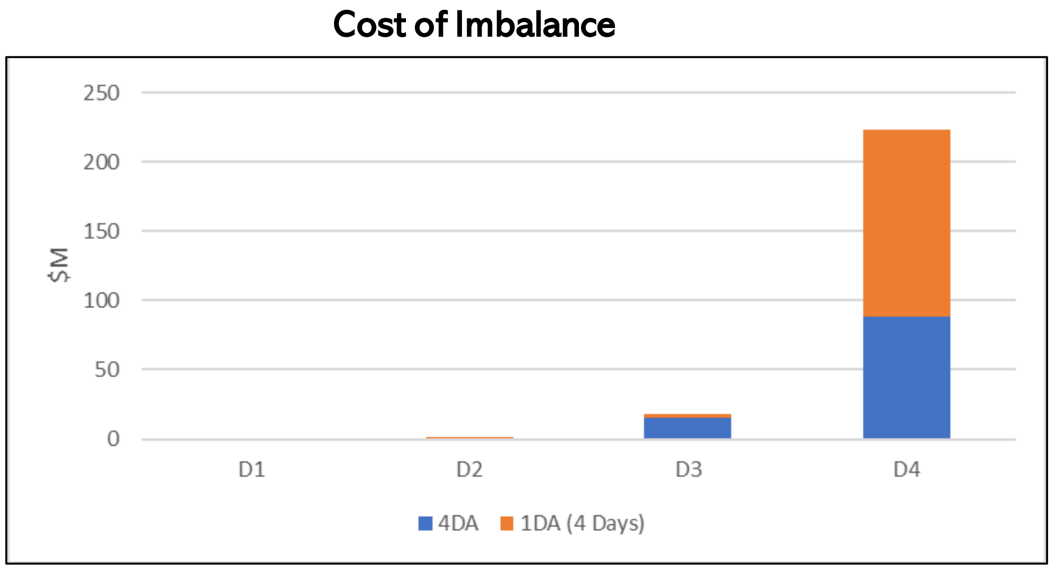




Closer Look at 4 Days

- BESS is 50% of PV Capacity
- 32-hour BESS
- 4-day UC will account for forecast error and minimizes lost load on days 3 and 4.
- Larger BESS can reduce lost load to zero.



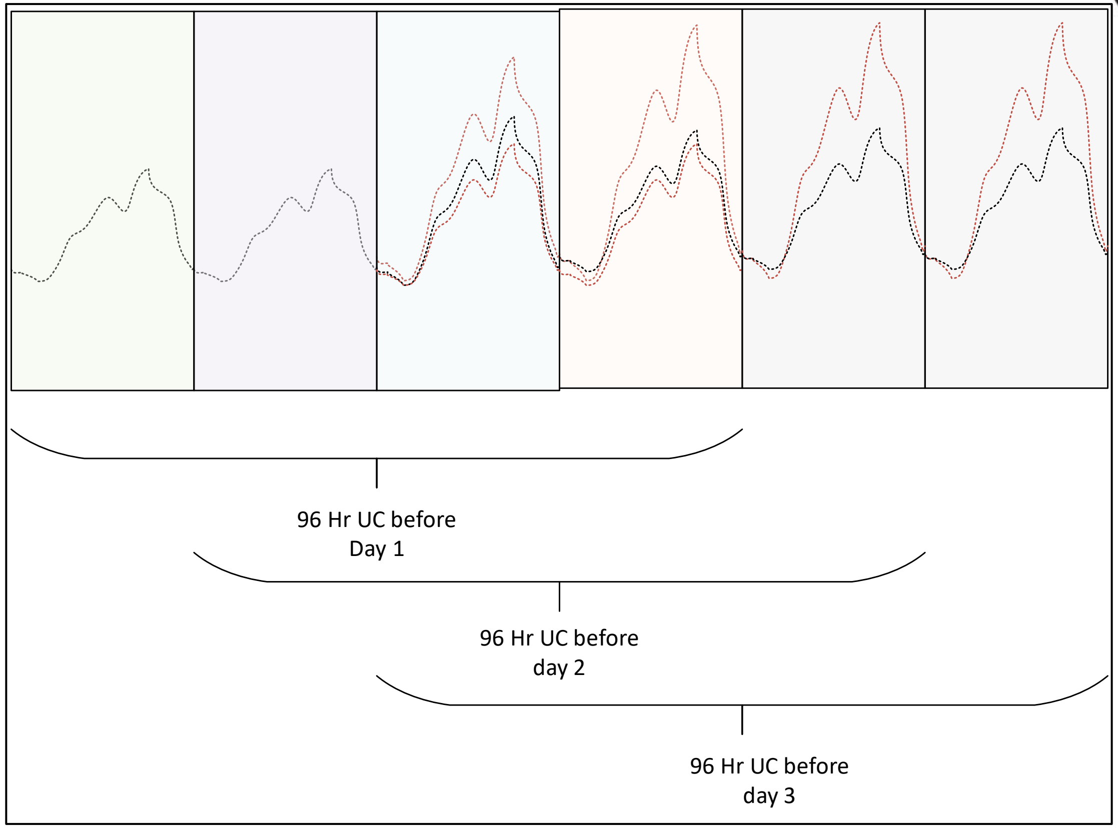


Practical Considerations

- Every day the multi-day UC process repeats.
- The forecast will be updated so the schedule for day 3 solved at day 2 will not be the same as the schedule for day 3 solved at day 1.

Several possibilities exist for handling this situation:

- The schedules for days 2 through N are only advisory:
  - Only the schedule for day 1 is binding.
  - This still leaves the multi-day optimization in the hands of the storage operators.
- The schedules for days 2-N are "financial" obligations but are not physical:
  - The financial obligations can be settled at the spot price on the day.
- The schedules for days 2-N are physical and are "adjusted" in subsequent days.



Other Concepts

- Transparency:
  - ISO should know state of charge for all storage
  - Market should be informed on total stored energy levels
  - Ownership of stored energy must be transparent (traders as opposed to operators)
  - Any constraints / targets for total stored energy should be transparent
- Storage as a Regulated Asset:
  - Separate storage ownership from energy ownership – storage collets a regulated tariff for use (as with some gas storage)

Long Duration Energy Storage in Integrated Resource Planning

- Focus on Weather Events; Atmospheric Rivers in Wintertime.
  - PV Production Reduced Seasonally; lower capacity factor.
  - PV Production reduced dramatically during rainstorms.
- How Frequent are Events?
- What is their Duration? Affects LDES duration.
- What is the time between Events? Affects LDES ability to recharge.
- What are Trade-offs? LDES vs. Excess PV vs. Backup Gas vs. Demand Response?

A Different Paradigm is Called For

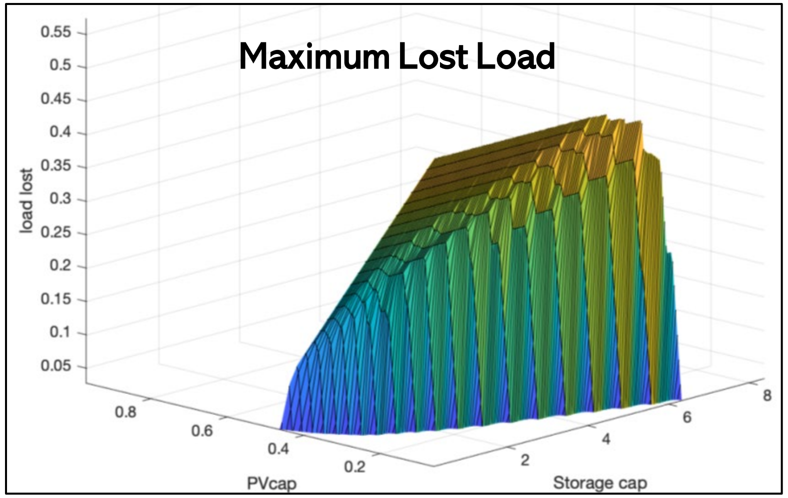
- Production Costing and ALL other Storage Analyses and Control Focus on the Charging / Discharging as the Decision Variables, and either take Duration as a Given or Calculate it from the Charge/Discharge Schedule.
- This is an outgrowth of considering storage as an energy-limited generator.
- Instead we Consider Energy Storage to be the ”Inventory” in a Production and Delivery Framework. The Purpose of Inventory is to Buffer Production and Delivery Constraints so as to Balance Demand.
- This opens the door to a huge domain of analytics and tools that are commonly used in operations research and other fields (weather, inventory, health care, failure analysis).
- These domains routinely handle stochastics as the heart of the problem.
- One approach to inventory management yields closed form expressions and decision rules – optimal “re-ordering” algorithms – dealing with demand variability and re-supply delay variability.
- Another approach based on Markov processes is more promising and flexible – this example illustrates this.

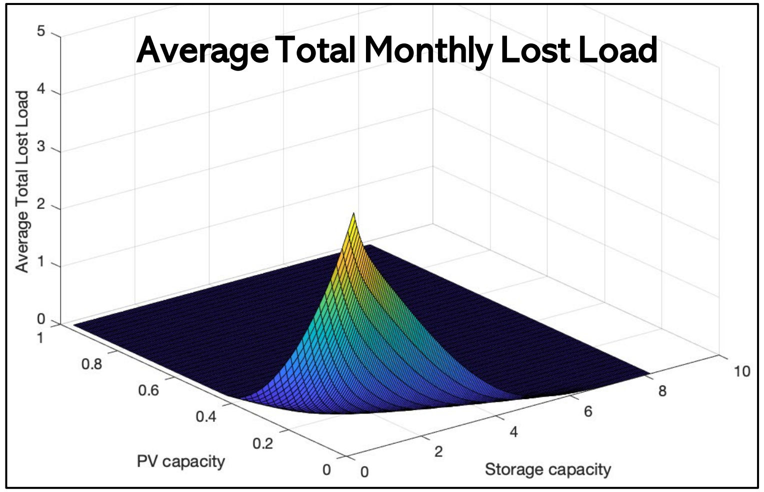
Lost Load: as a function of PV and Storage Capacity

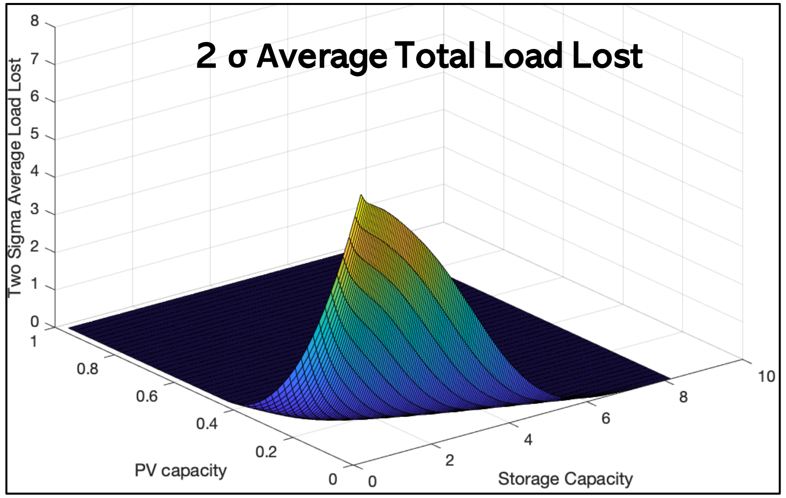
- The maximum is 0.5 p.u. which tracks the “severe” weather degrading PV by 50%, without any storage.
- Sectional linearity of the results: opportunities for analysis.
- PV capacity is more effective per unit than is storage as the PV is “always there” if degraded unlike storage which has to cover multiple day events.

- The total lost load is the sum of lost load across all days in a simulation; this is averaged across the 2000 simulations for each combination.
- This exhibits a non-linear behavior, note.

- “Mean plus 2 Sigma” average total monthly load lost.
- More useful planning criteria than the simple mean or the simple maximum.
- Could be used in a BCA among PV, storage, and DR for example



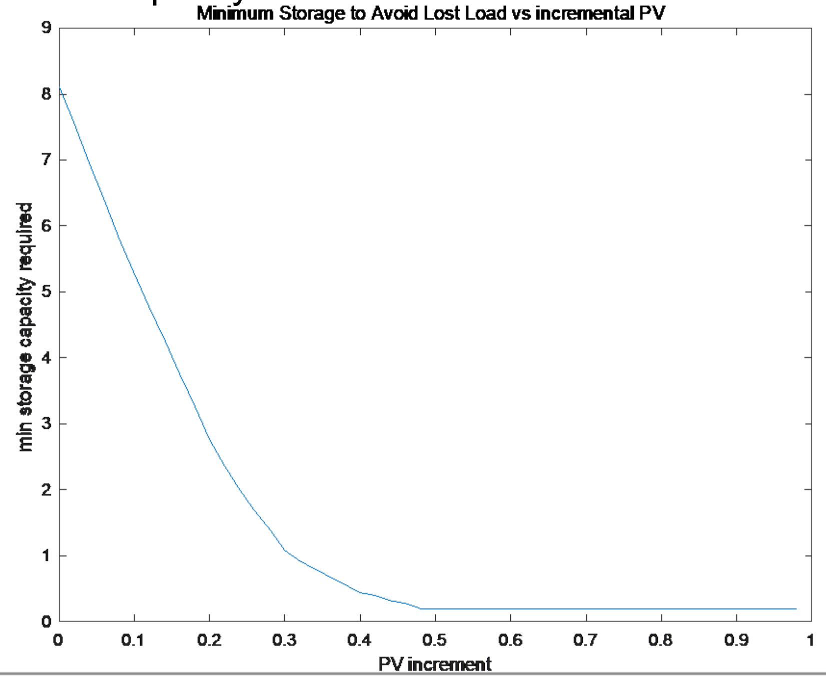




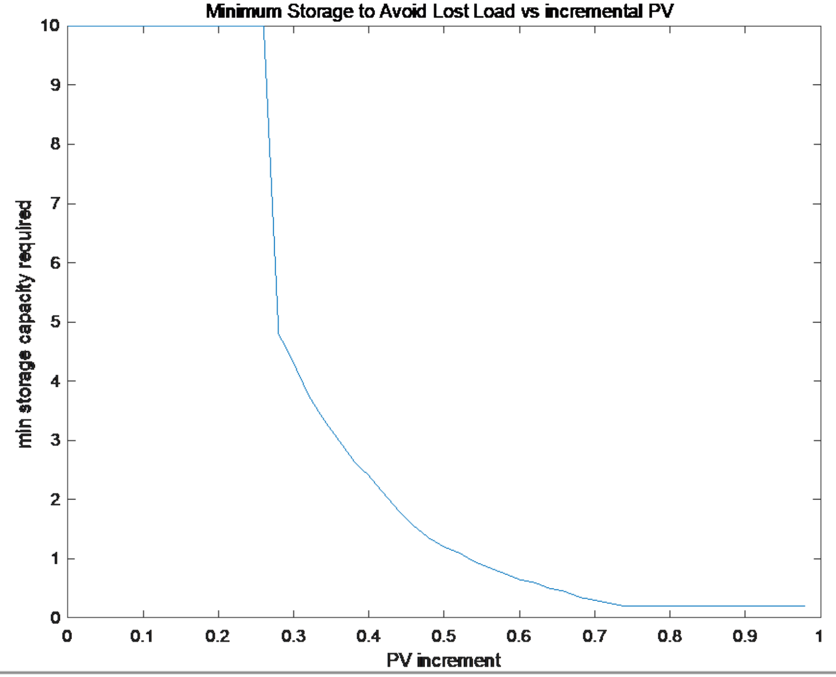
LDES Capacity Requirements

- For each of the 1000 Monte Carlo simulations can calculate the storage level at which load lost first occurs
- The minimum of this across the simulations becomes the minimum storage capacity needed for a given increment of PV capacity.

- More Decrease in PV Production (75% vs. 50%) from Severe Weather.
- PV drops to 25% or less of capacity on rainy days – but this is probably extreme worst case for statewide behavior just ran.



Impact of severe weather



Inventory Management Concepts for Resource Planning

- Markov processes can be powerful tools for inventory management.
- Incorporate renewable production levels, duration of weather events, storage state of charge, conventional resource availability as attributes of states.
- Storage charge / discharge decisions are "transition costs".
- The math allows for closed form expressions derived to calculate expected outcomes accurately.
- Stochastic Dynamic Programming: long used for hydro thermal scheduling, note to develop optimal charge / discharge strategies.
- Stay Tuned for Ongoing Development.