APS Solar Partner Program (SPP) Phase II – Lessons Learned

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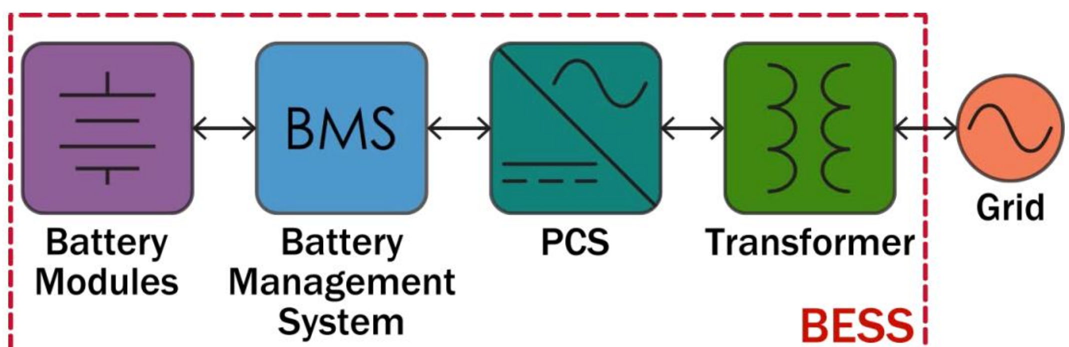
Overview

- **APS/EPRI SPP Phase II**
  - Utility voltage control
  - Battery storage system (2MW/2MWh)
  - Voltage, power factor, grid operations
  - High penetration PV

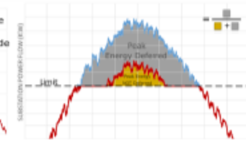


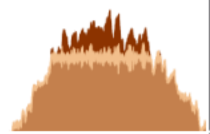
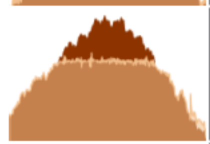
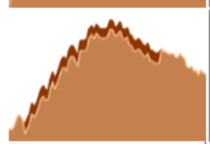
APS SPP Phase II - Lessons Learned

BATTERY	Measurement based battery dispatch preferred over scheduled	BESS downstream of feeder constraint offers most value (even smaller sizes)	Direct communi-cation path with low latency for effective response	Draw losses from the grid-side to preserve battery capacity
GRID OPS	Low VAR flow, not power factor, should be the goal	Clearly set voltage control priorities to eliminate potential conflict	Utility devices for large voltage change, then inverter for smoothing	Only load transfer can resolve voltage issues when BESS and VVO cannot
HUMAN INTERFACE	Need to simplify battery-grid operator interface	Extensive operator training / change management are necessary	Standardize MW and VAR flow reference directions	Alarm prioritization and management with mitigation is recommended
OTHER	Clear requirements RFP test reports and extensive FAT are necessary	Battery inverters will need to follow IEEE 1547 advanced functionality	Routine operations, daily dispatch and optimization should be automated	Engineering time series study prior to implementation (charge / discharge)

Battery Operation

- Measurement Based vs Scheduled Dispatch
  - Measurement based preferred
  - Consistent peak reduction
  - Highest energy deferral
  - Requires reasonable load shape forecast assumption
- Use direct measurement communication path
  - Low latency and response time
  - Direct more robust in various operating scenarios
  - Lower comm loss probability

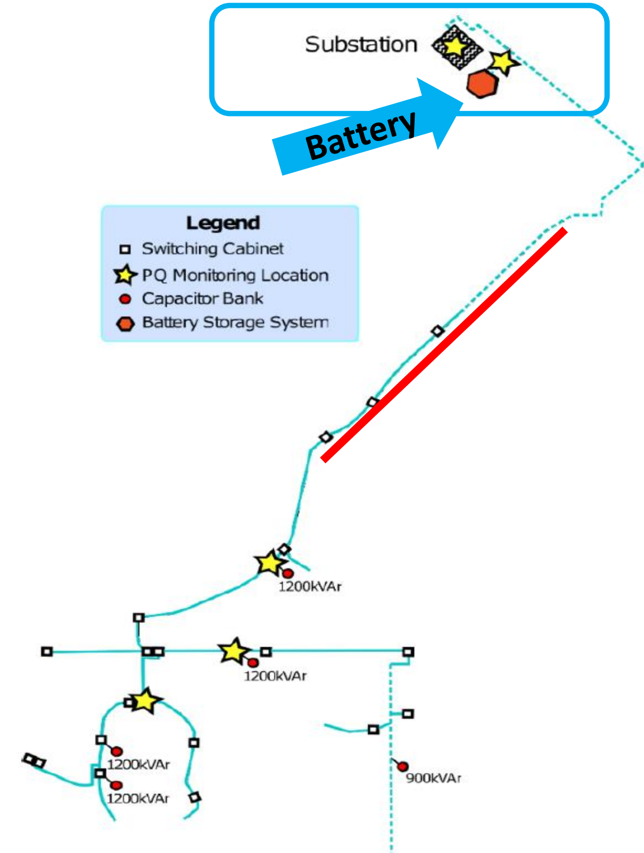


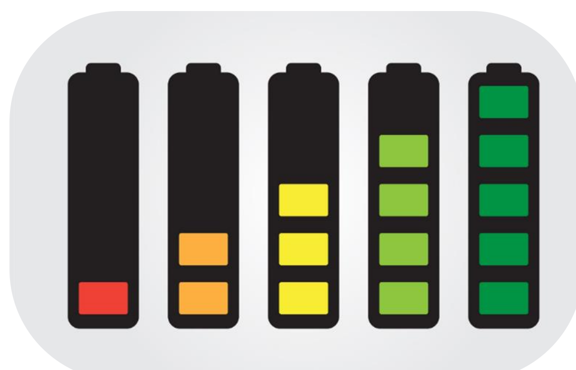
	ASSET PROTECTION	Decrease in Power Above Peak (%)	<- As a Ratio (kW/kW)	Peak Energy Deferral (%)	<- As a Ratio (kWh/ kWh)	Date Observed (Feeder)
	Measurement-based – Sufficient Capacity, High Ramp Rate	77%	519 / 676	96%	780 / 813	8/24/2017 (Feeder A)
	Measurement-based – Sufficient Capacity, Low Ramp Rate	84%	599 / 714	99%	706 / 712	2/22/2018 (Feeder A)
	Measurement-based – Lighter Load	91%	165 / 181	99%	118 / 119	8/20/2017 (Feeder B)
	Measurement-based – Insufficient Capacity	7%	68 / 957	71%	1663 / 2349	8/24/2017 (Feeder B)
	Scheduled Dispatch – High Discharge Limit	31%	354 / 1148	48%	652 / 1256	10/26/2017 (Feeder B)
	Scheduled Dispatch – Low Discharge Limit	40%	349 / 869	60%	668 / 1109	10/14/2017 (Feeder B)

Battery Operation

- Locate battery downstream of feeder constraints
  - If ahead, no deferral possible
  - Distributed closer to loads

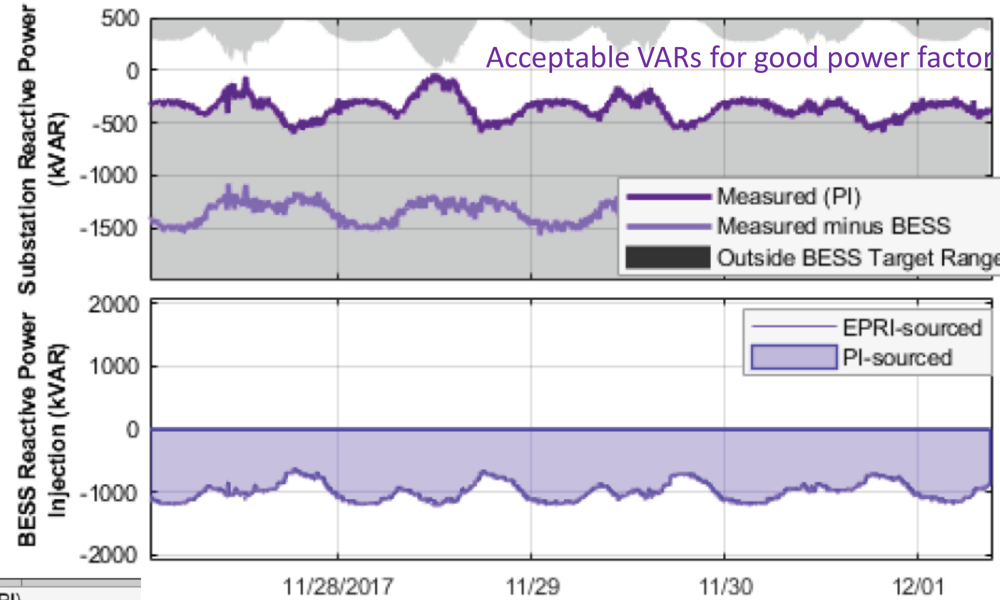
- Draw inverter losses from the grid (not the battery)
  - When idle, energy is lost
  - Affects desired objectives

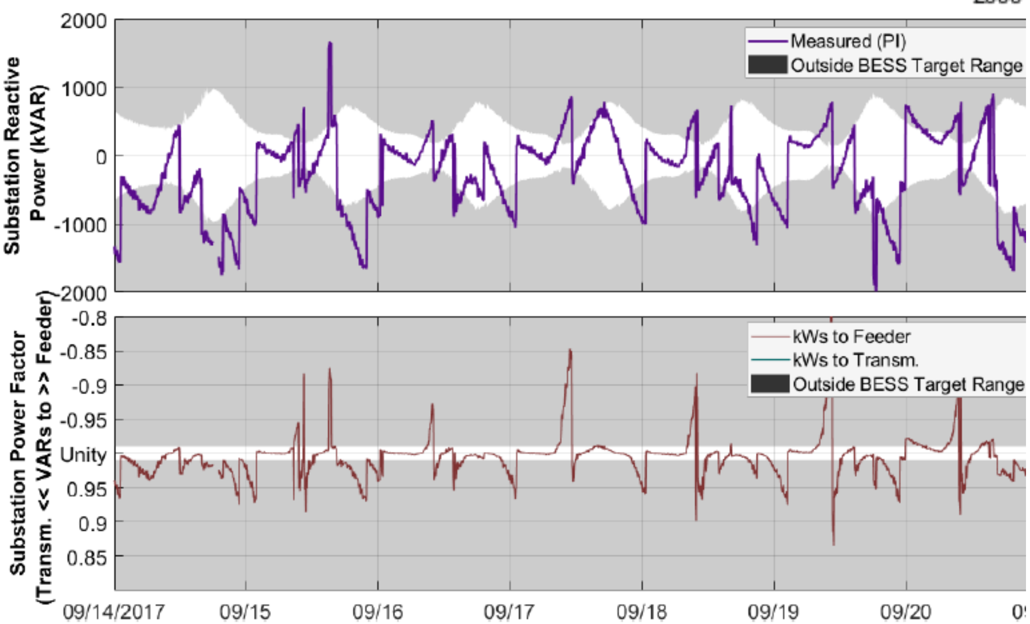


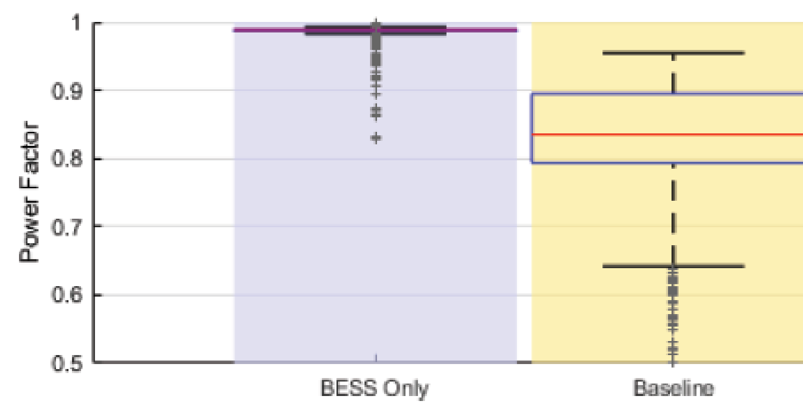


Grid Operation & Impacts

- Manage feeder VAR flow, not power factor
  - BESS inverter managing VARS / PF hold to min targets
  - Utility voltage control managing voltage / VARS / PF hold close to 1

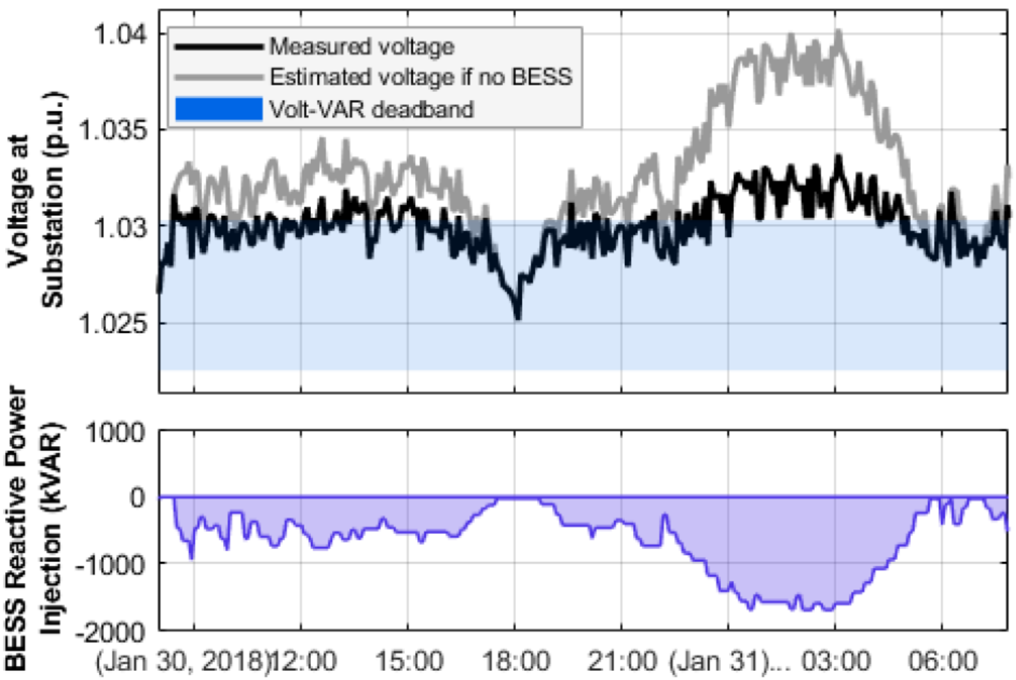




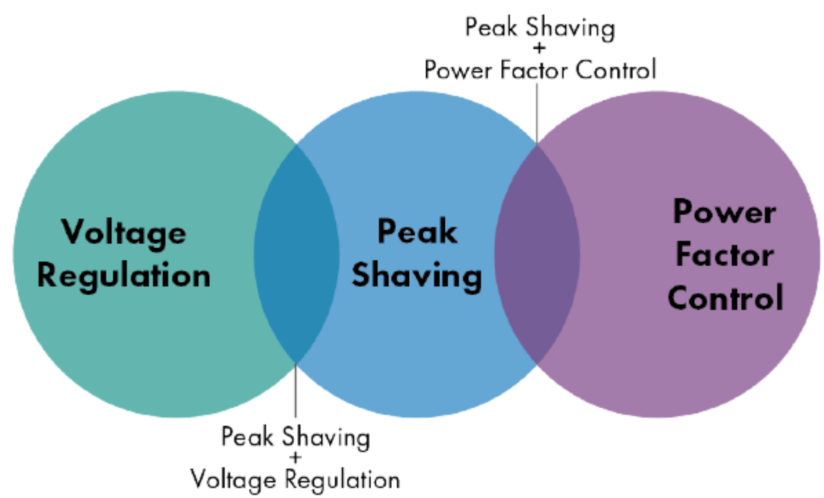


Grid Operation & Impacts

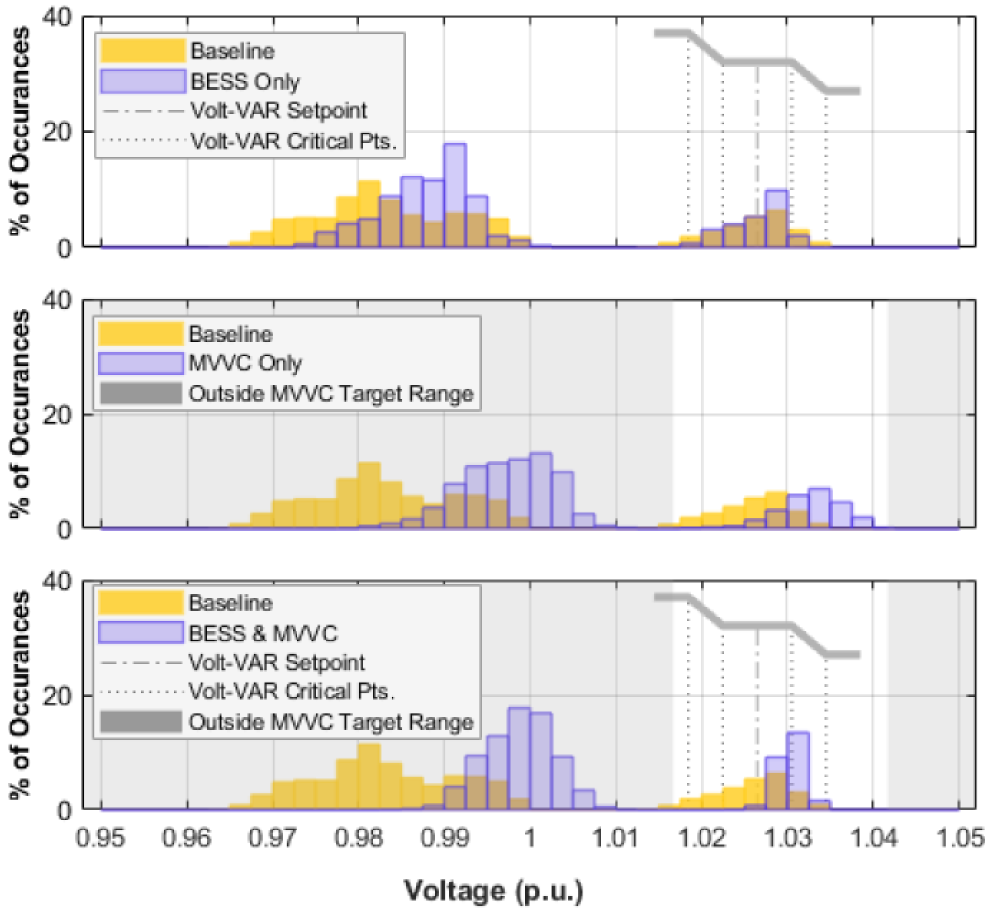
- Utilize utility voltage control for large changes
- Clearly set voltage priorities to eliminate conflict



Less variability – closer to 1.0



Grid Operation & Impacts



- Battery only doing voltage control
  - Less variability than baseline
- Utility capacitors and regulators doing voltage and PF control
  - Less variability than baseline, higher overall system voltage profile
- Battery, capacitors and regulators doing voltage and PF control
  - Minimum variability with best voltage profile

Human-Machine Interface

- Data intensive application
  - Simplify battery interface for operators
  - Automate dispatch decisions
  - Ease of operation important
  - Complex technology with many functions
- Batteries operate as both load and generation
  - Convention (lingo) must be standard
  - Injecting or absorbing both MW and MVAR
  - … also performs voltage control

Human-Machine Interface

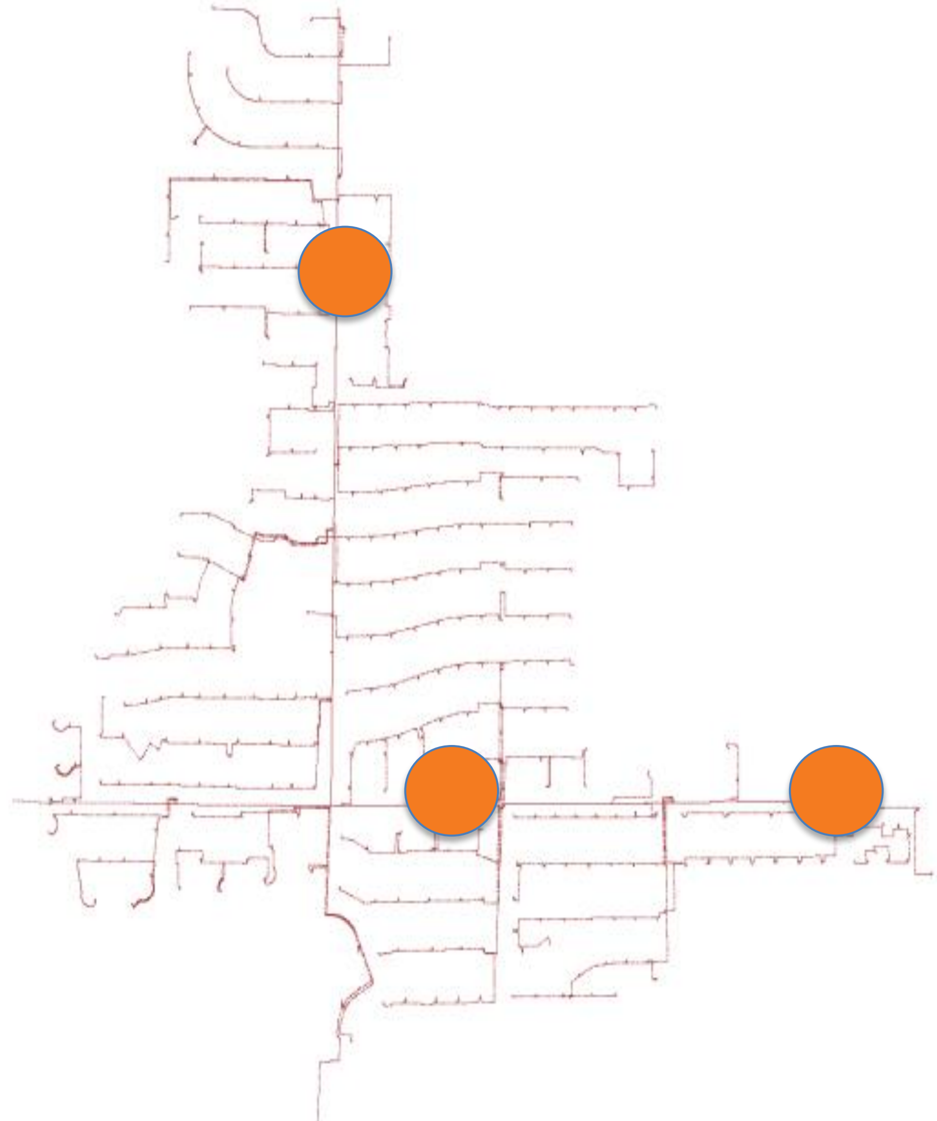
- Extensive training is required
  - New technology, not extension of existing
  - Capabilities that do not exist elsewhere
- Alarms can be overwhelming
  - Especially during disturbance, operators need guidance on what to do, not just system states

Other Lessons Learned

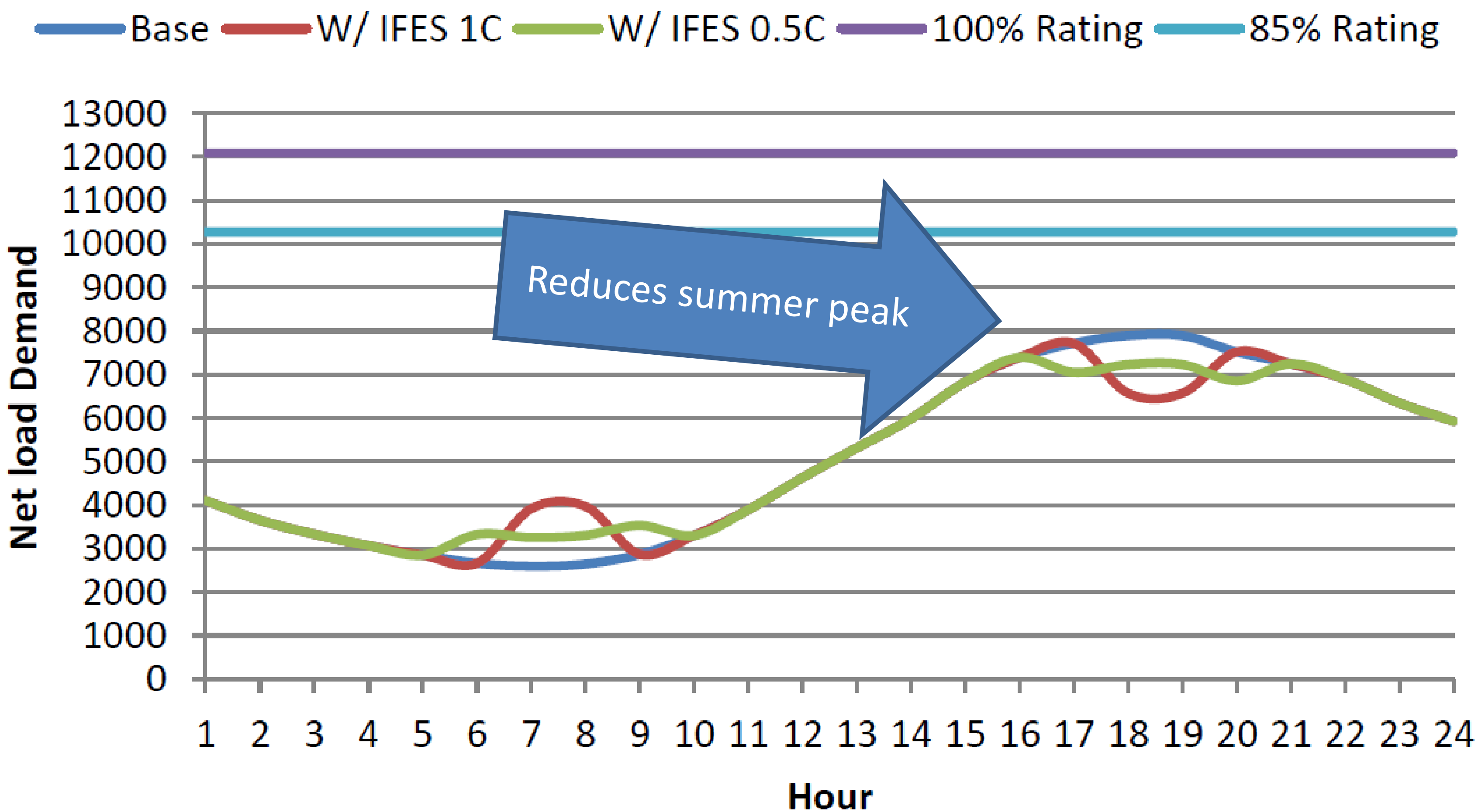
- Clear requirements and expectations up front
  - Alignment on expected operating conditions
  - Alignment on technology capabilities
  - Test and verify system details prior to installation
- Battery inverters will need to align to IEEE 1547
  - They may or may not today
  - Outlines Volt/VAR, voltage and frequency ride-thru
  - Communication and control parameters
- Automate routine and simple functions
- Time series studies to understand daily dispatch

Intermediate Feeder Energy Storage

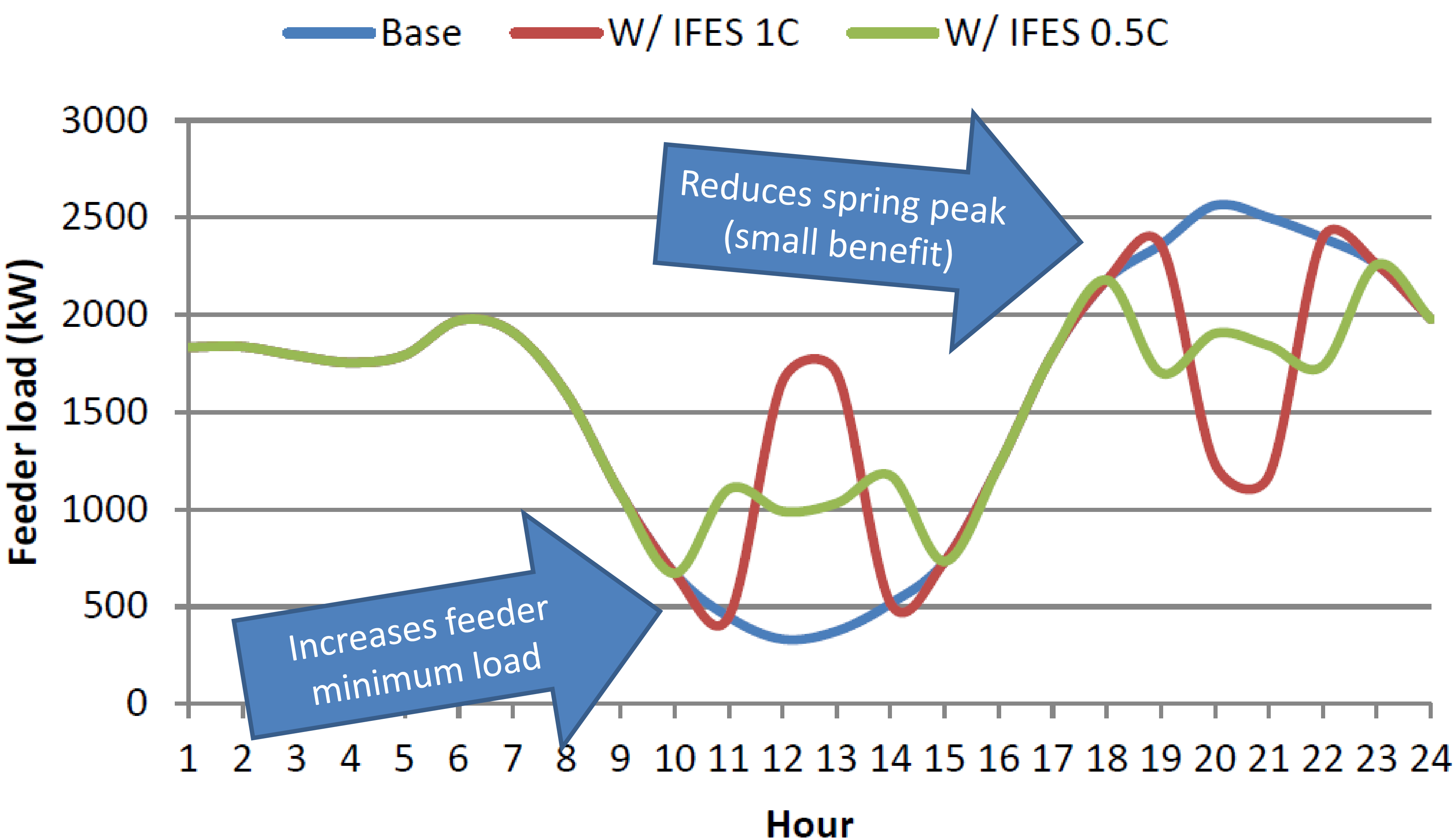
- Delivered scope
  - 1 x 380 kW
  - 2 x 507 kW
  - Total capacity 1.39 MW
- Use cases
  - Thermal load management
    - Charge from PV
    - Shave peak
  - Voltage management
    - Not intended to replace capacitor (1200 kVAr)
    - Feeder capacitors retrofit with 1-phase controls
    - Inverter / capacitor inter-operability and fine-tune voltage control



Peak Day
Batteries operating at full and ½ capacity



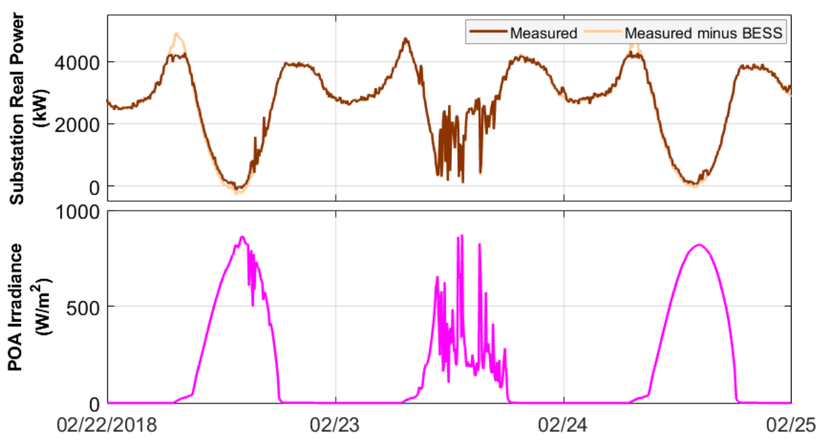
Minimum Load Day (Max PV Output) Batteries operating at full and ½ capacity



QUESTIONS?

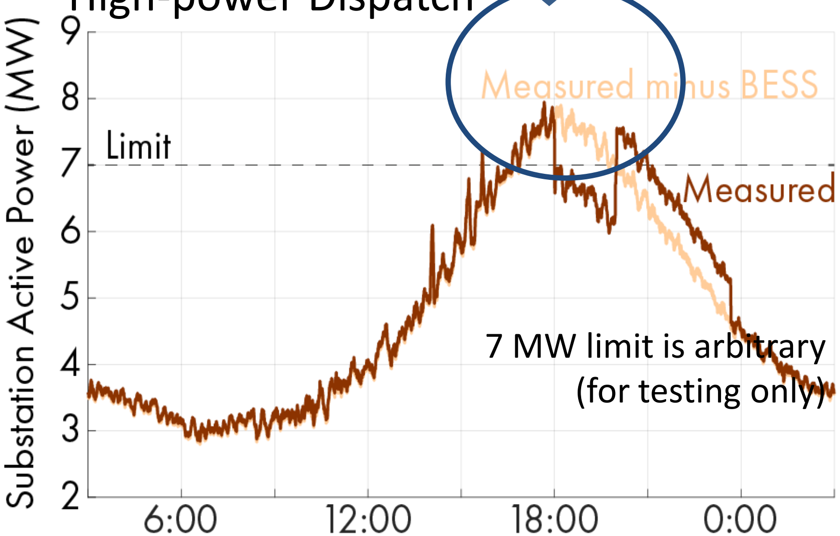
Other Examples with SPP

- Solar Partner Program BESS
  - Feeder peak demand shaving
  - Demand profile shaping
    - High PV penetration circuits
  - Feeder voltage control and VVO integration
  - VVO interoperability
    - Capacitors and regulators
    - Advanced inverters
    - BESS inverters



- Missing the peak (left)
- Charging right after peak (right)

High-power Dispatch



Low-power Dispatch