Energy storage in Electric Power Systems

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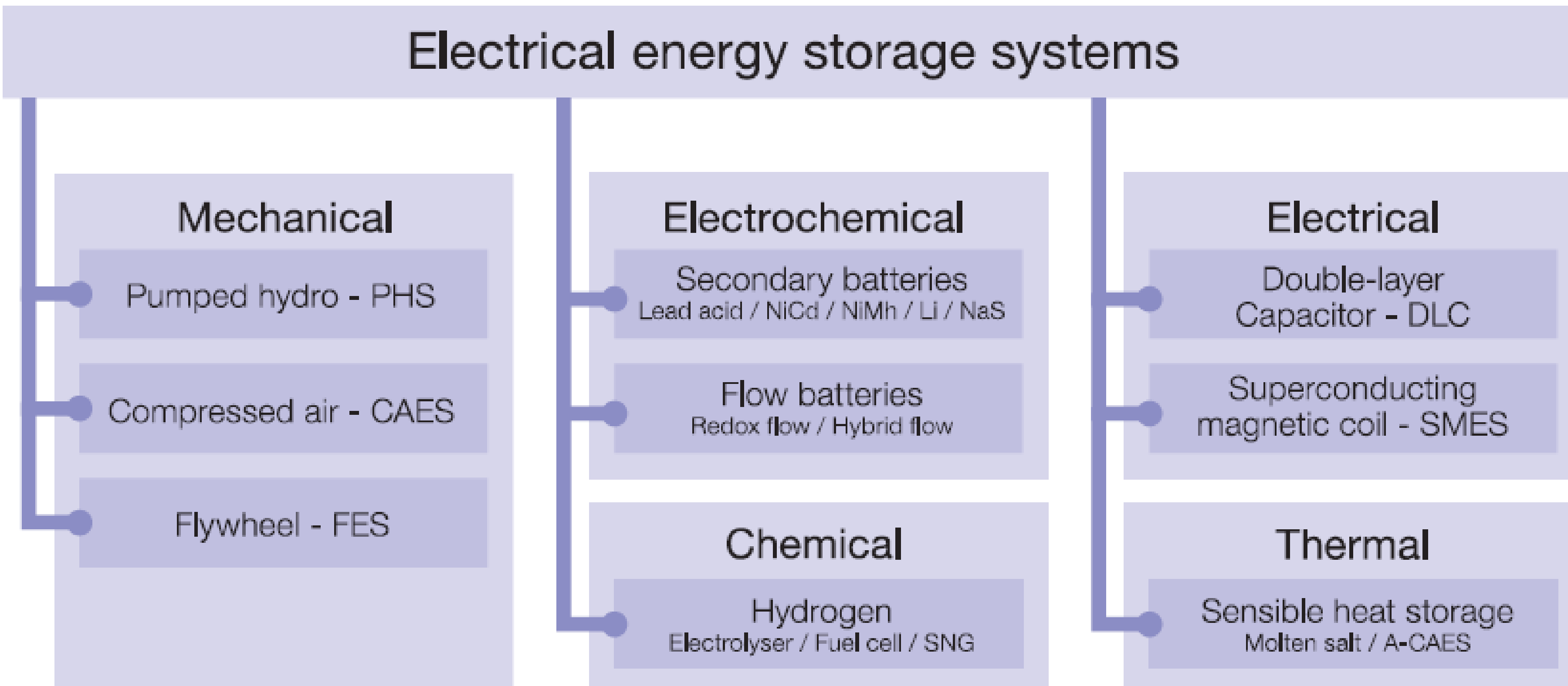
Overview

- Impact of variable generation on load curve
- Energy storage technologies
- Battery Energy Storage Systems
    - Residential application
    - Commercial application
- Mobile applications

Adding variable generation (VG) to the mix

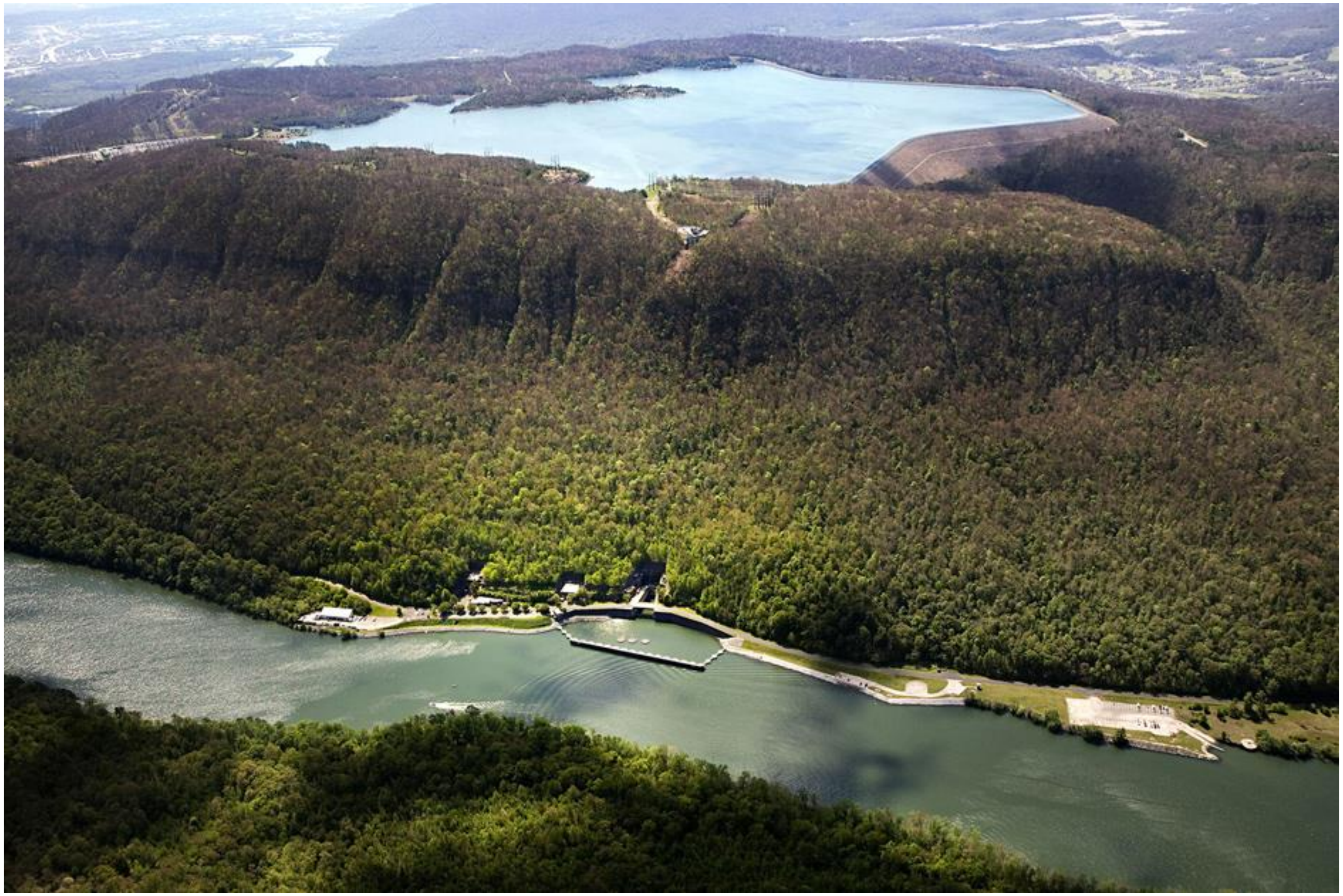
- Solar and wind are excellent sources of clean, renewable energy, but as they contribute a larger share to the generation fleet, their integration will become increasingly challenging.
- The reason: solar and wind cannot be dispatched in the same way as other sources of energy, such as nuclear, hydro, and fossil fuels.
- Because the grid must operate “just in time,” with generation continually matching demand, special accommodation is required to integrate a significant contribution from the sun or the wind.

Classification of Energy Storage Systems



https://www.energystorageexchange.org/projects

Traditional energy storage: pumped hydro



Classes of Energy Storage

- The choice of an energy storage device depends on its application in either the current grid or in the renewables/VG-driven grid; these applications are largely determined by the length of discharge.

Common Name	Example Applications	Discharge Time Required
Power Quality	Transient Stability, Frequency Regulation	Seconds to Minutes
Bridging Power	Contingency Reserves, Ramping	Minutes to ~1 hour
Energy Management	Load Leveling, Firm Capacity, T&D Deferral	Hours

Advantages of expanded use of energy storage

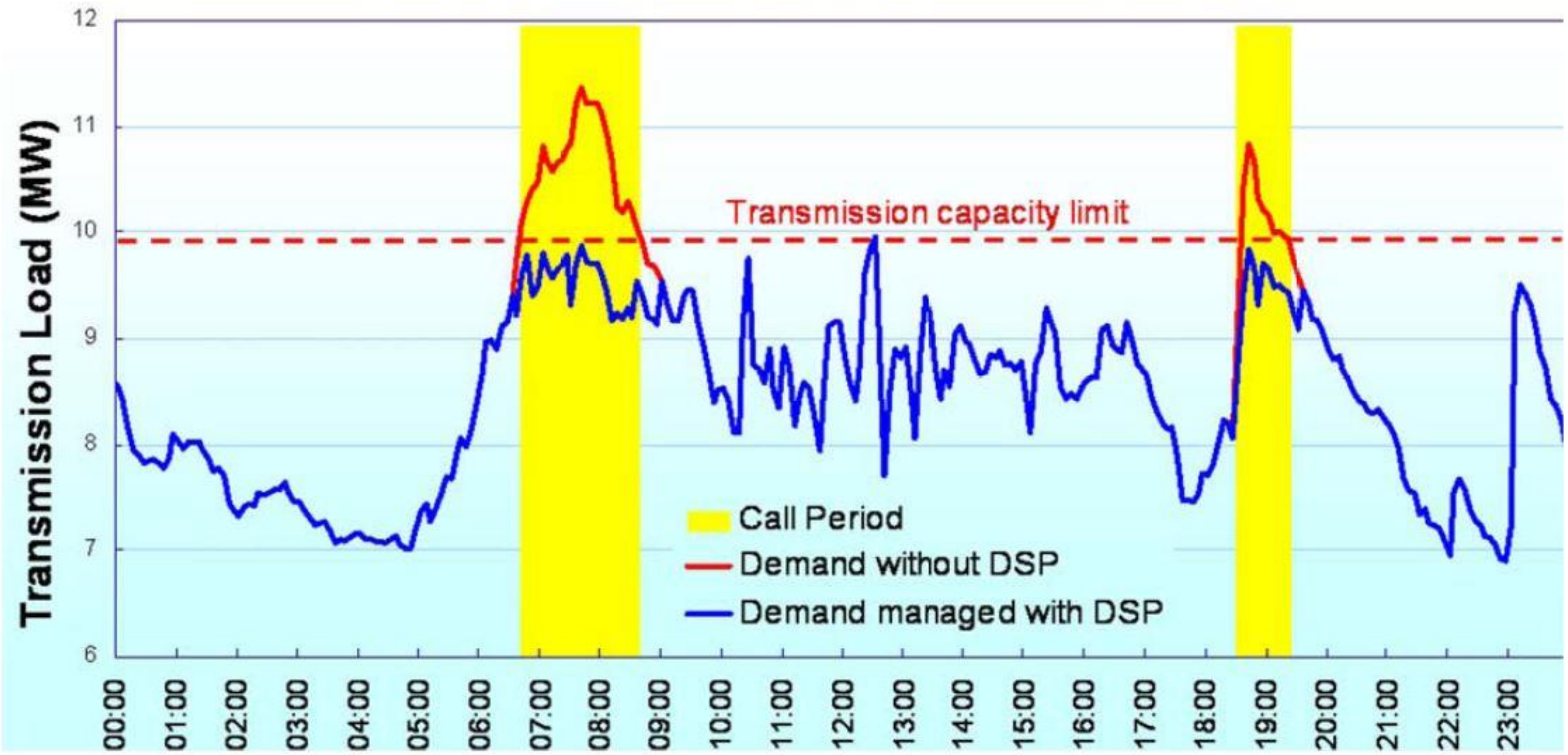
- Energy storage can be employed by utilities to facilitate the integration of photovoltaic (PV) generation and mitigate possible negative impacts on the distribution system by:
  - avoiding system upgrades required for PV integration
  - mitigating voltage fluctuations at the primary distribution side resulting from intermittent distributed PV generation
  - reducing distribution system losses through improved utilization of distributed generation
  - deferring upgrade of substation equipment by time-shifting peak PV generation to coincide with system load peak

Energy Storage Applications

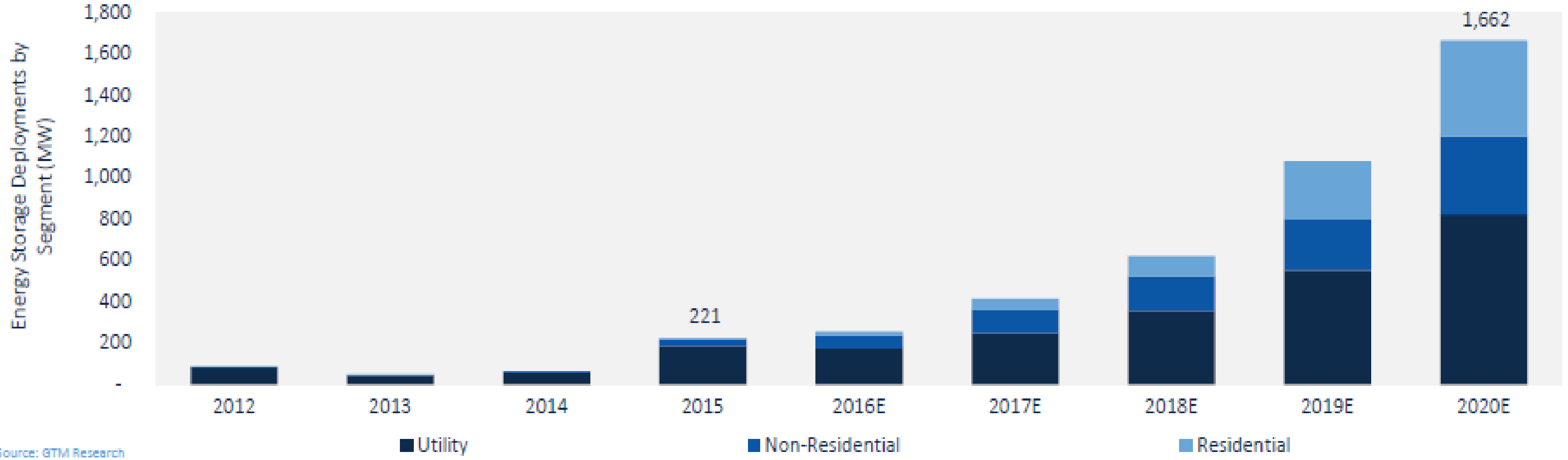
Incidental Benefits	
18.	Increased Asset Utilization
19.	Avoided Transmission and Distribution Energy Losses
20.	Avoided Transmission Access Charges
21.	Reduced Transmission and Distribution Investment Risk
22.	Dynamic Operating Benefits
23.	Power Factor Correction
24.	Reduced Generation Fossil Fuel Use
25.	Reduced Air Emissions from Generation
26.	Flexibility

Category 1 — Electric Supply
1. Electric Energy Time-shift
2. Electric Supply Capacity
Category 2 — Ancillary Services
3. Load Following
4. Area Regulation
5. Electric Supply Reserve Capacity
6. Voltage Support
Category 3 — Grid System
7. Transmission Support
8. Transmission Congestion Relief
9. Transmission & Distribution (T&D) Upgrade Deferral
10. Substation On-site Power
Category 4 — End User/Utility Customer
11. Time-of-use (TOU) Energy Cost Management
12. Demand Charge Management
13. Electric Service Reliability
14. Electric Service Power Quality
Category 5 — Renewables Integration
15. Renewables Energy Time-shift
16. Renewables Capacity Firming
17. Wind Generation Grid Integration

Deferral of Distribution Feeder investment



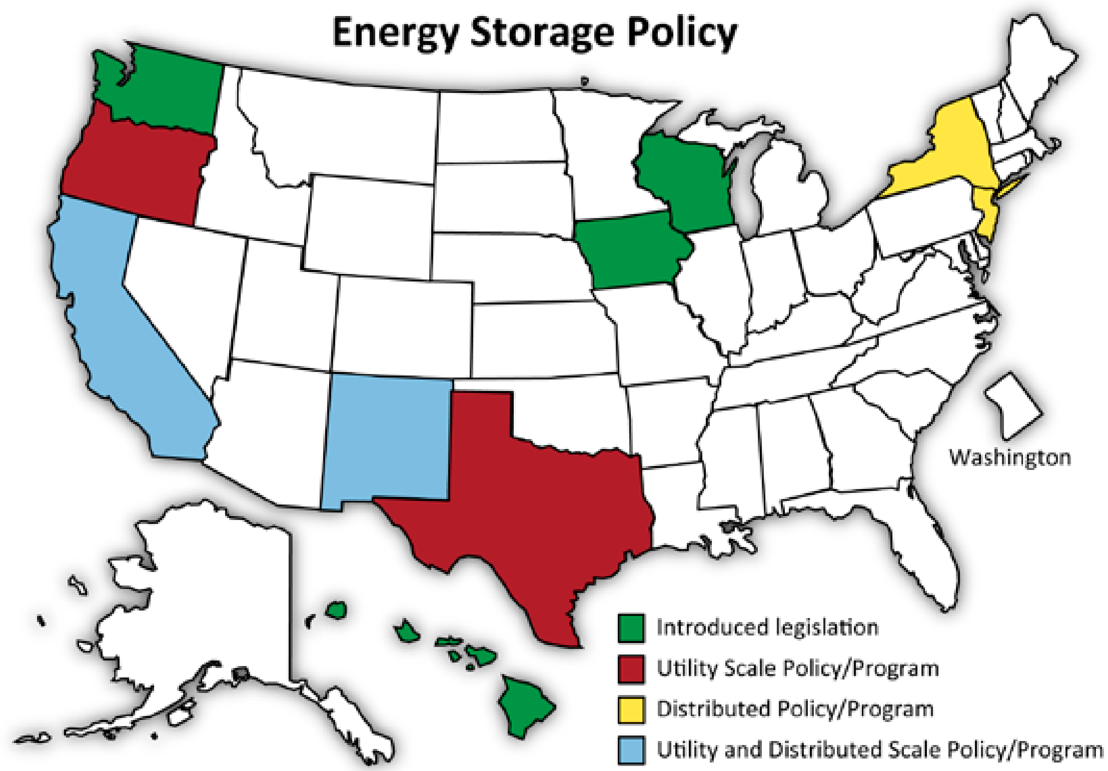
Expected Growth in U.S. Annual Energy Storage Deployments



Source: GTM Research

Energy Storage Policies in US

- Several states have recently introduced policies related to the support and development of energy storage technology markets

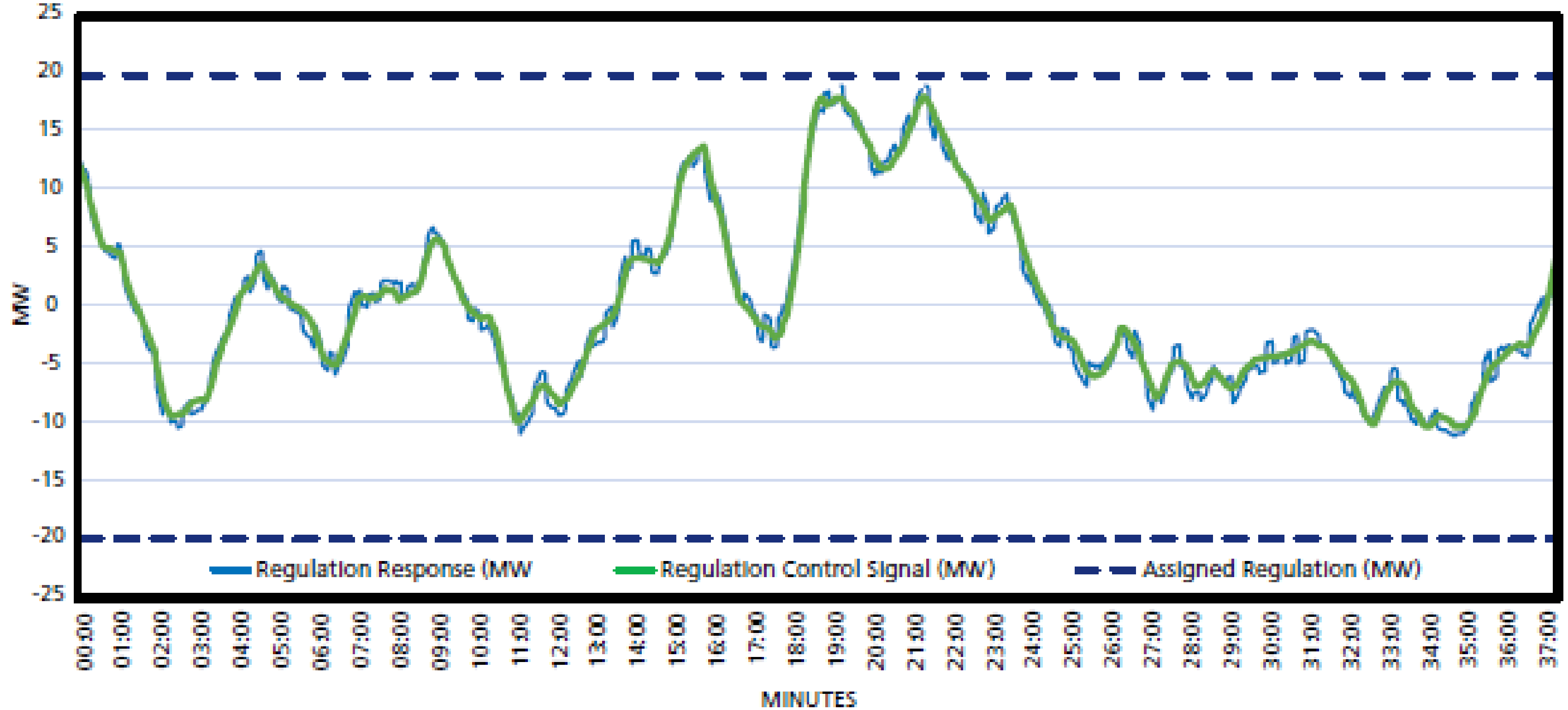


A 34-MW, 245-MWh Na-S battery installation in Japan

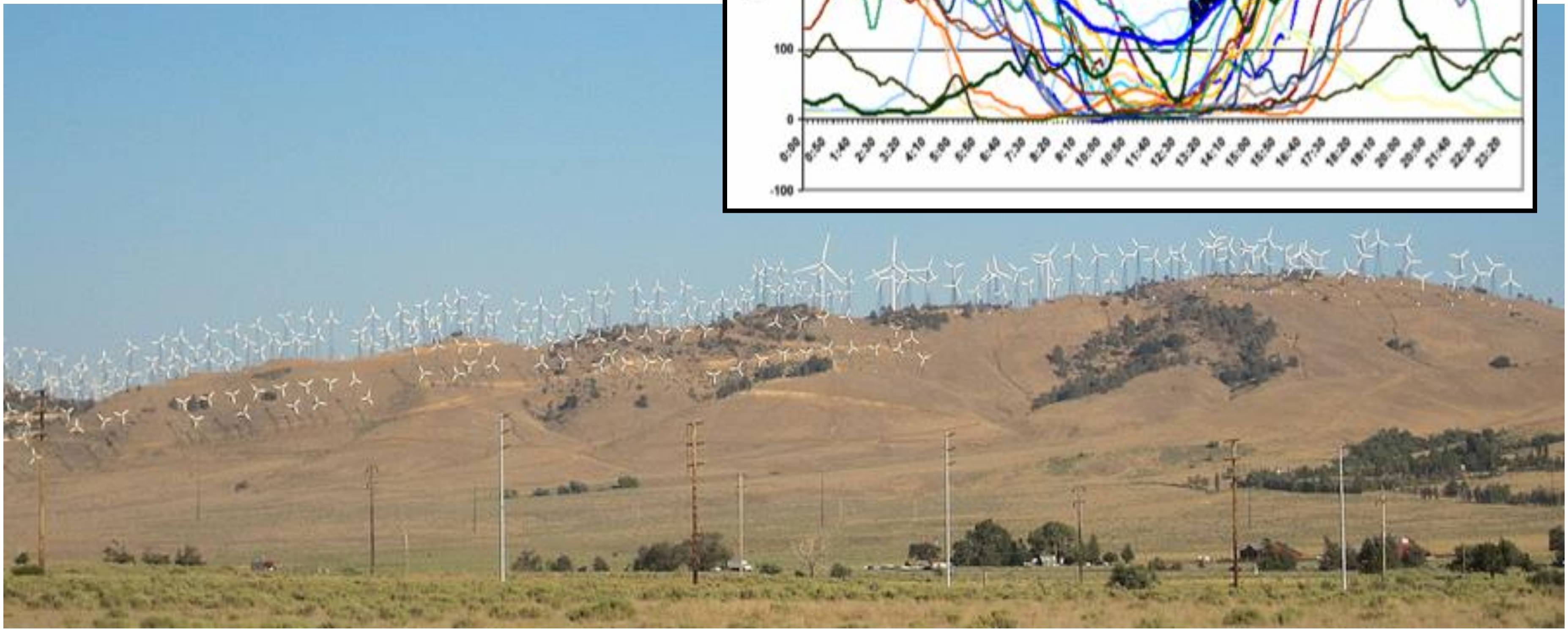
Battery Energy Storage Operational Capacity

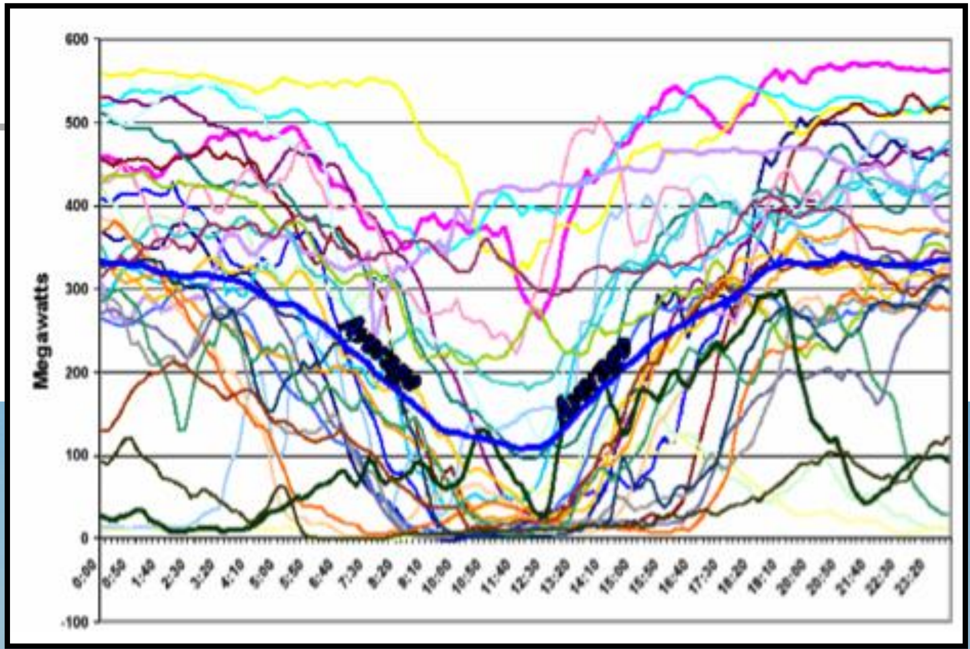
edf renewable energy

15445 Innovation Drive
San Diego, CA 92128
www.edf-re.com



Tehachapi wind farm (Capacity: 4,500 MW)

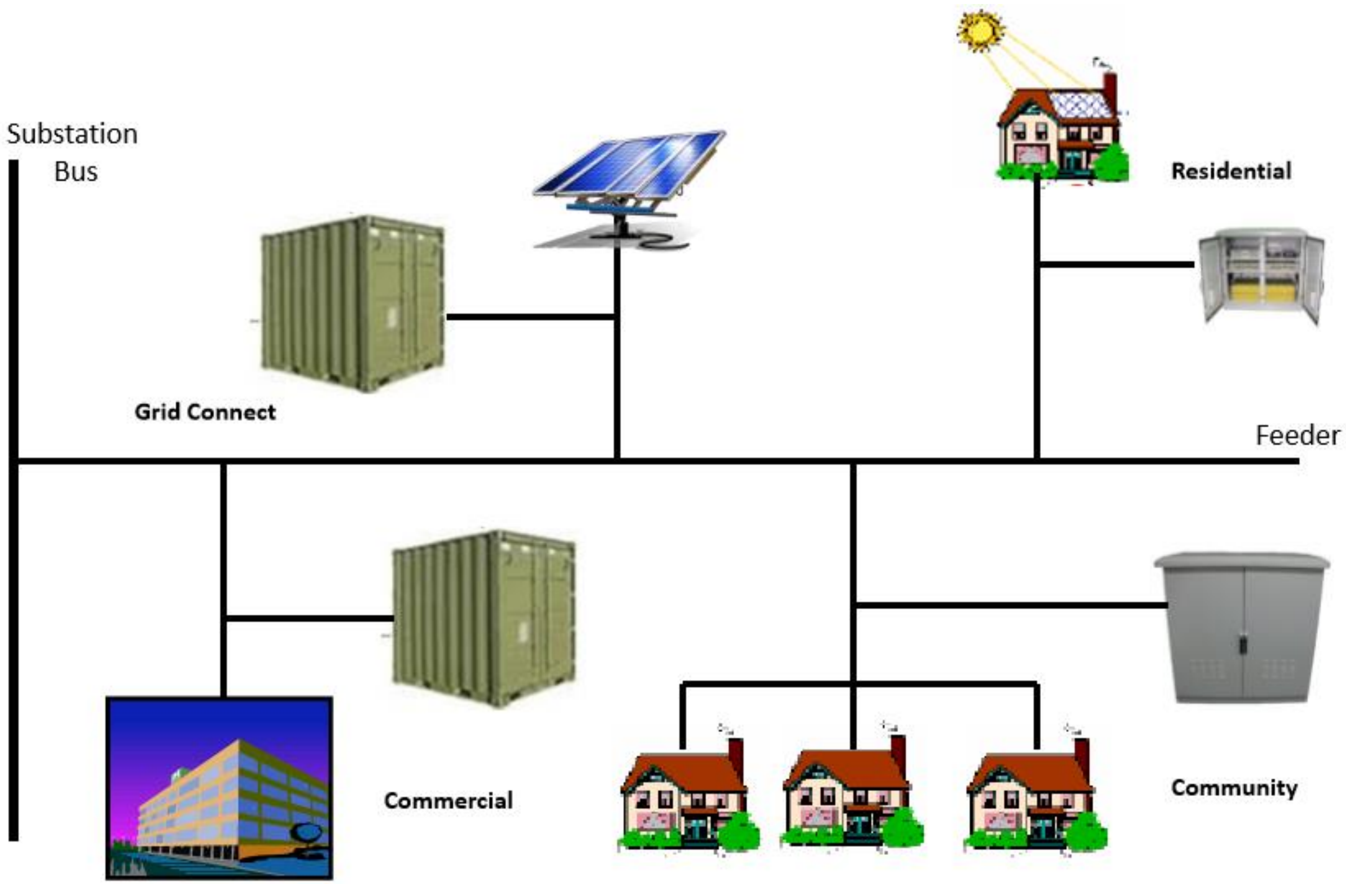




Large-Scale BESS Installations

- 32 MWH BESS features lithium-ion batteries housed inside a substation in Tehachapi, CA.

Distributed Energy BESS



Community Energy Storage (multiple customers)

- Typical CES Power and Energy Ratings
  - 25 kW
  - 50 kWh

Residential Applications (single customer)

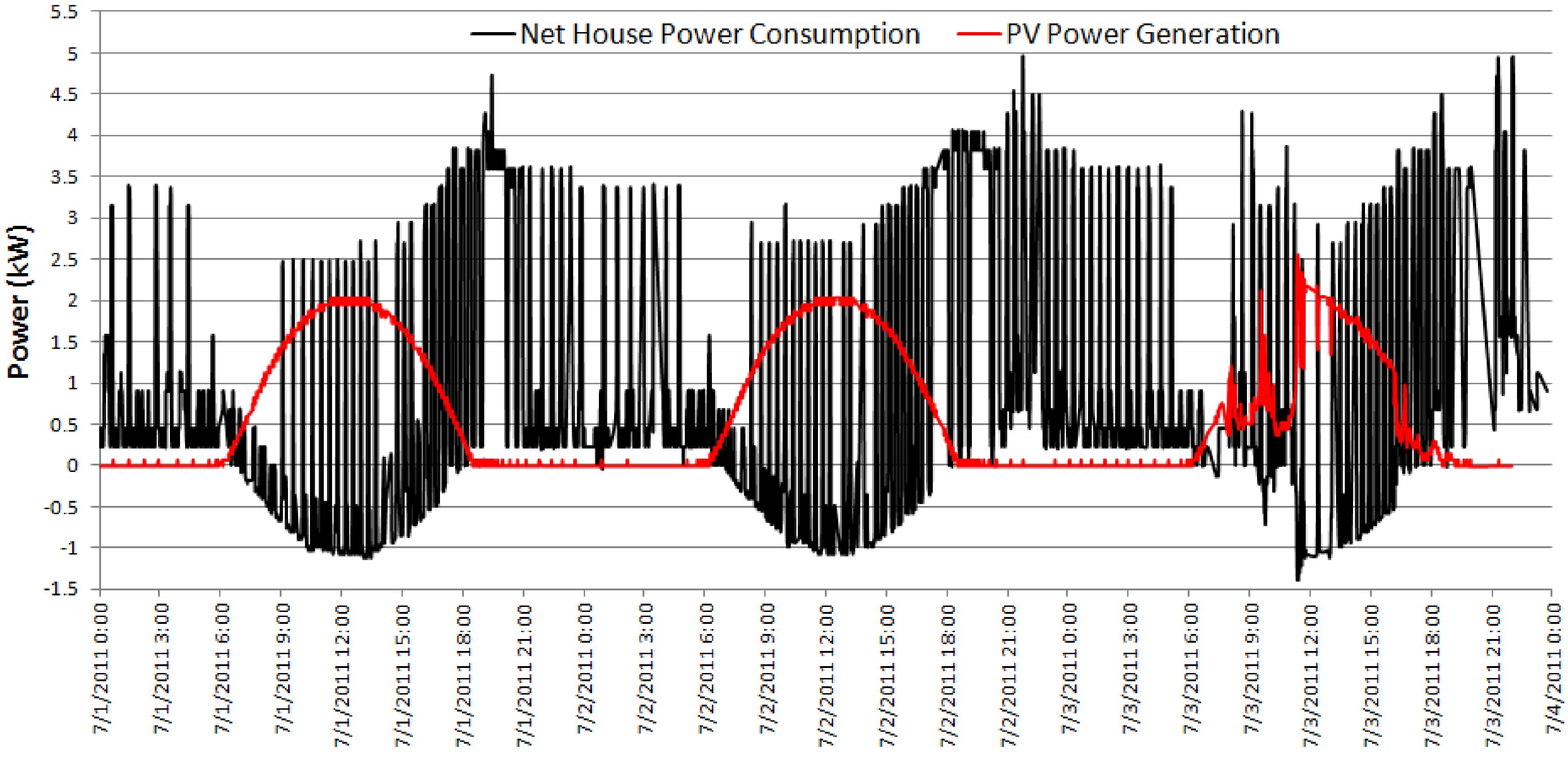
- Typical Power and Energy Ratings:
  - 2-5 kW
  - 5-15 kWh

Bombard – Adera Power (Las Vegas, NV)

- PV-BESS expected to expand as power exported to the grid is becoming less and less costly.

Testing of a BES for Residential Applications

- Part of DOE Smart Grid Demo Projects
- Collaborators: NV Energy and Pulte Homes

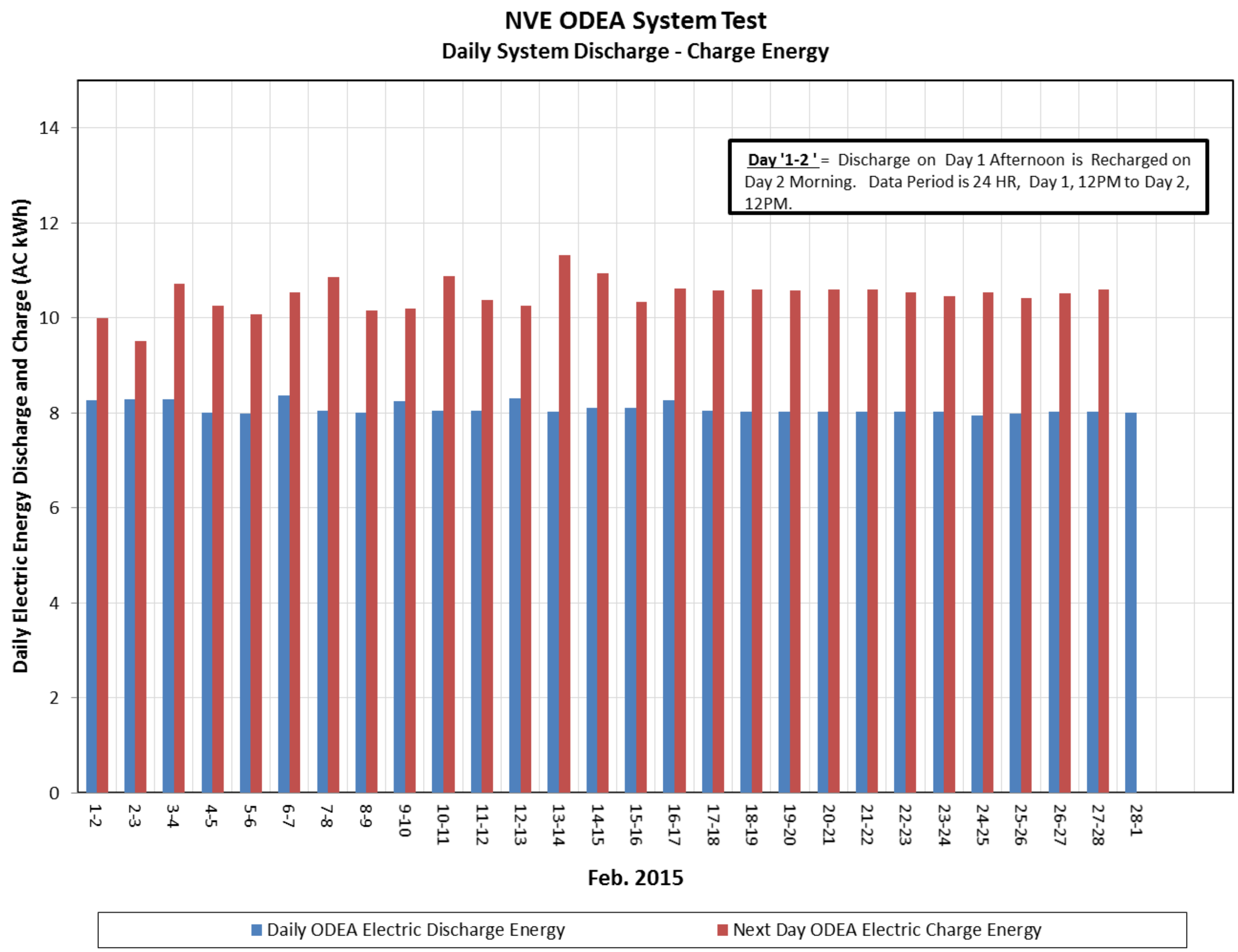


Adding a Battery Energy Storage System to the Mix

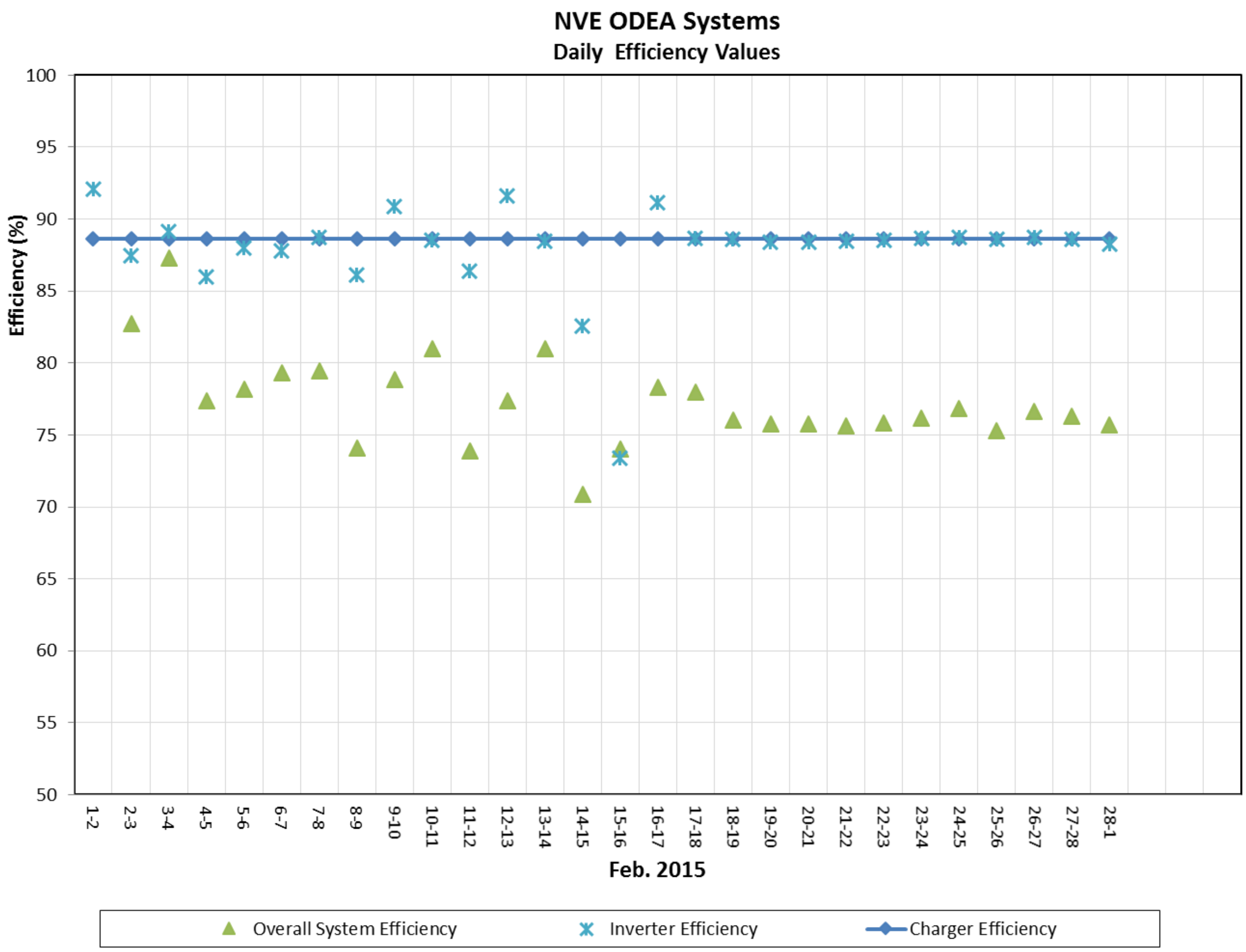
- Biggest challenge with solar energy: intermittency
- Solution: combine energy storage and load management capability.
- BESS Applications include:
  - Peak shaving
  - Load shifting
  - PV power generation smoothing
  - Align PV generation with load consumption
  - Etc…

4.5 kW/10 kWh Residential BESS

Charge/Discharge Test

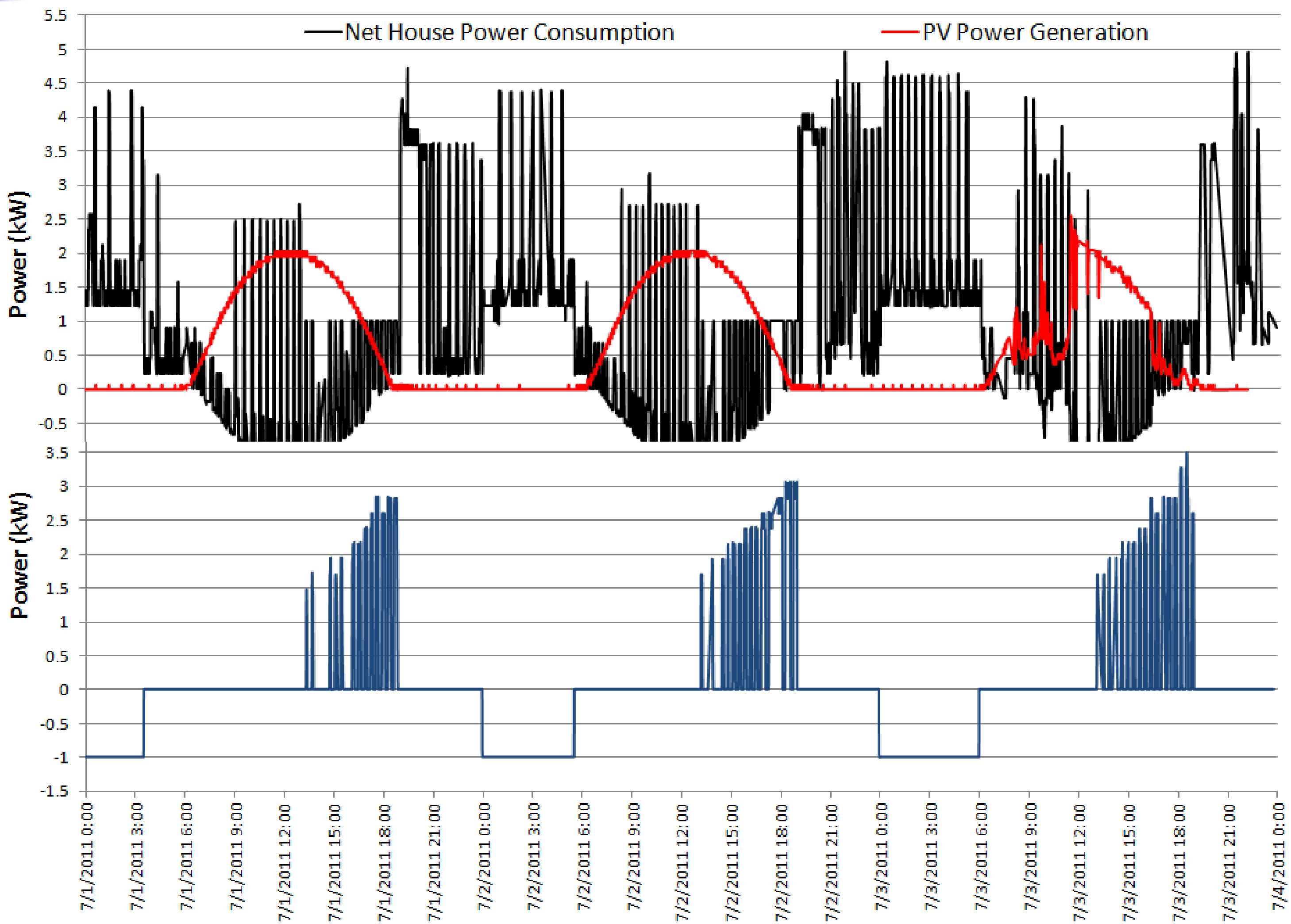


Round trip efficiency



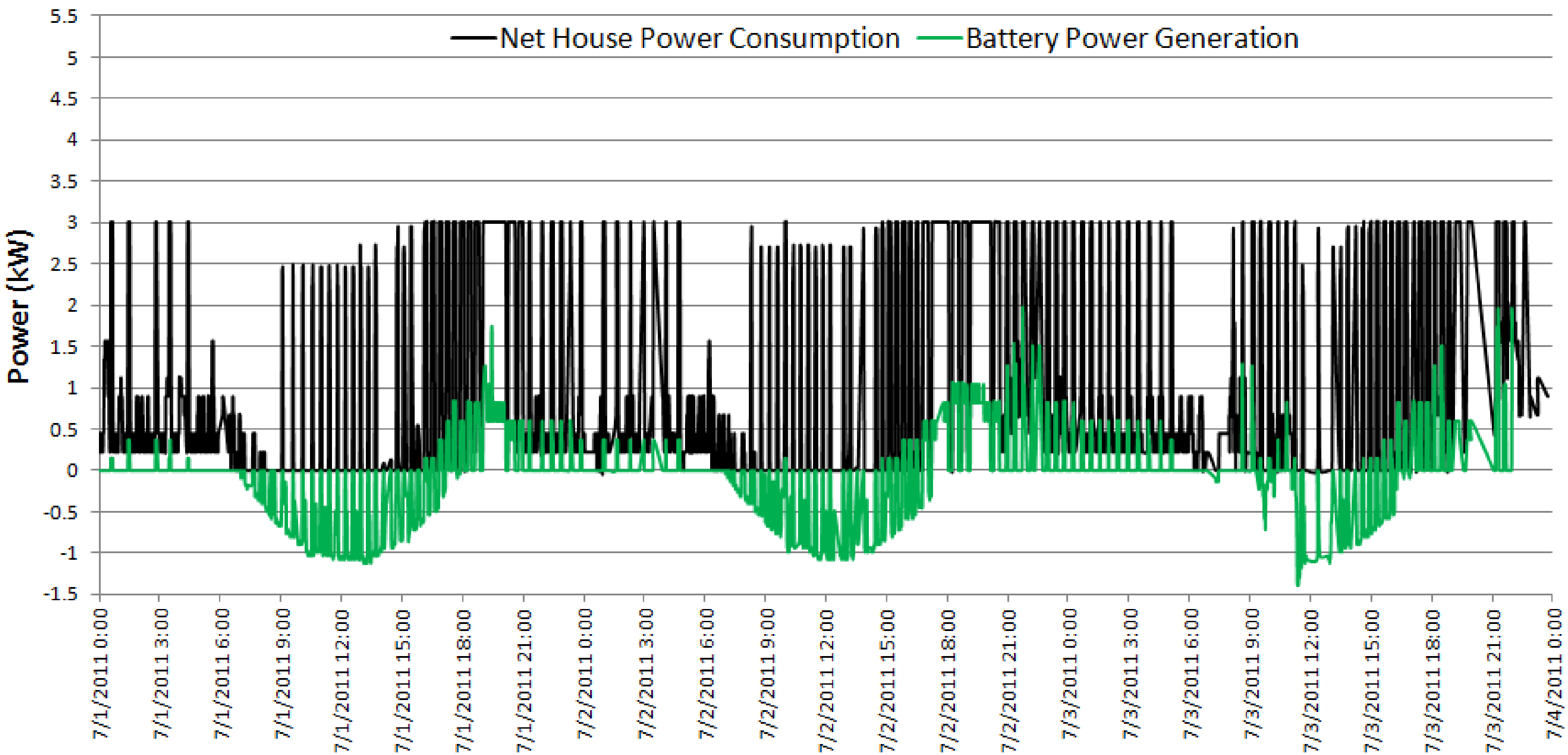
Application 1: Customer enrolled in TOU pricing

- Battery saves money by reducing consumption during periods when total demand for electricity is highest (1:00pm-7:00pm, June-September)



Application 2: Keep Maximum Demand Below 3 kW

- Use battery to provide power demand above 3 kW limit.
- Use excess PV power to charge battery



Charging/discharging optimization[x]

- Different electricity rate plans
- Payback period exceeds over 10 years (without incentives)

Plan A (Peak: 1-8 p.m.)	On-peak $/kWh	Off-peak $/kWh	On-peak demand charge ($/kW)			Service Charge /Mon
			0-3	*3-10*	*>10*	
Summer	$0.0486	$0.0371	$8.03	$14.63	$27.77	$30.94
Summer Peak	$0.0633	$0.0423	$9.59	$17.82	$34.19	$30.94
Winter	$0.0430	$0.0390	$3.55	$5.68	$9.74	$32.44
Plan B	**$/kWh**			**FIT $/kWh**		
Winter (Nov-Apr)						
On-peak (12-7 p.m.)	$0.19847			$0.03040		
Off-peak	$0.06116			$0.02831		
Summer (May-Oct)						
On-peak (12-7 p.m.)	$0.24477			$0.02989		
Off-peak	$0.06118			$0.02897		

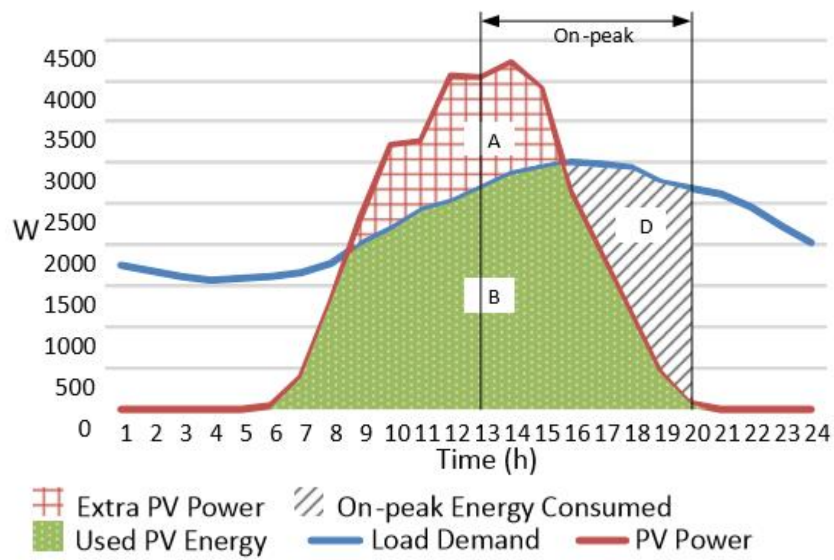


Figure 2. Daily PV energy distribution

[x] X. Wang, G.G. Karaday, "Hybrid Battery Charging Strategy for Maximizing PV Customers' Economic Benefits, IEEE PES GM 2016

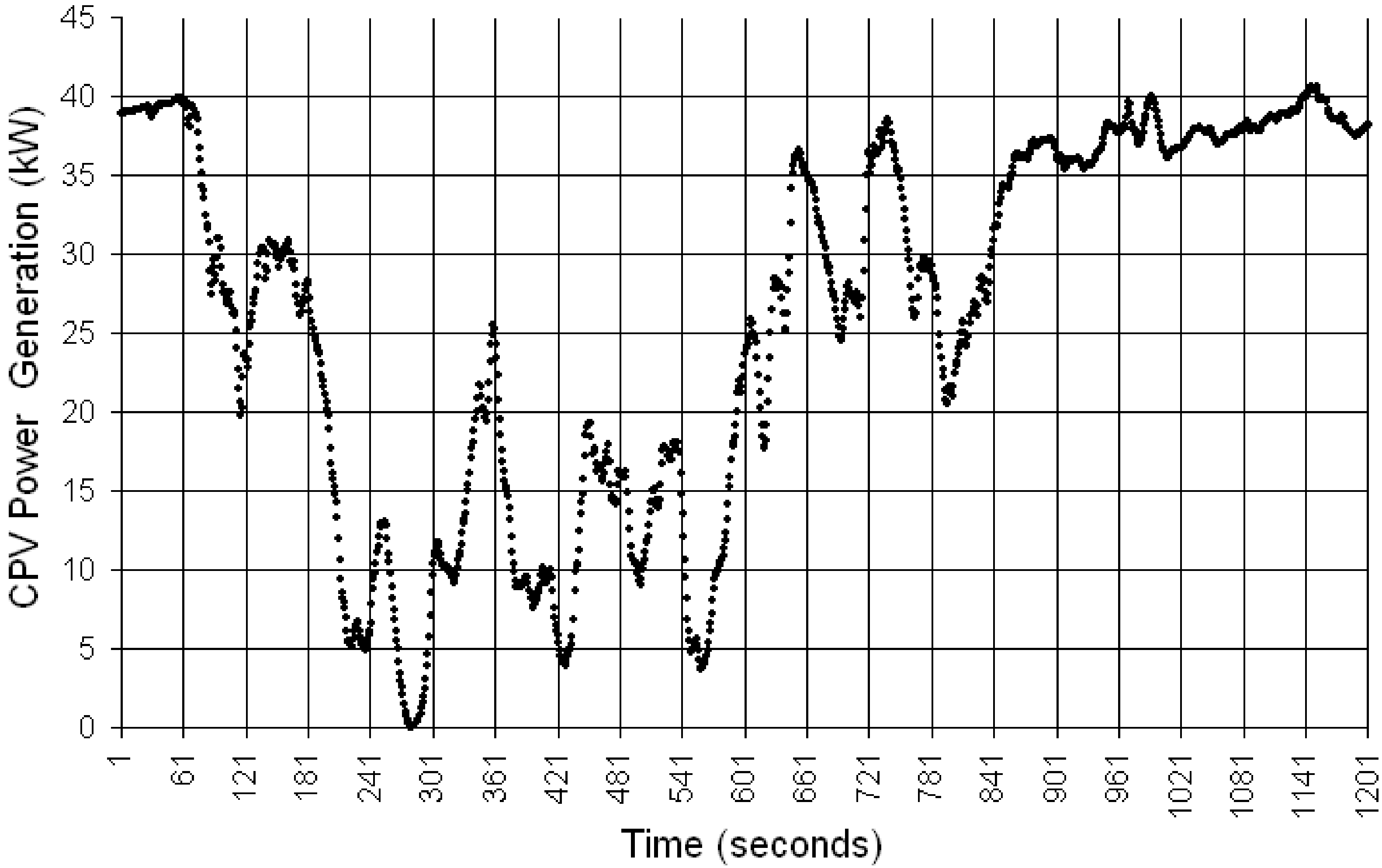
PV Power Smoothing

- Energy storage system integration with PV can be designed to operate in many ways such as:
  - **PV Power Firming:** Level PV output power during cloud transients throughout the day, then gets recharged at night and be ready for the next day.
  - **PV Power Smoothing:** the storage system will generate and absorb energy to smooth out PV array power fluctuations.
- The next slides evaluate the placement of an BES at the PCC of a commercial-size Concentrating PV system for the purpose of reducing the ramp rate, or “power smoothing”.

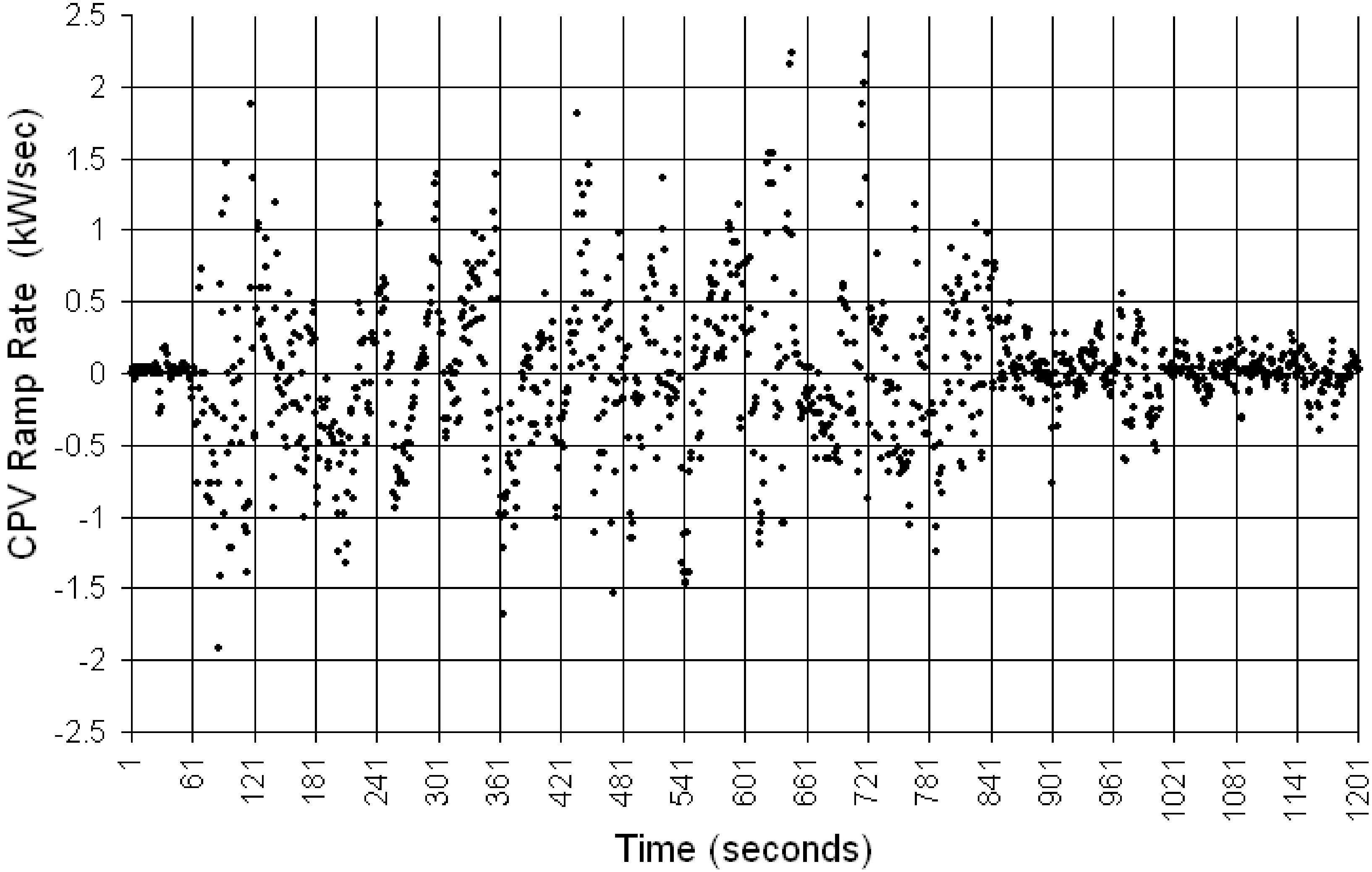
PV Plant Description

- Power rating: 55 kW.
- Surface 300 m^2
- No. of cells: 5,600
- Type of cell: III-V multi-junction
- Concentration factor: 500
- Cell efficiency: 25%

Power production during 20-minute period of passing clouds



Power Ramp Rate (KW/Sec)



Power Smoothing by BES

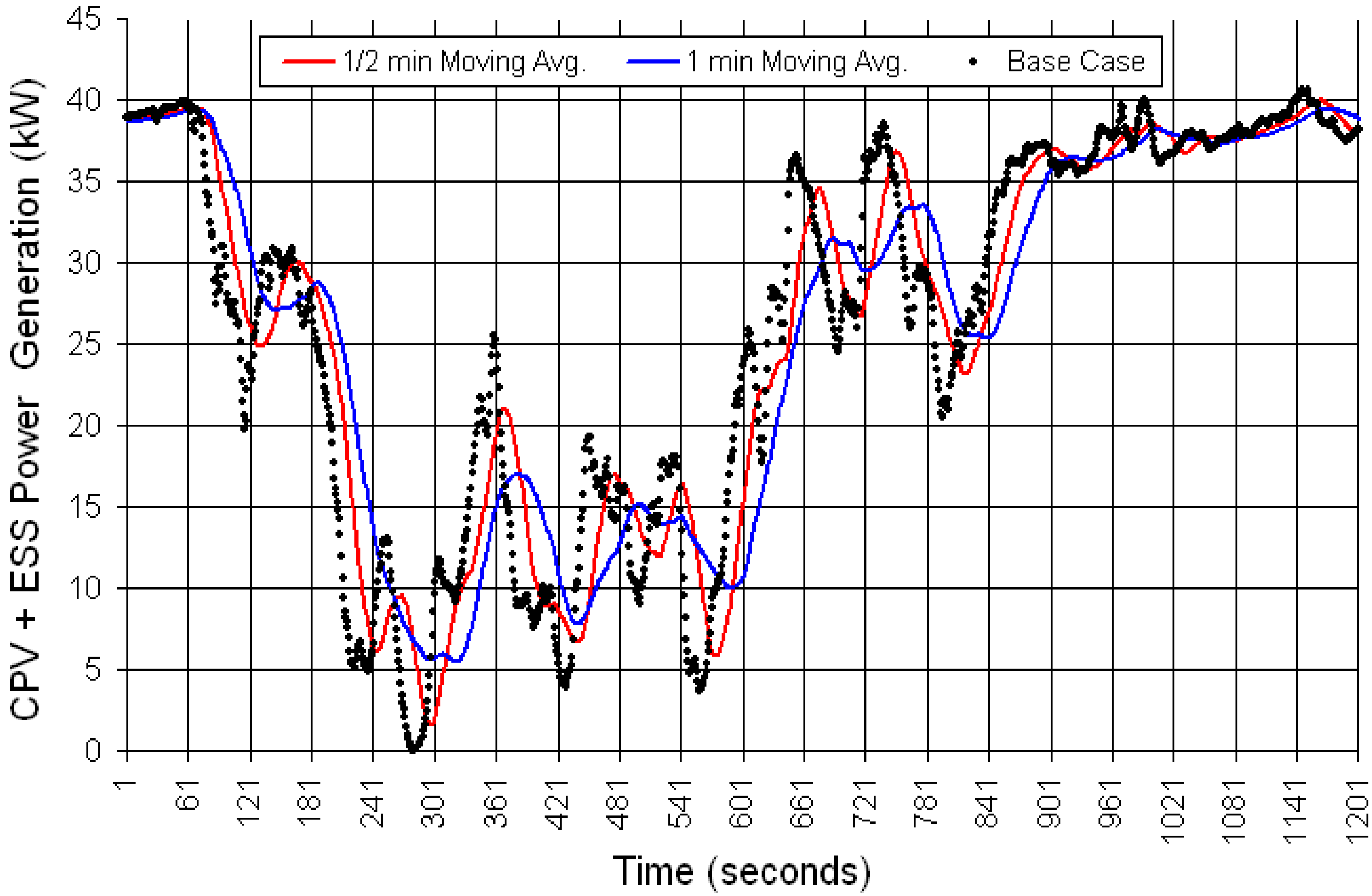
- Reducing power fluctuations depends to several factors such as desired power quality, PV system location in the feeder and specific controls of voltage regulation equipment.
- Ramp rate control (or smoothing) by means of a BES is achieved by continuously monitoring the PV power output and commanding the BES to charge or discharge in a way that limits the combined PV-BES power.

Power Smoothing by BES

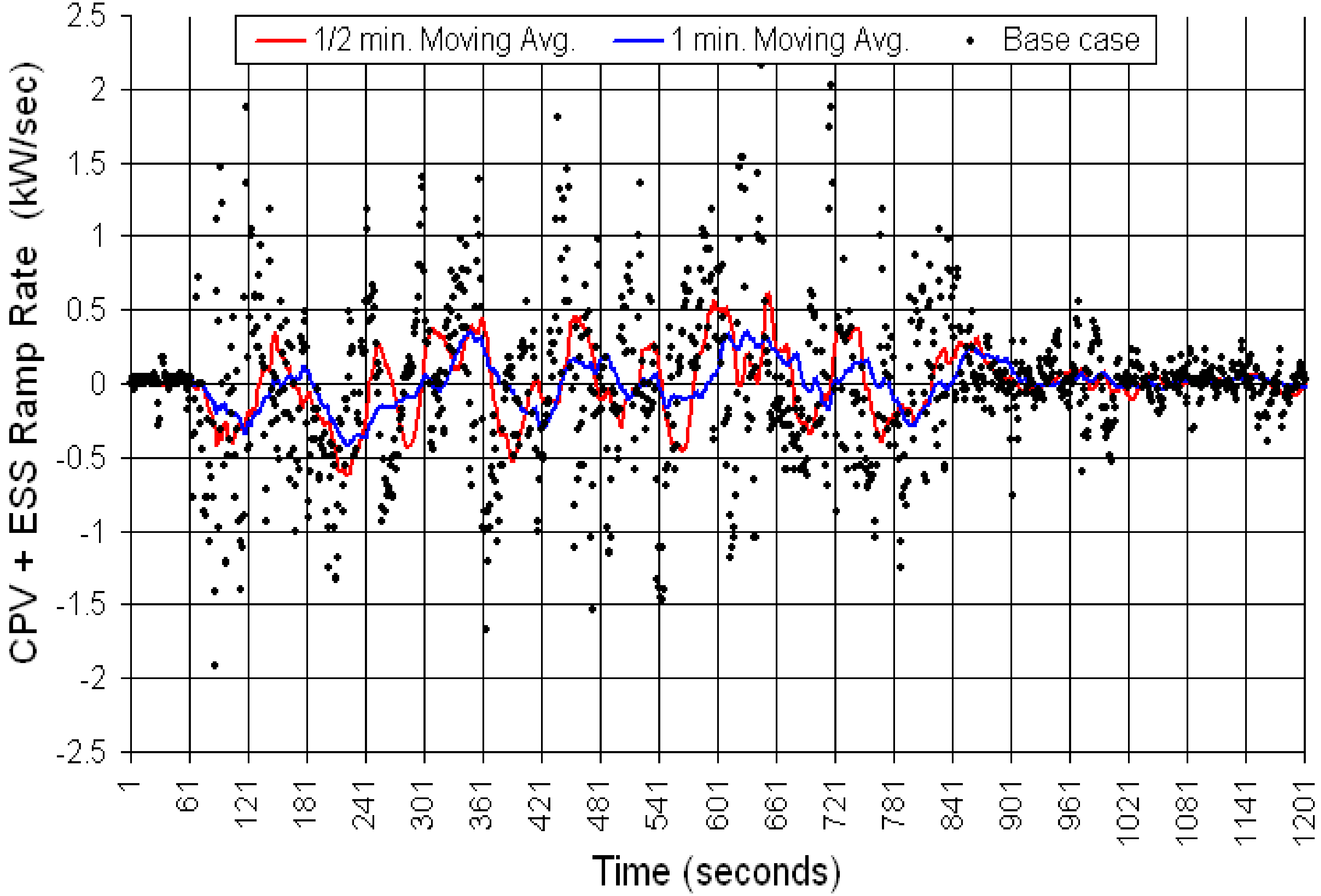
- For ramp rate control, the method based on **moving average** (MA) provides satisfactory results as it defines the current direction with a lag because it is based on past power values.
- The BES is to supply a power $P_{e,n+1}$ that is equal to the deference between the updated moving average and the new PV power generated, i.e.,

$$\overline{P}_{e,n+1} = \overline{P}_{s,n+1} - P_{s,n+1} = \overline{P}_{sn} + \frac{(1-n)P_{s,n+1} - P_{s1}}{n}$$

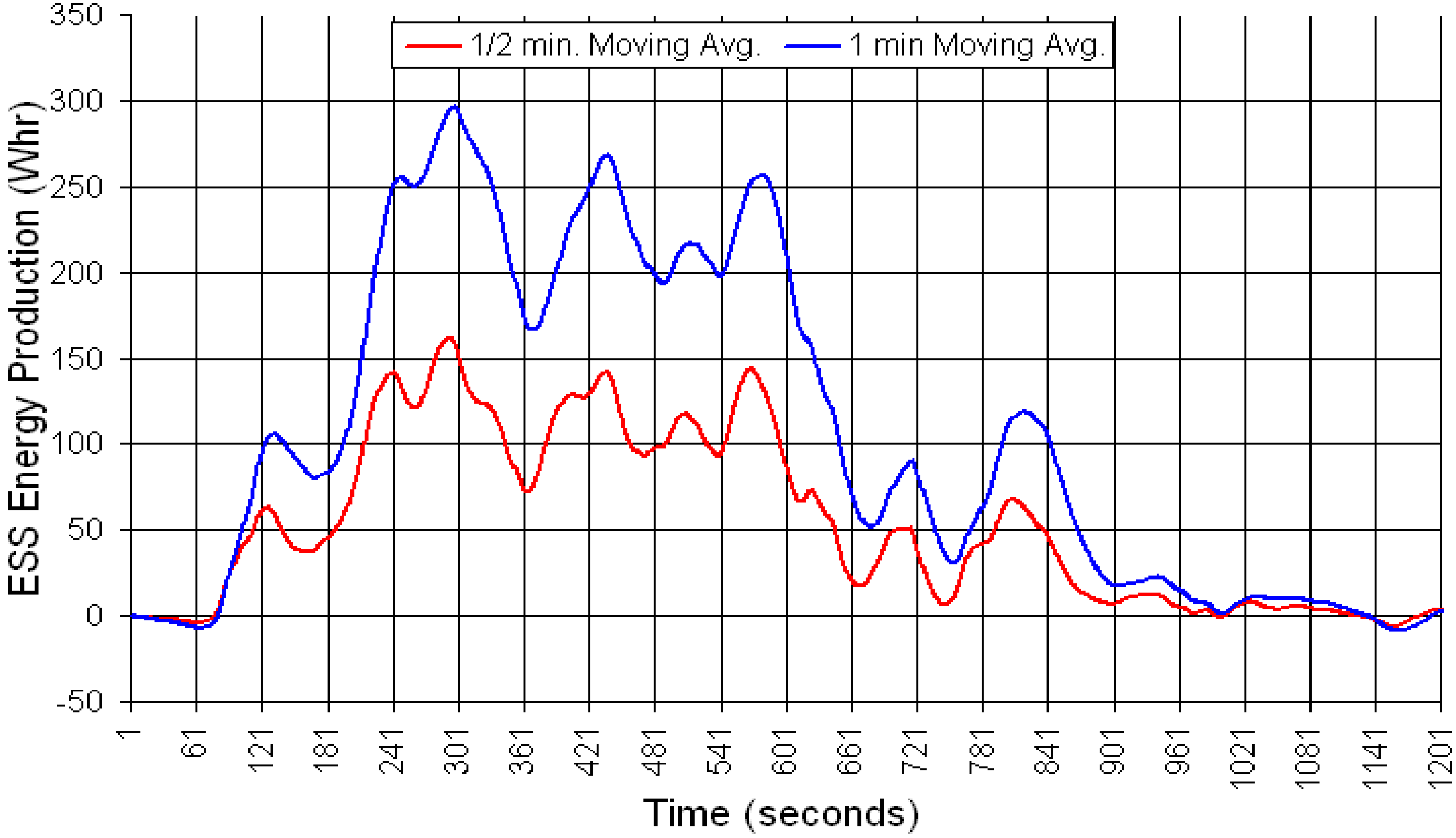
Power Variability of CPV-BES Combination



Power Ramp Rate of CPV-BES Combination



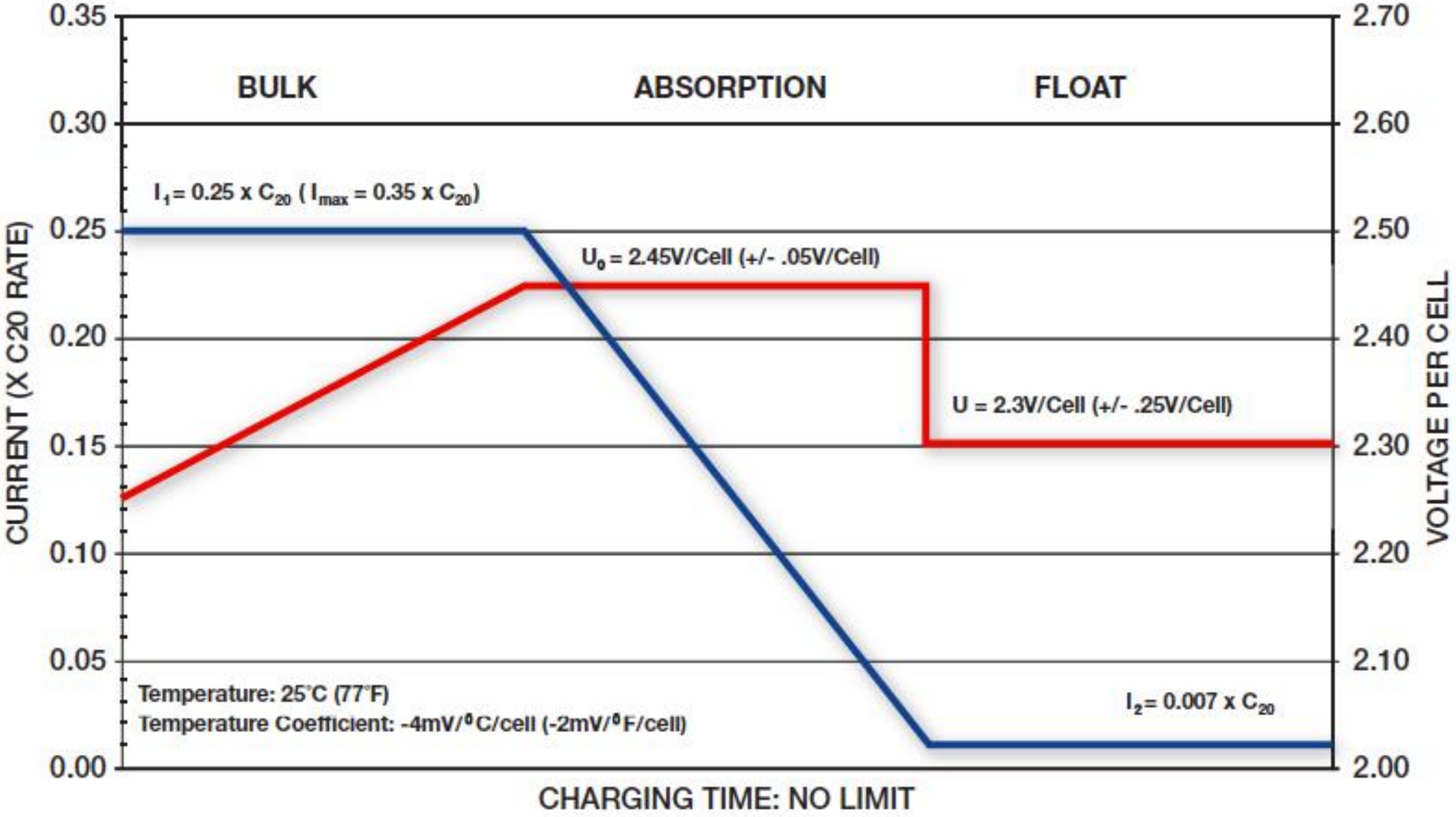
BES Sizing



300 Wh/1.25 kW (for 1 min moving average)
160 Wh/1.5 kW (for ½ min moving average)

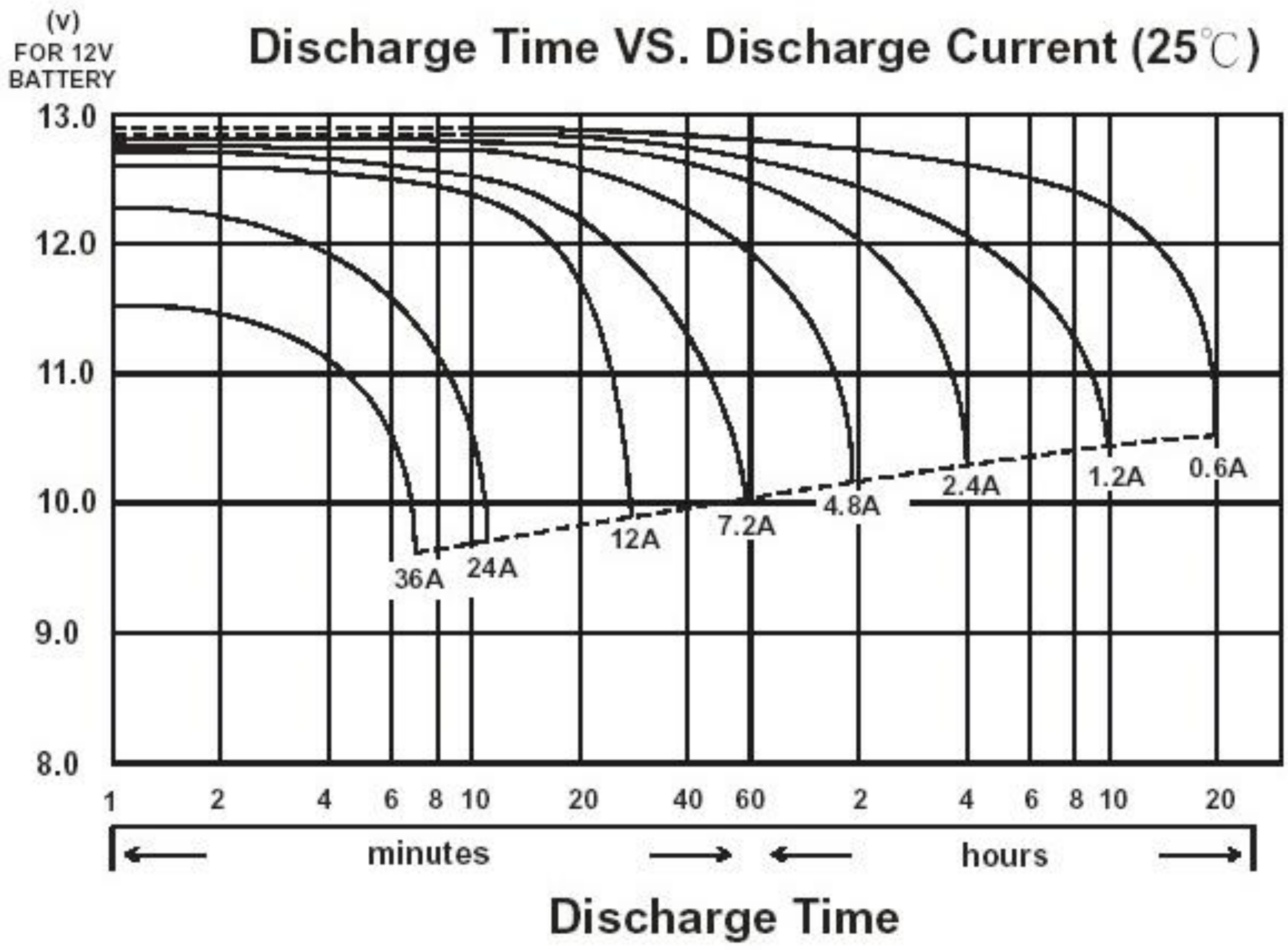
Typical battery charging curve

- What if recommended charge curve is not followed?
- What is the impact of shallow discharges?

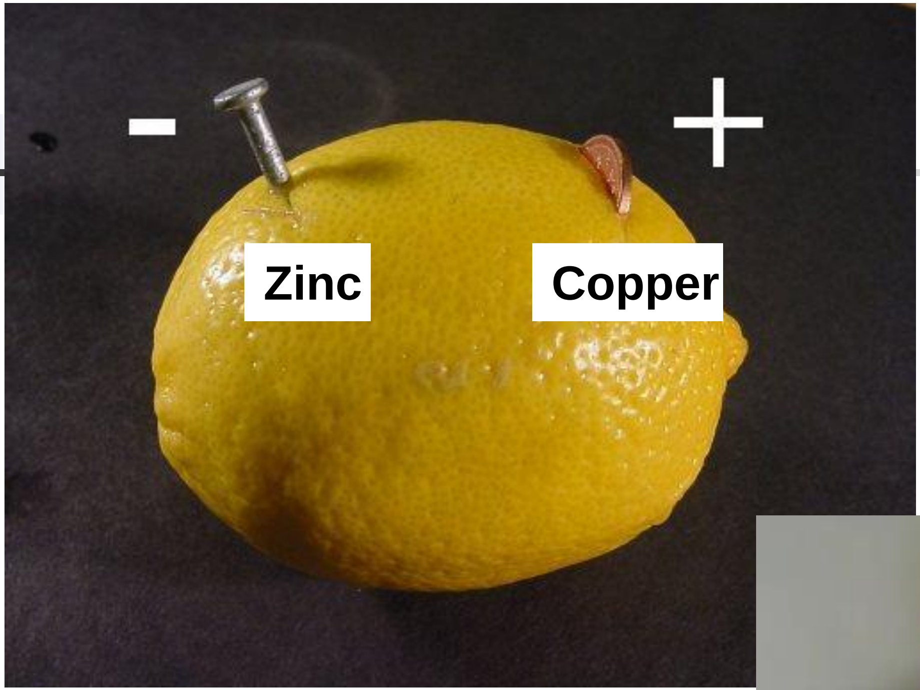


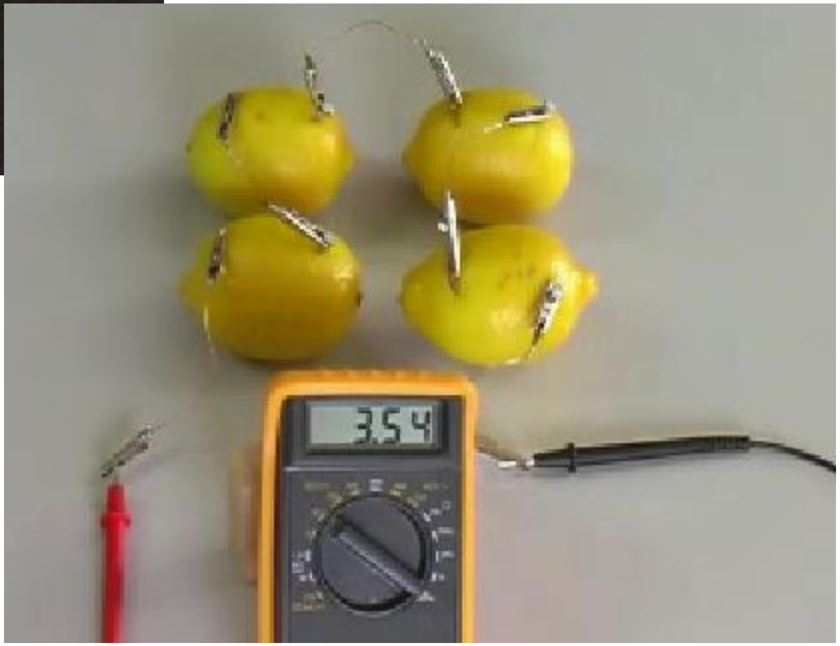
Battery discharge curves

- Battery capacity under variable discharge rate?



Lastly ….testing a lemon battery!





4 lemons can power one a bright LED for over 24 hrs!