Energy storage in Electric Power Systems

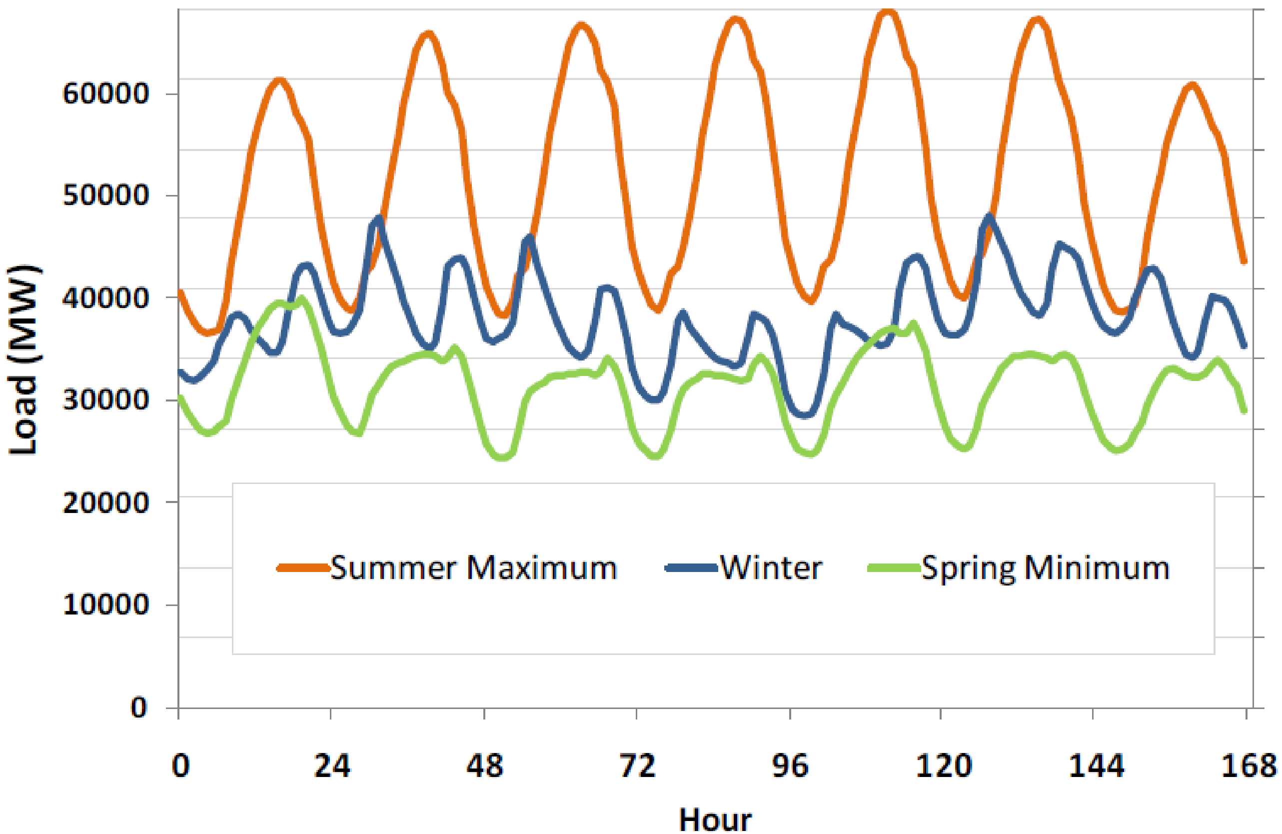
ECG 743

Overview

- Conventional generation scheduling.
- Impact of variable generation on load curve
- Energy storage technologies
- Battery Energy Storage Systems

Operation of the electric grid

- The operation of electric power systems involves forecasting electricity demand, scheduling and operating a large number of power plants to meet that varying demand.



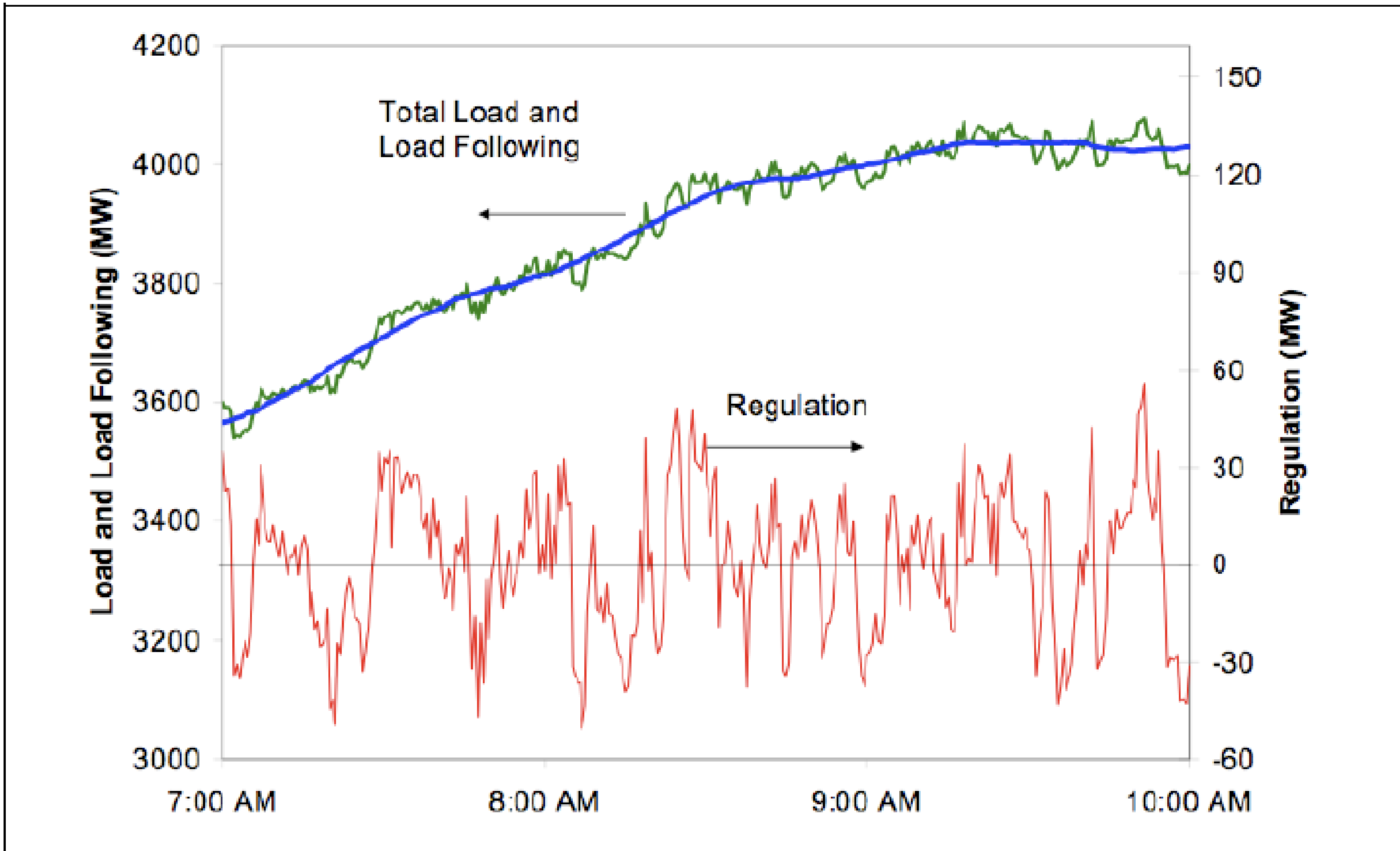
Power Plant Classification

- Electric utilities operate a variety of power plant types:
  - **Baseload units** (e.g., nuclear and coal) - used to meet the large constant demand for electricity.
  - **Load-following units** (e.g., hydroelectric, natural gas) – used to meet the variation in load. These are further categorized as
    - **intermediate load units** - used to meet most of the day-to-day variable demand;
    - **peaking units –** used to meet the peak demand and often run less than a few hundred hours per year.

Power Plant Classification

- In addition, electric utilities must keep additional plants available to meet unforeseen increases in demand, losses of conventional plants or transmission lines. This class of responsive reserves is referred to as **operating reserves**.
- Frequency regulation and contingency reserves are among a larger class of services referred to as **ancillary services**, which require units that can rapidly change output.

Power Plant Classification



Spinning Reserves

- Because of the rapid response needed by both regulation and contingency reserves, a large fraction of these reserves are provided by plants that are online and “spinning” - referred to as **spinning reserves**.
  - Spinning reserves are provided by partially loaded power plants.
  - The need for reserves increases the cost and decreases the efficiency of an electric power system compared to a system that is perfectly predictable.

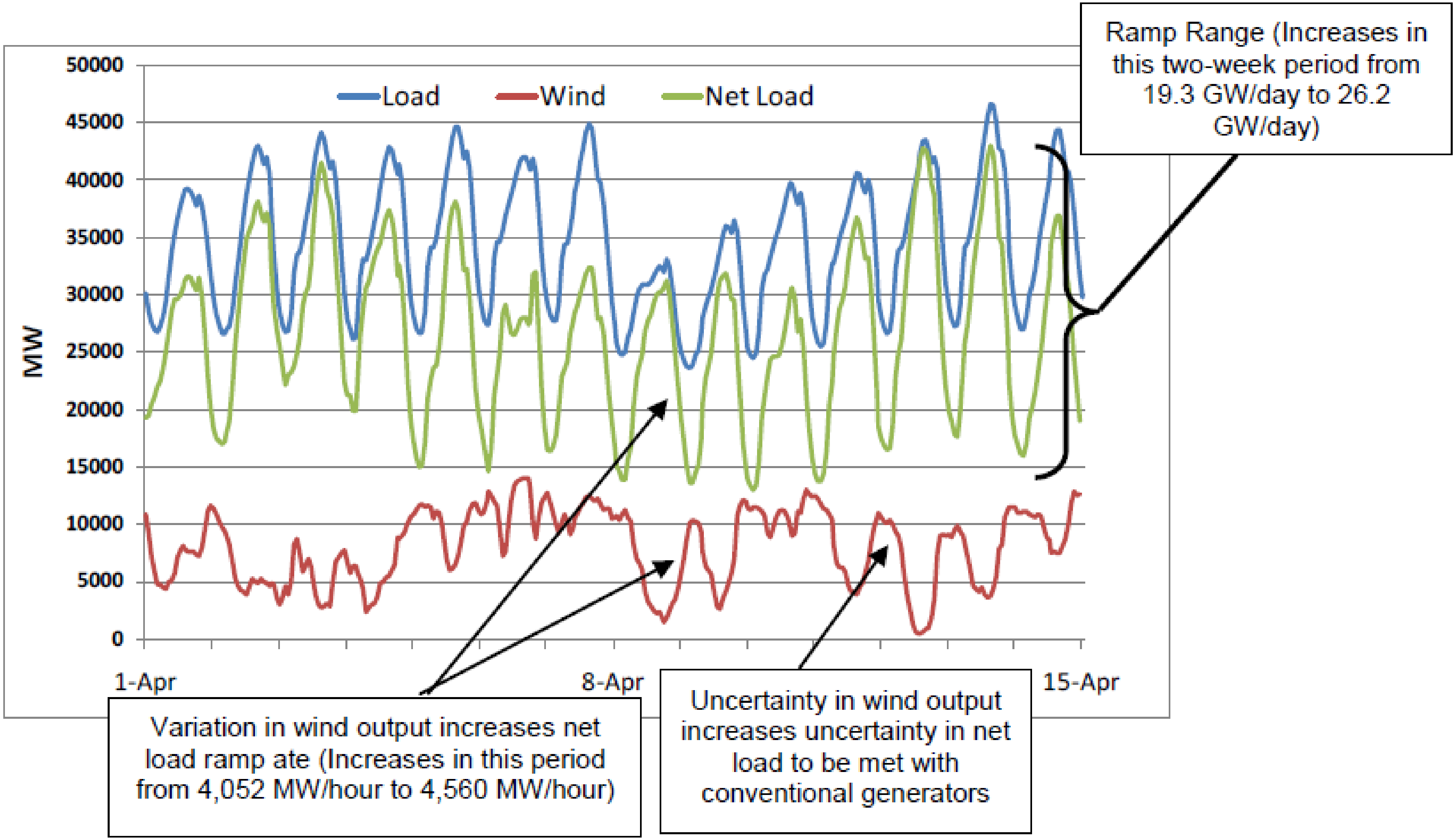
Adding variable generation (VG) to the mix

- 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.

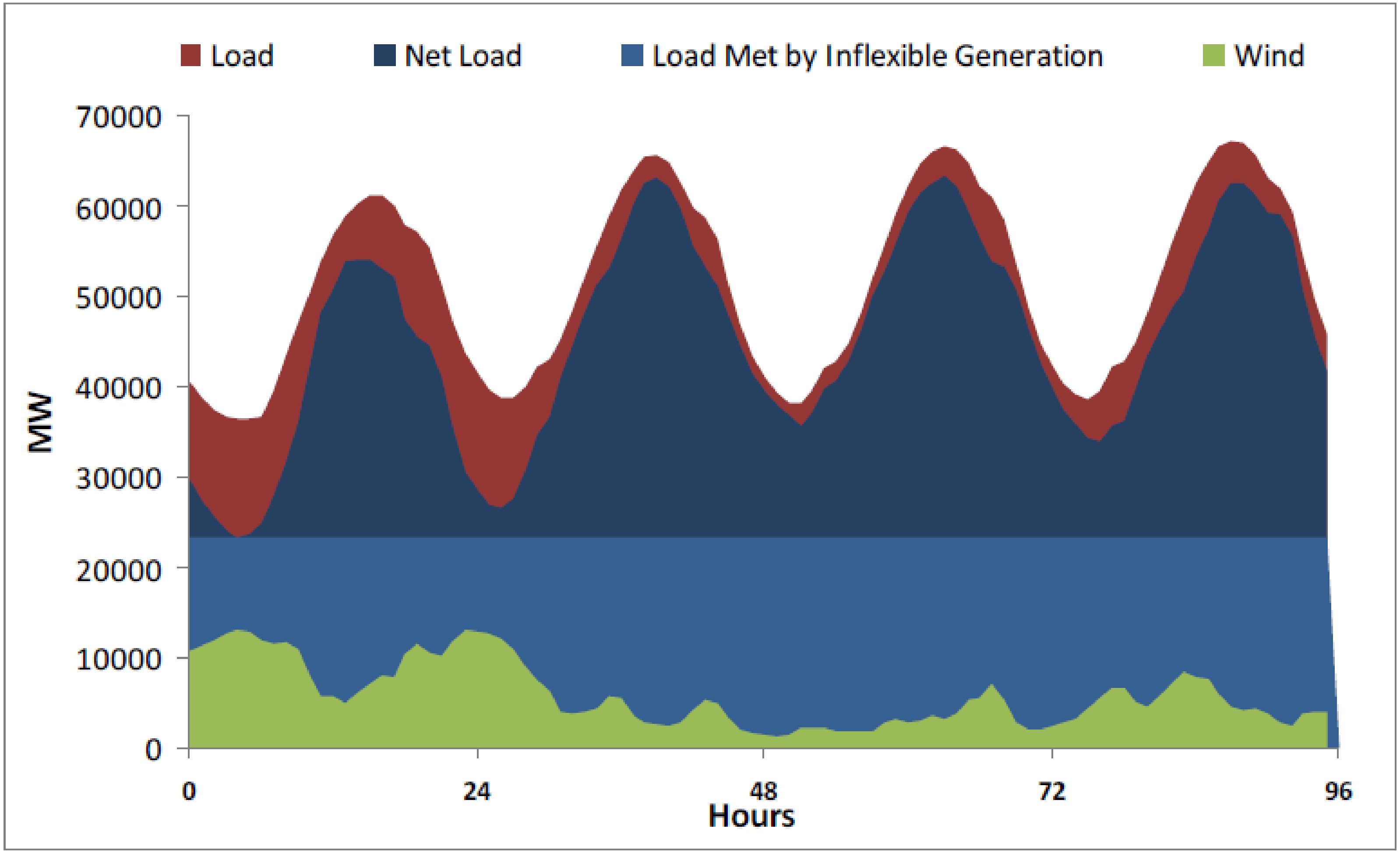
Impact of Variable Generation (VG)

- There are four significant impacts that change how the system must be operated and affect costs.
  - increased need for frequency regulation, because VG can increase the short term variability of the net load.
  - increase in the ramping rate, or the speed at which load-following units must increase and decrease output.
  - increase in overall ramping range – the difference between the daily minimum and maximum demand.
  - uncertainty in VG resource and resulting net load.

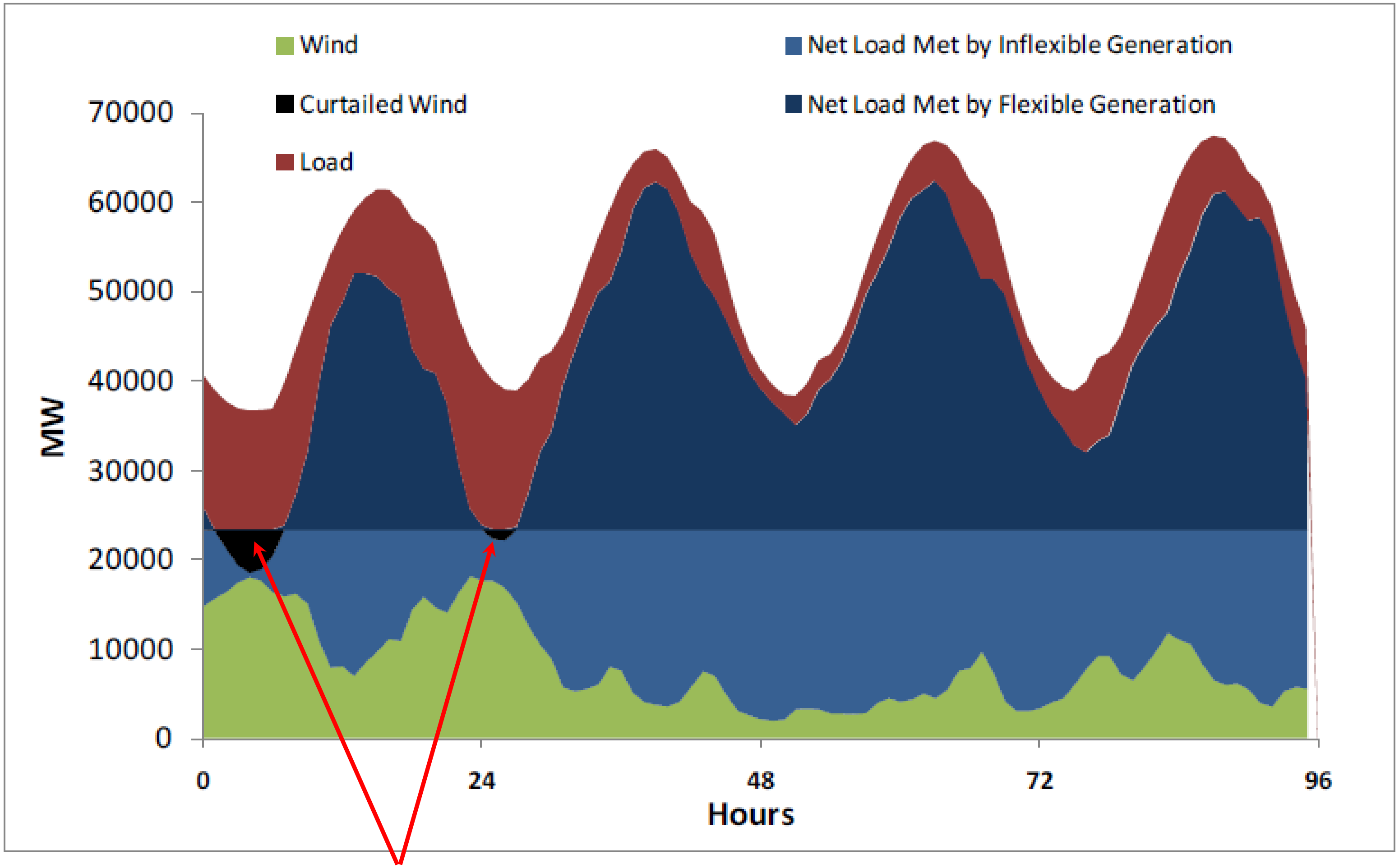
Impact of net load from increased use of VG



Dispatch with low VG penetration (8.5% of wind penetration)

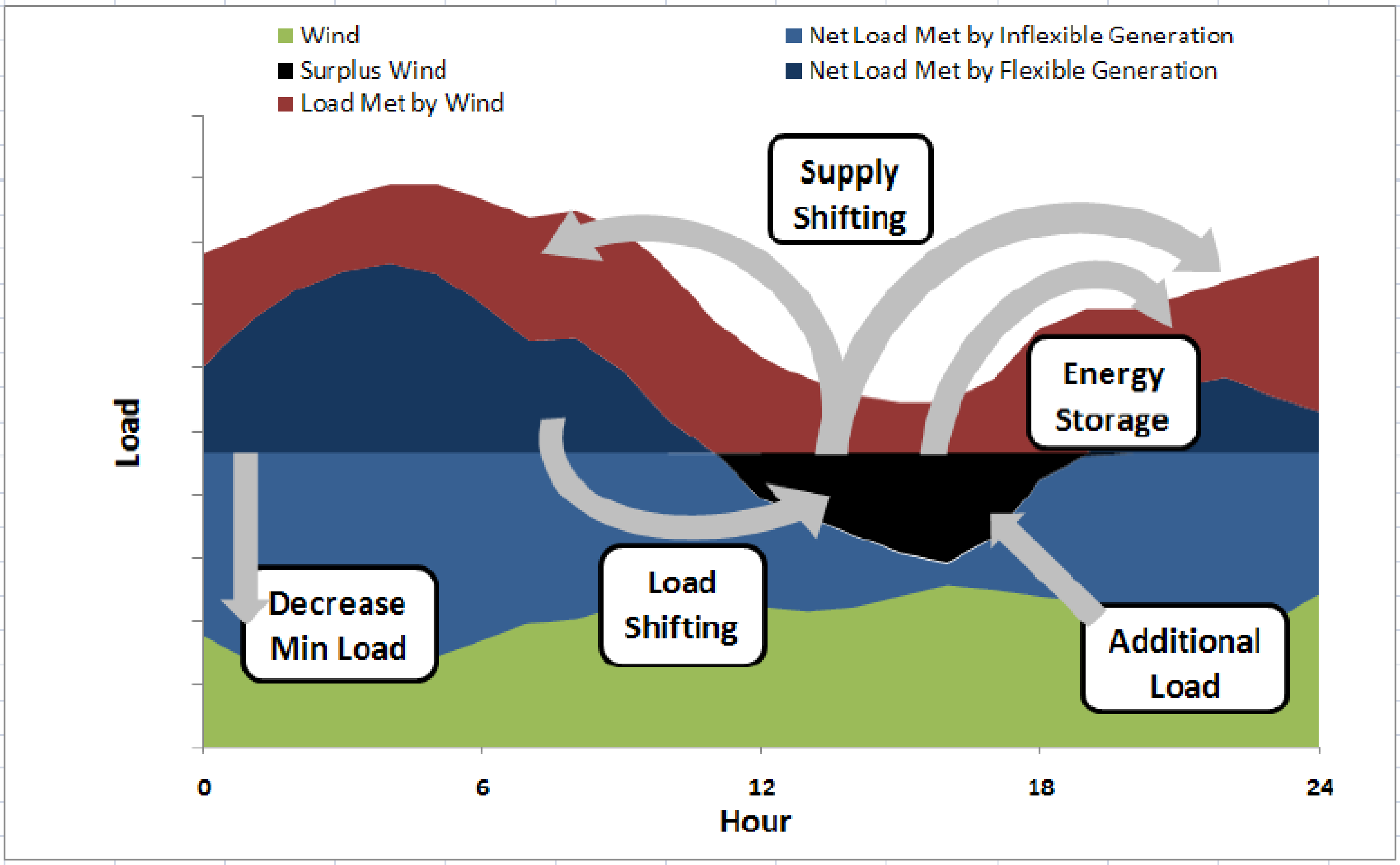


Dispatch with higher VG penetration (16% of wind penetration)

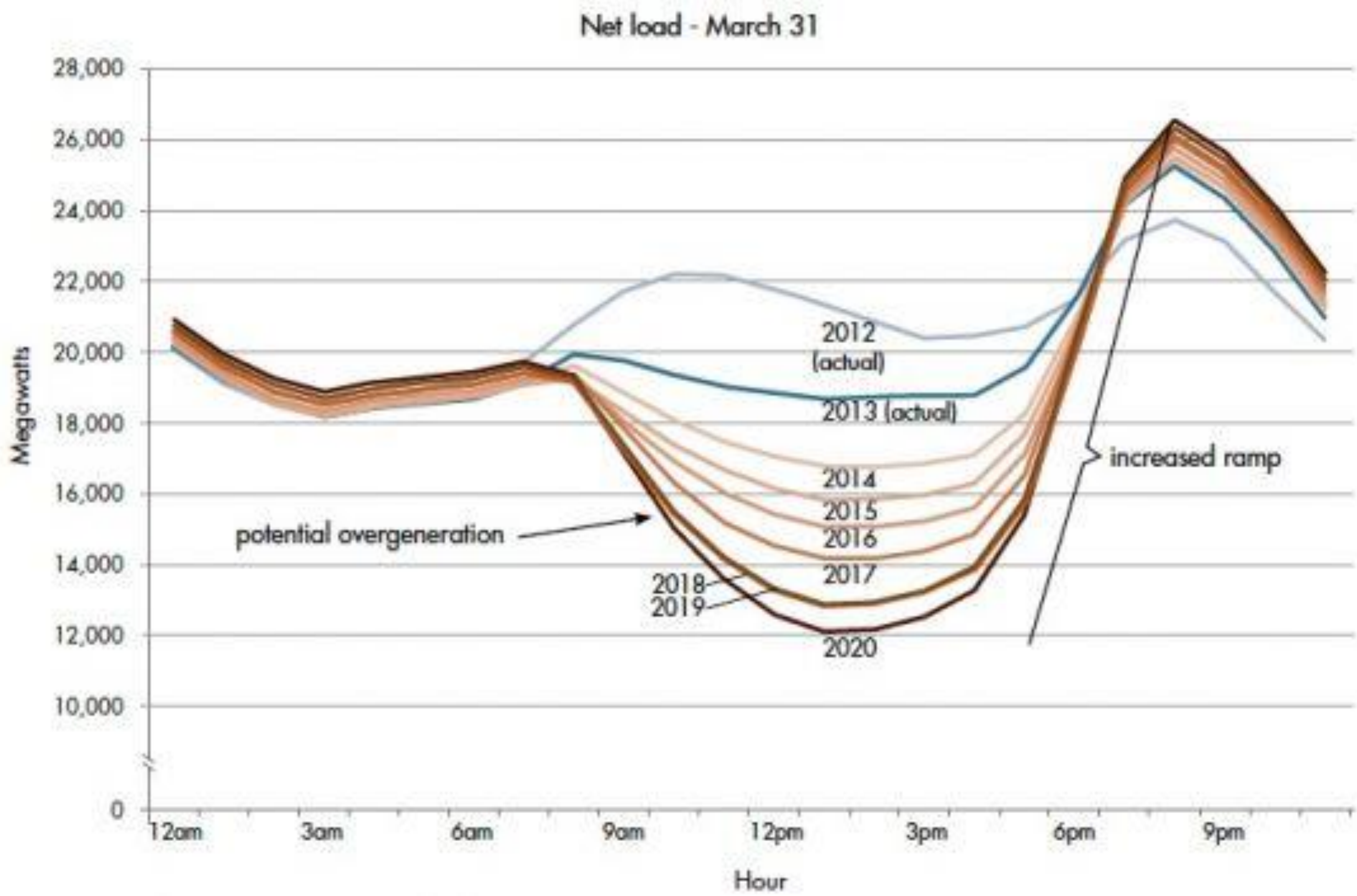


Displacement of units that are not traditionally cycled - may require VG curtailment.

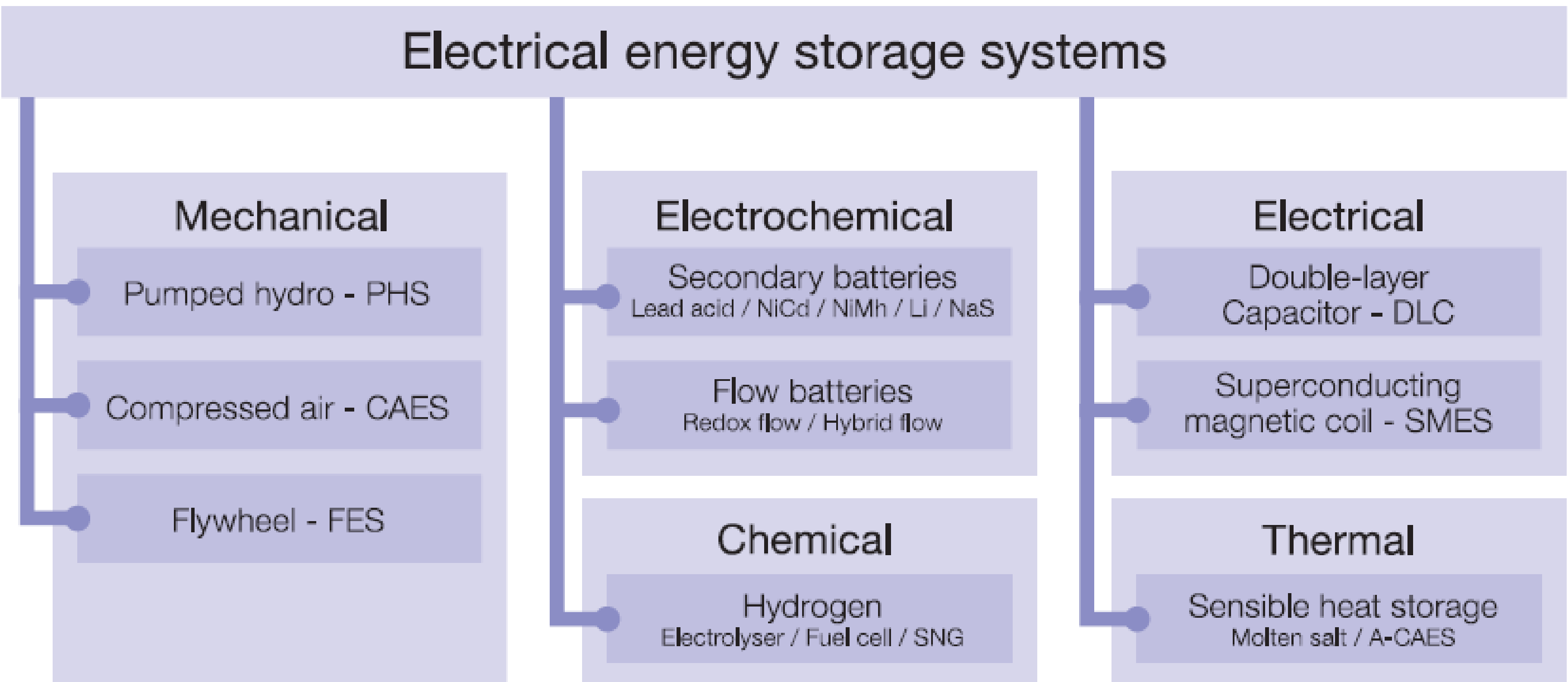
Options of decreasing VG curtailment



California "Duck Curve"
(Impact of high PV Penetration on Load Curve)



Classification of Energy Storage Systems

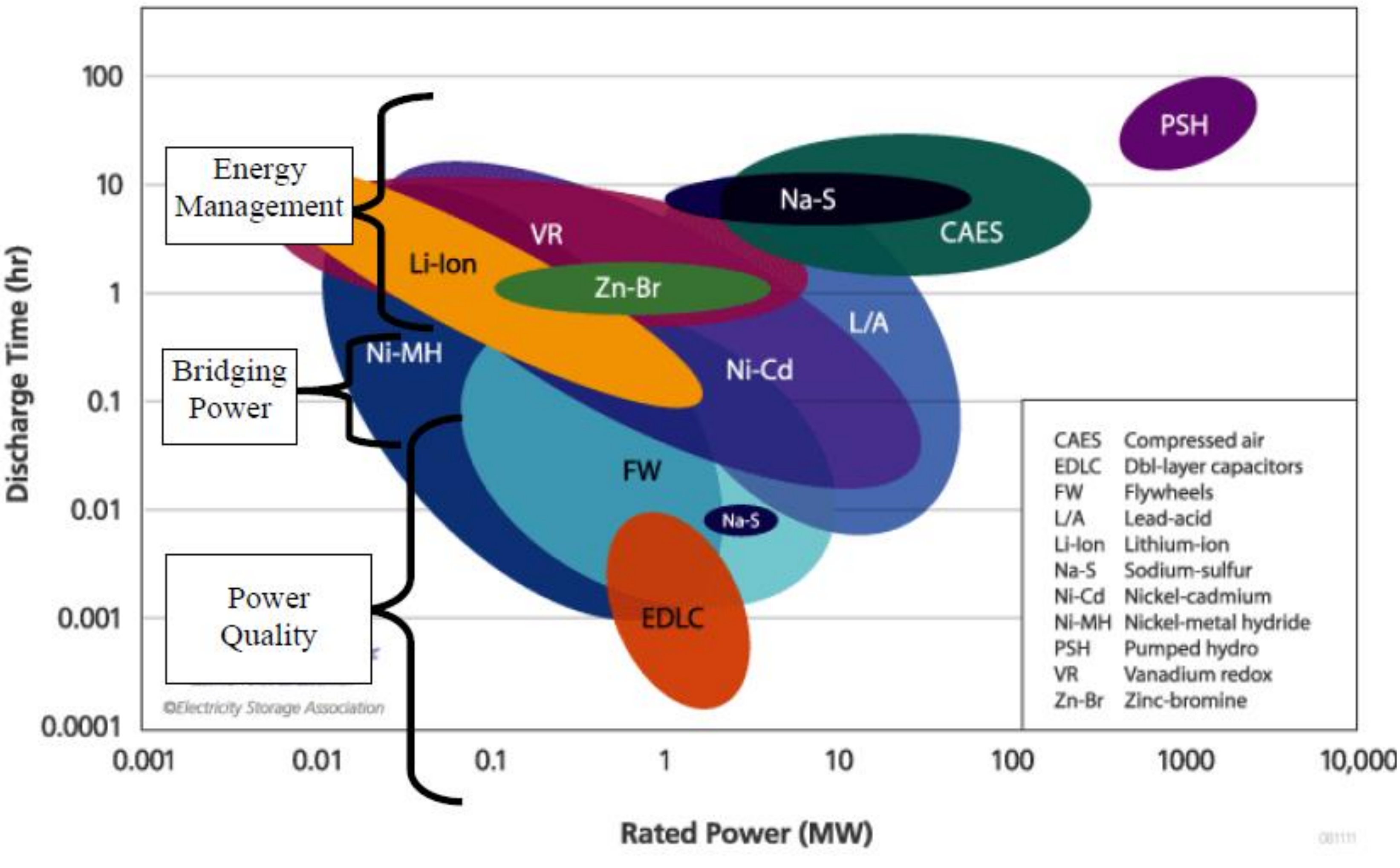


Classes of Energy Storage

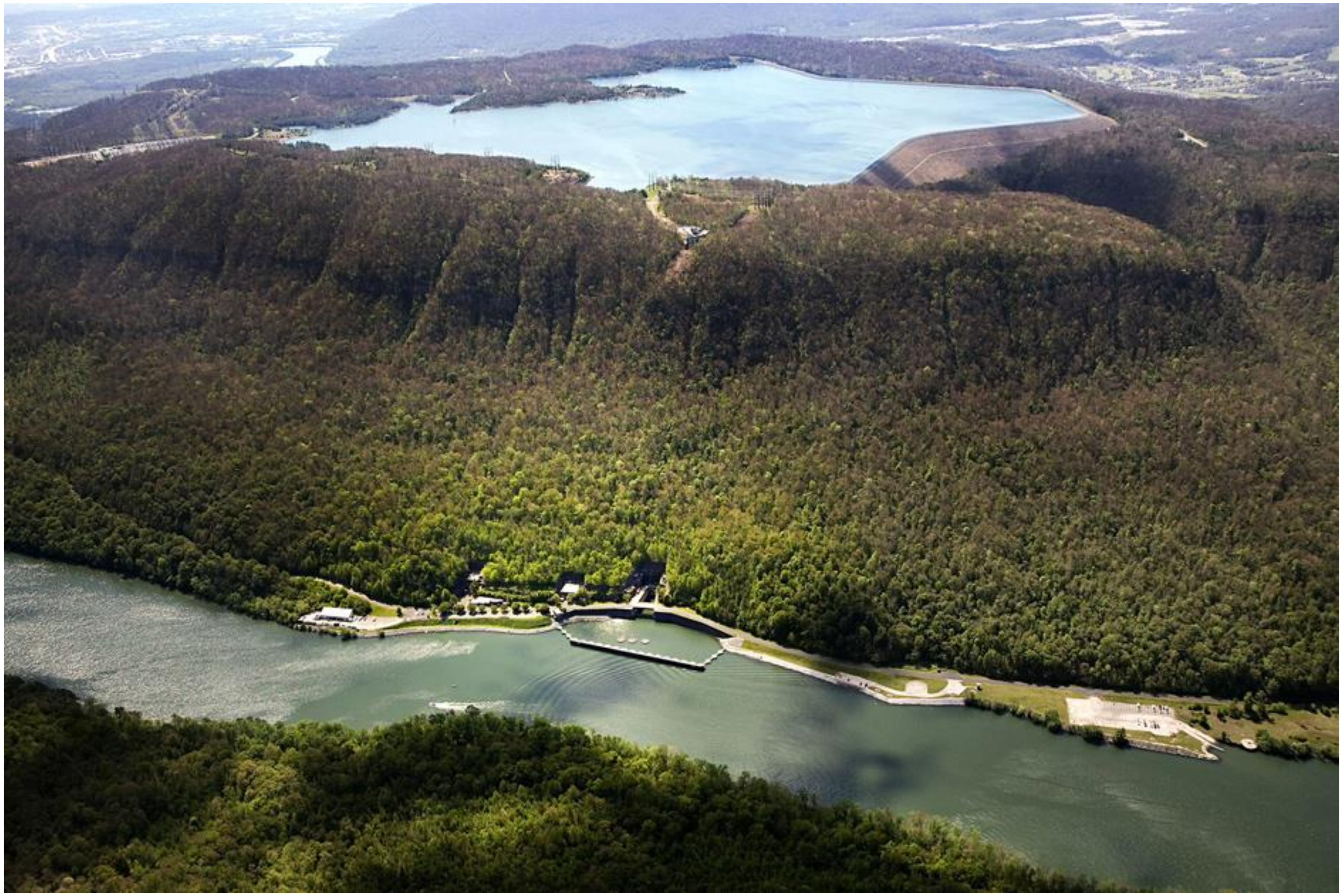
- The choice of an energy storage device depends on its application in either the current grid or in the renewables/VG-driven grid; these applications are largely determined by the length of discharge.

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

Energy Storage Technologies



Traditional energy storage: pumped hydro

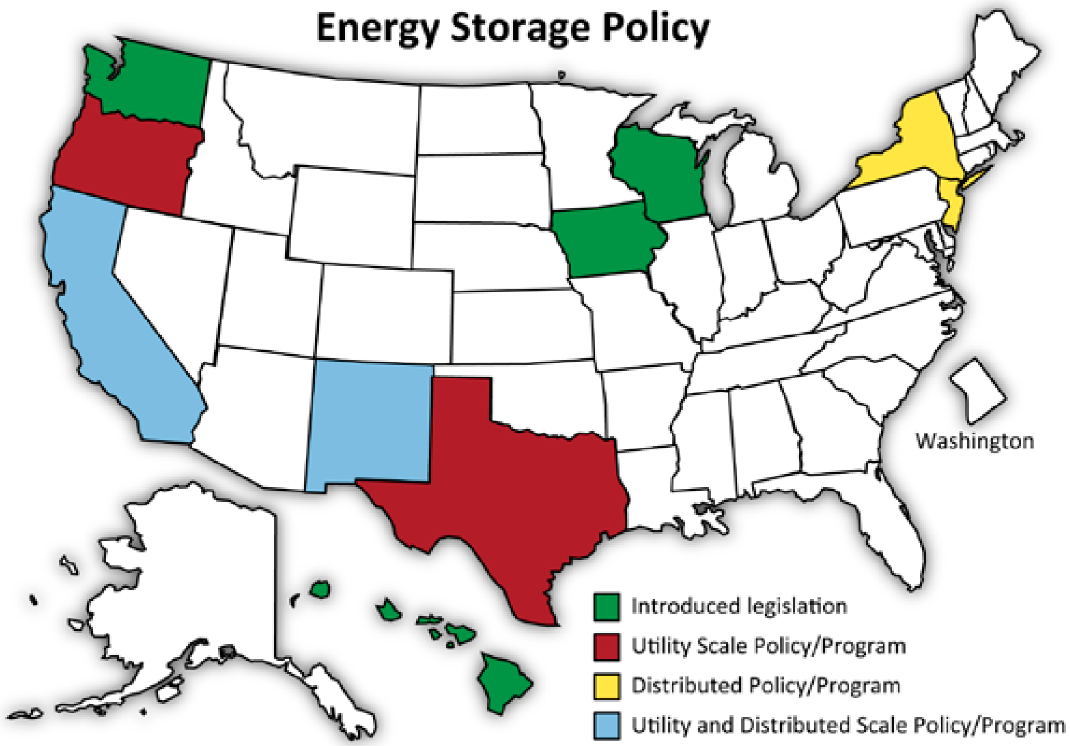


Role of energy storage

- Energy Storage Systems (ESS) have long been recognized as an effective way to alleviate the grid concerns due to their ability to quickly absorb or generate power.
  - This has led a number of states to create bills which require the procurement of ESS by a certain date.
- However, storage systems are rather expensive, and a utility or customer might not be guaranteed to achieve a desired return on its investment.
  - In order to justify their cost, other applications of ESS such demand-side management, or other ancillary services are being considered.

Energy Storage Policies in US

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

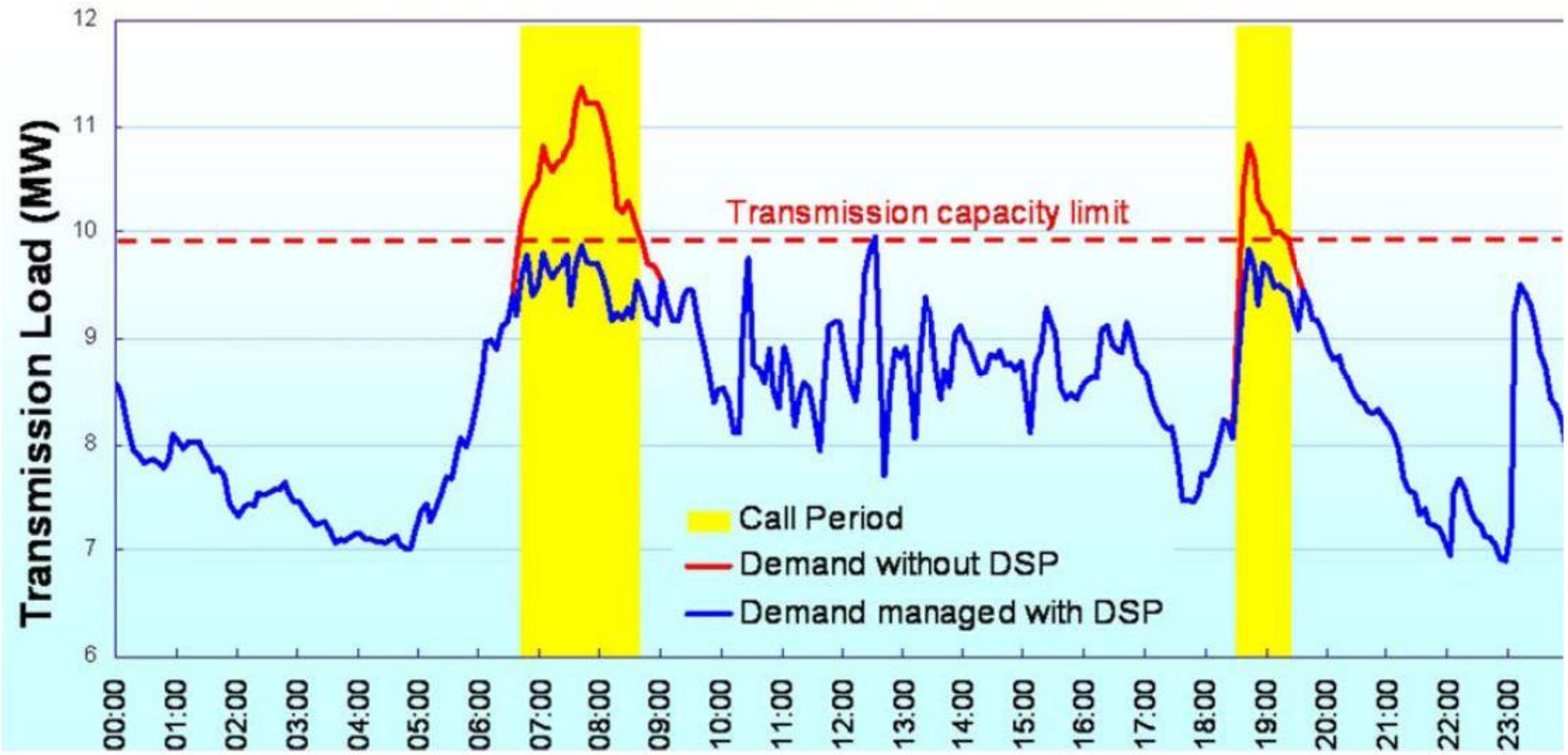


Energy Storage Applications

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

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

Deferral of Transmission investment



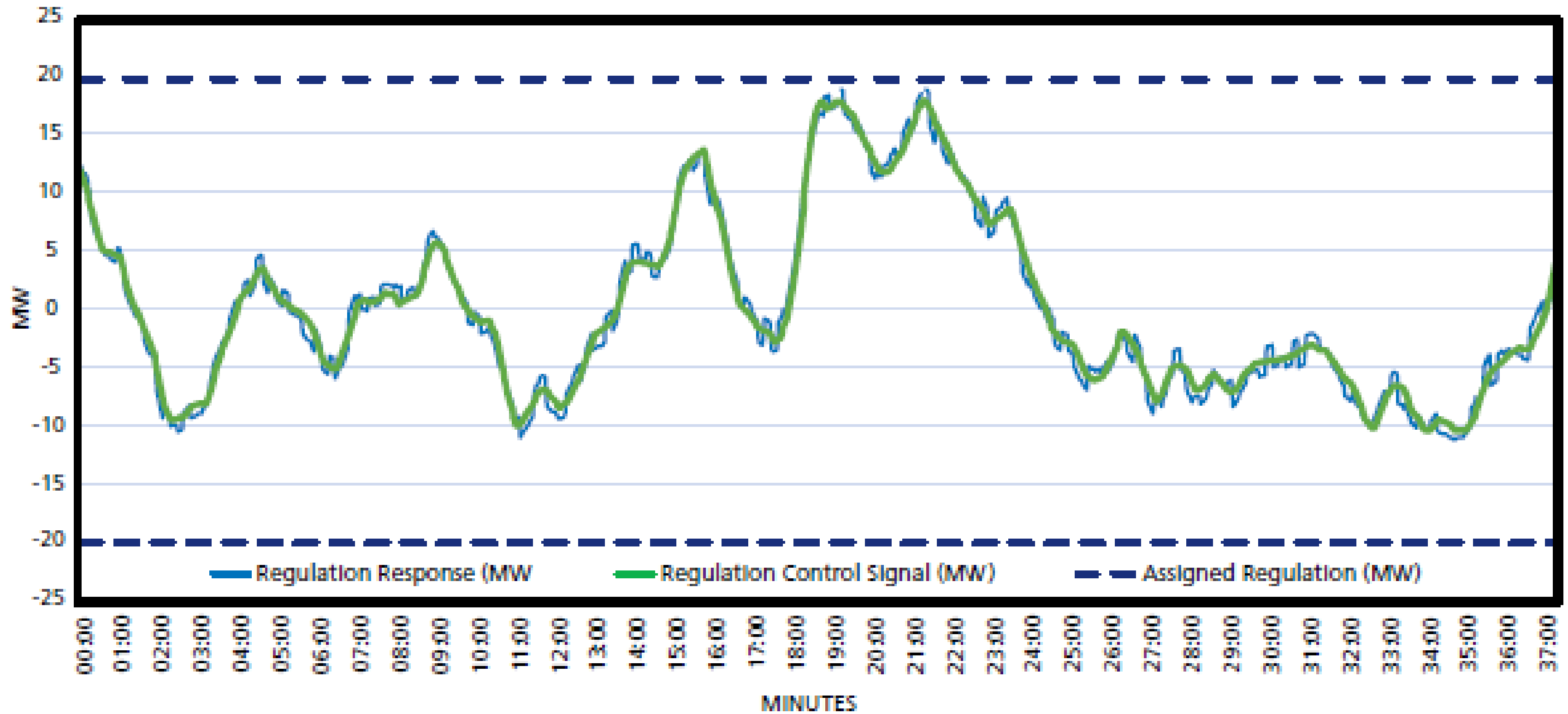
A 34-MW, 245-MWh Na-S battery installation in Japan

Battery Energy Storage Operational Capacity

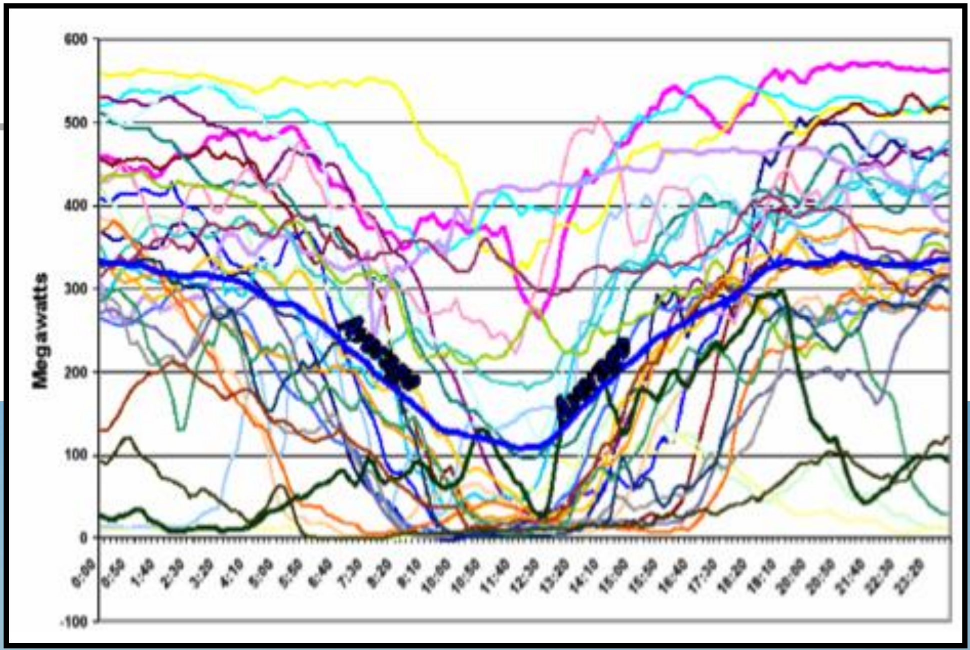
eDF renewable energy

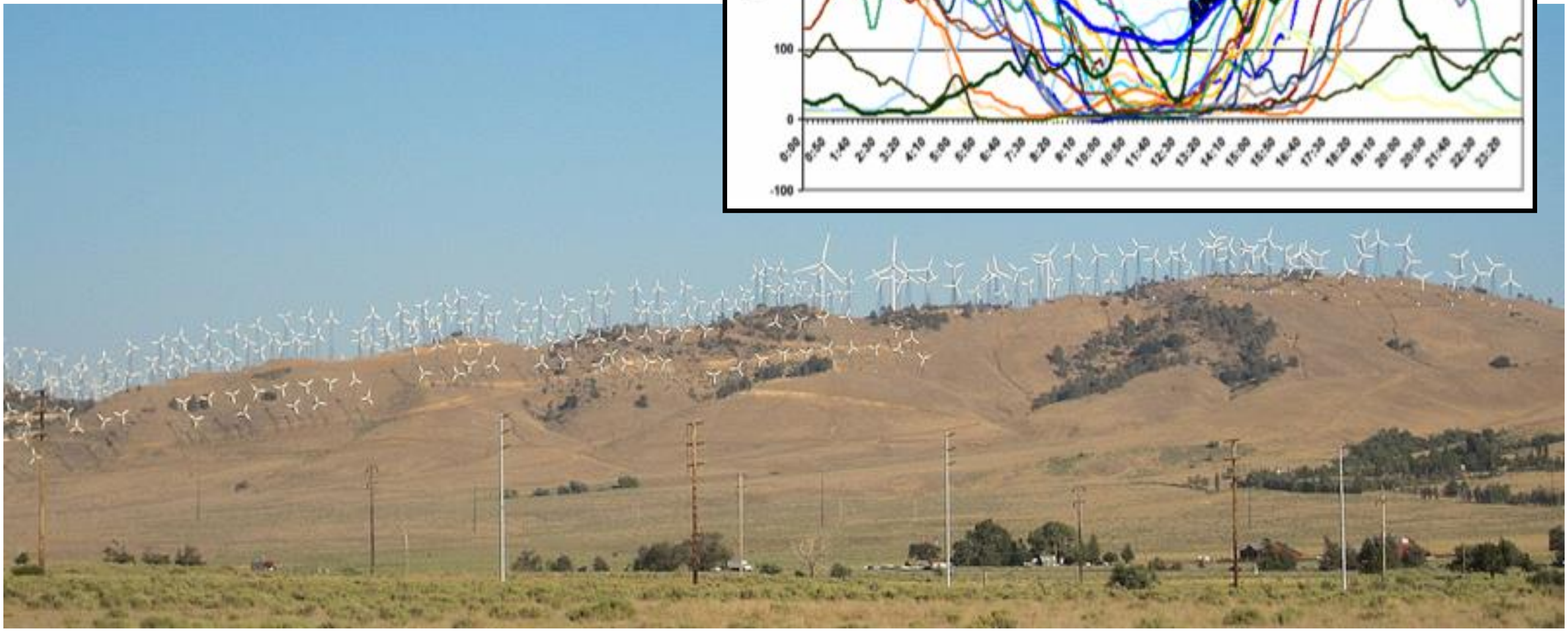
15445 Innovation Drive
San Diego, CA 92128

www.edf-re.com



Tehachapi wind farm (Capacity: 4,500 MW)

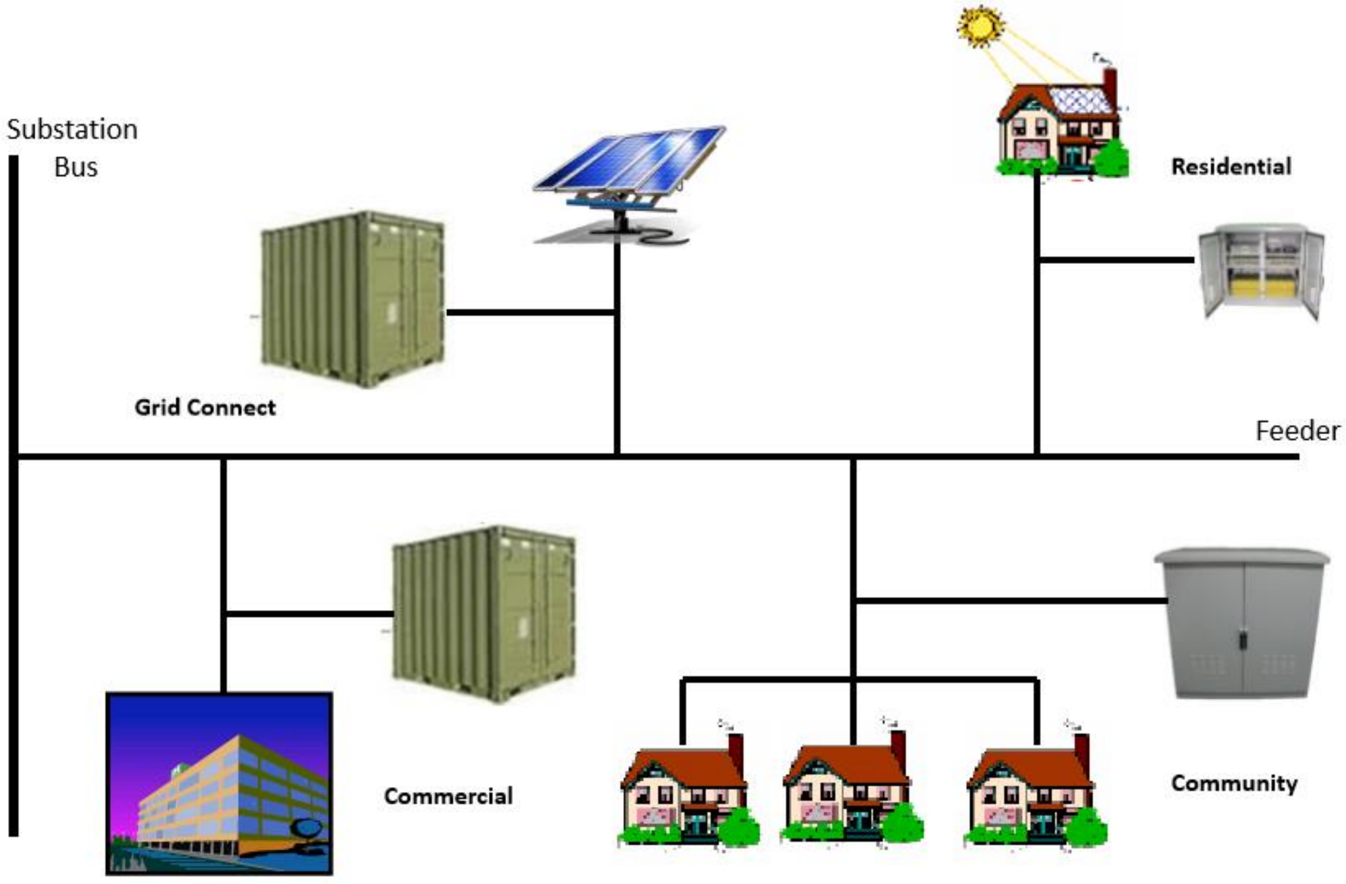




Large-Scale BESS Installations

- 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)

PERFORMANCE SPECIFICATIONS

AC Voltage (Nominal)	208 V, 220 V, 230 V, 277 V, 100/200 V, 120/240 V
Feed-In Type	Single & Split-Phase
Grid Frequency	50 and 60 Hz
AC Energy[1]	13.2 kWh
Real Power, max continuous[2]	5 kW (charge and discharge)
Real Power, peak (10 s)[2]	7 kW (discharge only)
Apparent Power, max continuous[2]	5.8 kVA (charge and discharge)
Apparent Power, peak (10 s)[2]	7.2 kVA (discharge only)
Imbalance for Single-Phase Loads	100%
Power Factor Output Range	+/– 1.0 adjustable
Power Factor (full-rated power)	+/– 0.85
Depth of Discharge	100%
Internal Battery DC Voltage	50 V
Round Trip Efficiency[1,3]	89.0%
Warranty	10 years

Residential Applications

Fronius Solar Battery 4.5
Fronius Solar Battery 6.0
Fronius Solar Battery 7.5
Fronius Solar Battery 9.0
Fronius Solar Battery 10.5
Fronius Solar Battery 12.0

Residential Applications

SUNNY BOY
3600 / 5000 SMART ENERGY

THE PERFECT COMBINATION OF PV INVERTER AND BATTERY

It comes with everything. The new Sunny Boy Smart Energy forms part of the SMA Integrated Storage Solution and is currently the easiest solution for typical household PV applications. This combination of a modern PV inverter and a battery with an effective capacity of 2 kWh not only optimizes increased self-consumption but also makes easy use of home-generated solar power possible virtually around the clock.

MERCEDES-BENZ ENERGY STORAGE SYSTEM

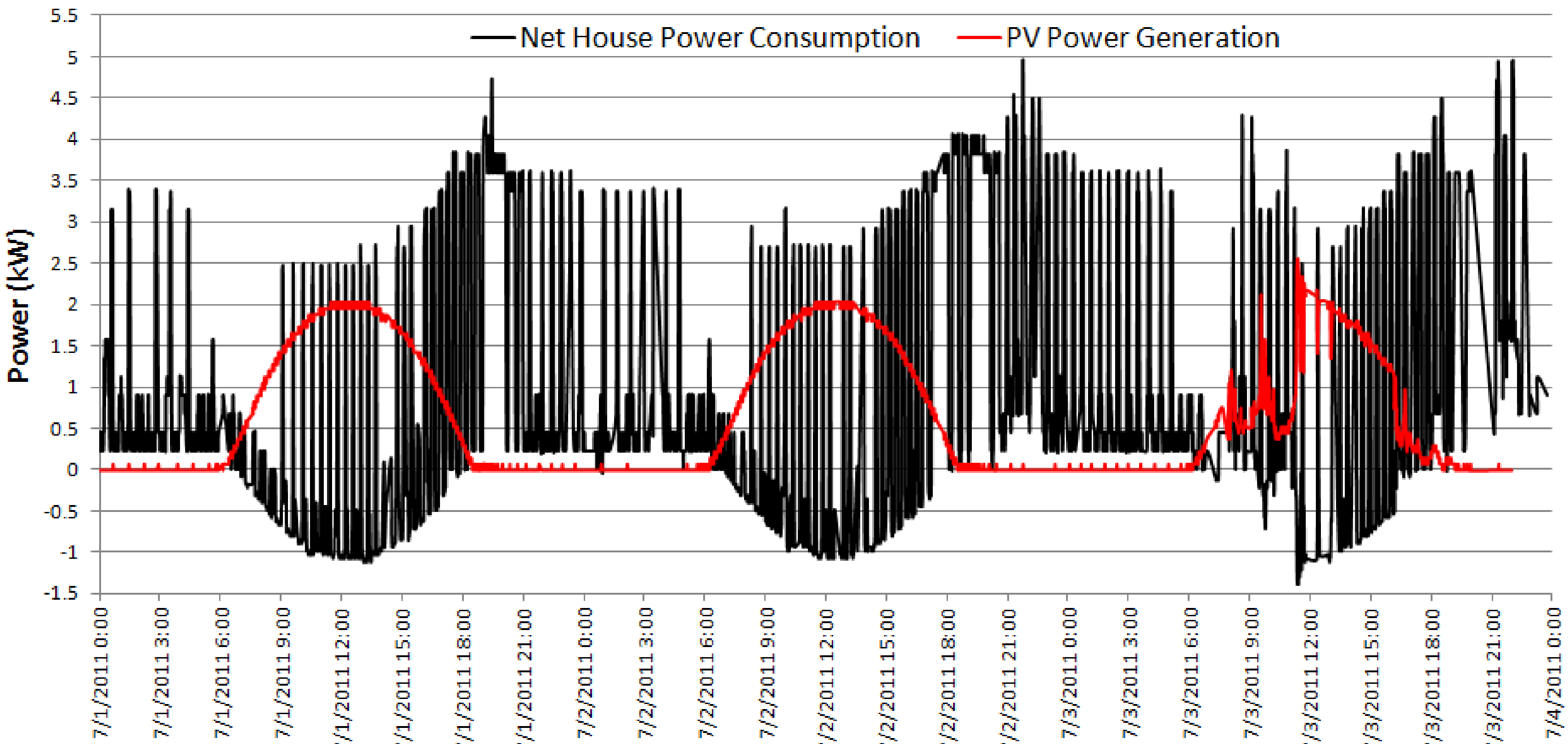
The Mercedes-Benz energy storage system offers a particularly long service life with the very safe lithium-ion technology, in the usual Mercedes-Benz "Made in Germany" quality. Wall and free-standing assembly are possible. Thanks to its modular and expandable system structure, the Mercedes-Benz energy storage system is perfectly suited for private homes and can be adapted to individual needs (2.5 – 20 kWh).

Residential Applications

Bombard-Adera (local company)

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…

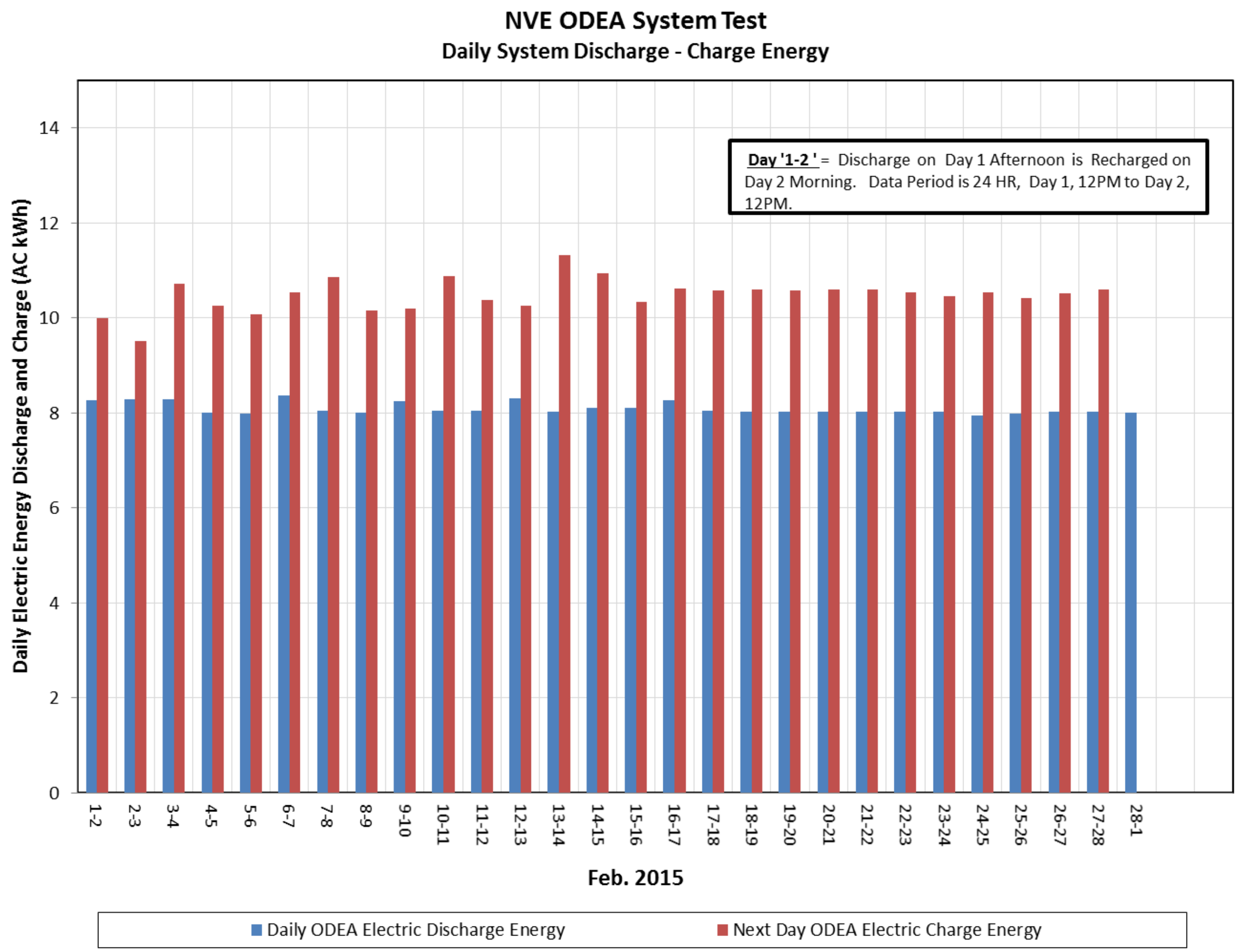
4.5 kW/10 kWh Residential BESS

BESS Specifications

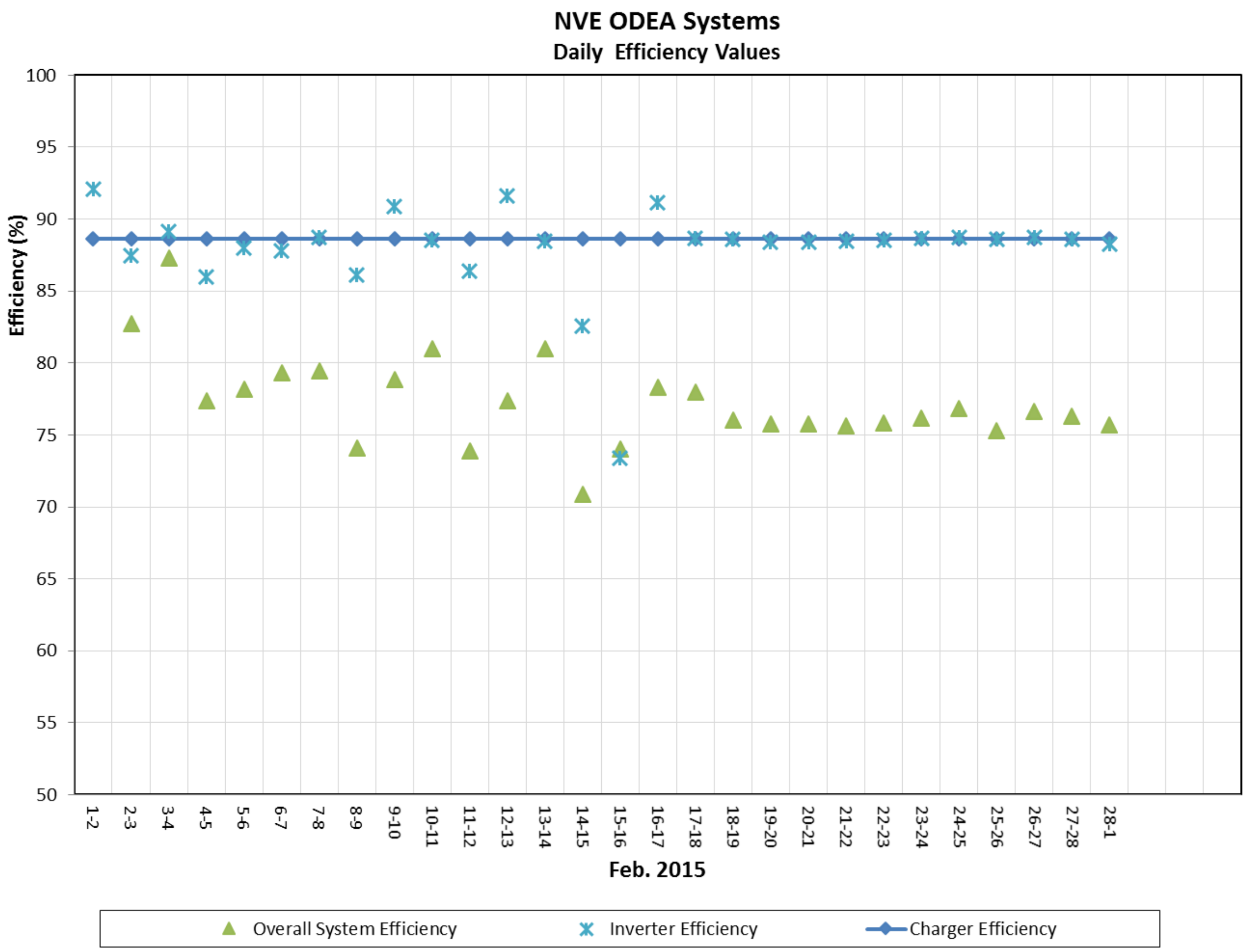
AC Electrical Specifications		
Model	SIS-6048-X	SIS-4548-X
Continuous Output Power	6,000 W	4,500 W
Surge Rating (10 Seconds)	12,000 W	9,000 W
AC Voltage	120/240 Vac Split-Phase	
Surge Current	105 A-L-N (15 sec) 52.5 A-L-L (15 sec)	75.5 A-L-N (20 sec) 40 A-L-L (20 sec)
AC Inputs (Grid | Generator)	2-60A 2-Pole: IEEE 62.41, 62.45 & 1.2x50ms, C37.90.1	
Nominal Frequency	58.5 to 60.5 Hz	
Output Waveform	True Sine Wave; Stable at 120 Vac within 4 cycles	
AC Output Voltage	L-N: 120 Vac ± 3%; L-L: 240 Vac ± 3%	
AC1 Frequency Range	59.4 to 60.4 ± 0.05 Hz (automatically adjusts)	
AC Transfer SW Speed	Isolation Contactor (30 KV BIL, 400 A continuous & interrupt 50 Ka fault duty for 2 cycles) 10 Ka Residential < 8 ms.	
Total Harmonic Distortion	< 5%	
Voltage Correction	Yes. ± 10%	
CEC Weighted Efficiency	92.5%	93.0%
Idle Consumption — Search Mode	< 8 W	
Ambient Air Temperature Operating Range	-13 to 122°F (-25 to 50°C)	
Emissions	FCC Class B	
Anti-islanding	UL1741:2005, CSA 107.1-01, Rule 21 Compliant.	
System Network	CAN BUS	
Cooling	Forced Air — Induction	
Backup Power	Yes. Configurable.	

Front View (Open Door)
72.5" high, 24.3" wide, 13.9" deep

Charge/Discharge Test

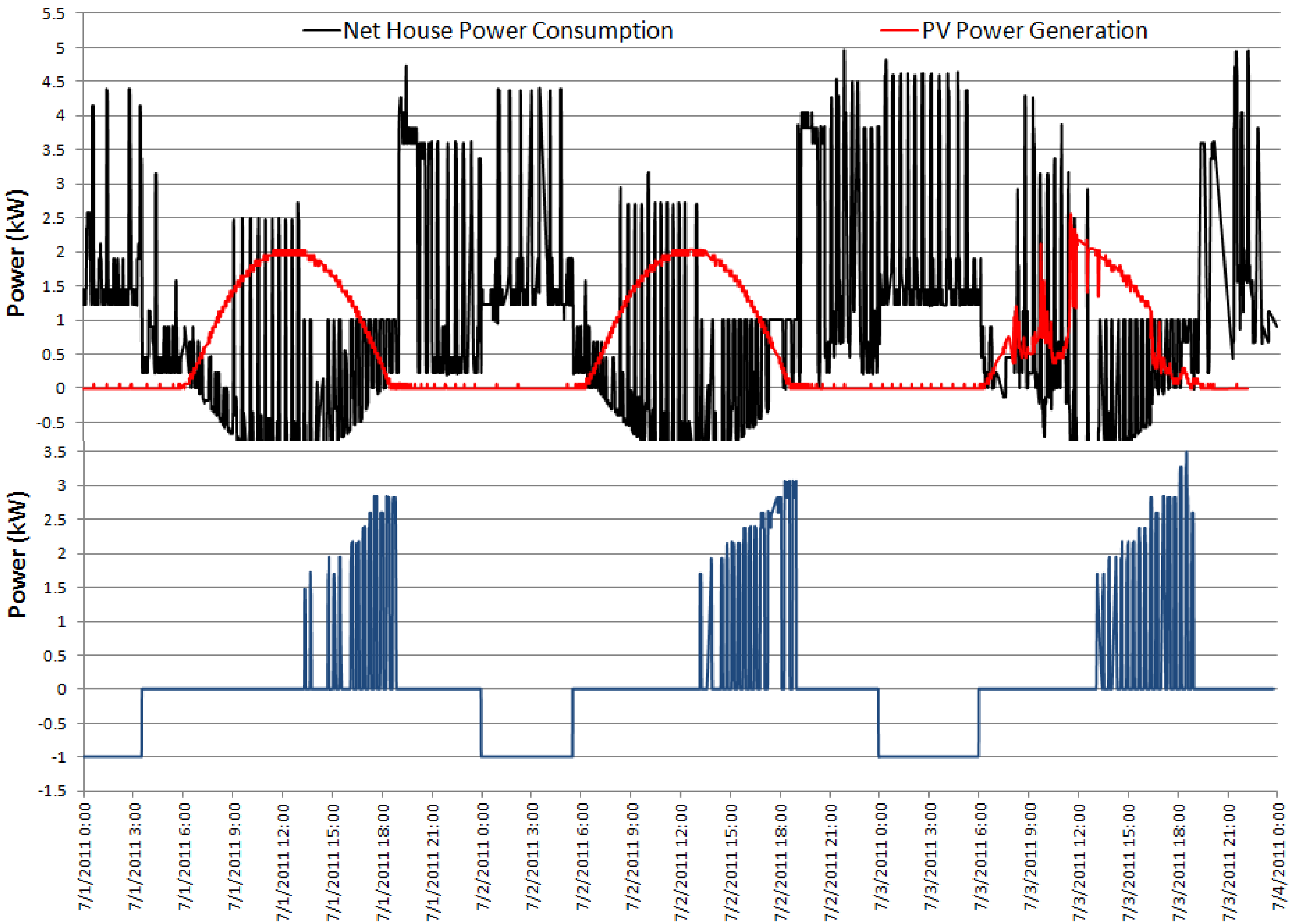


Round trip efficiency



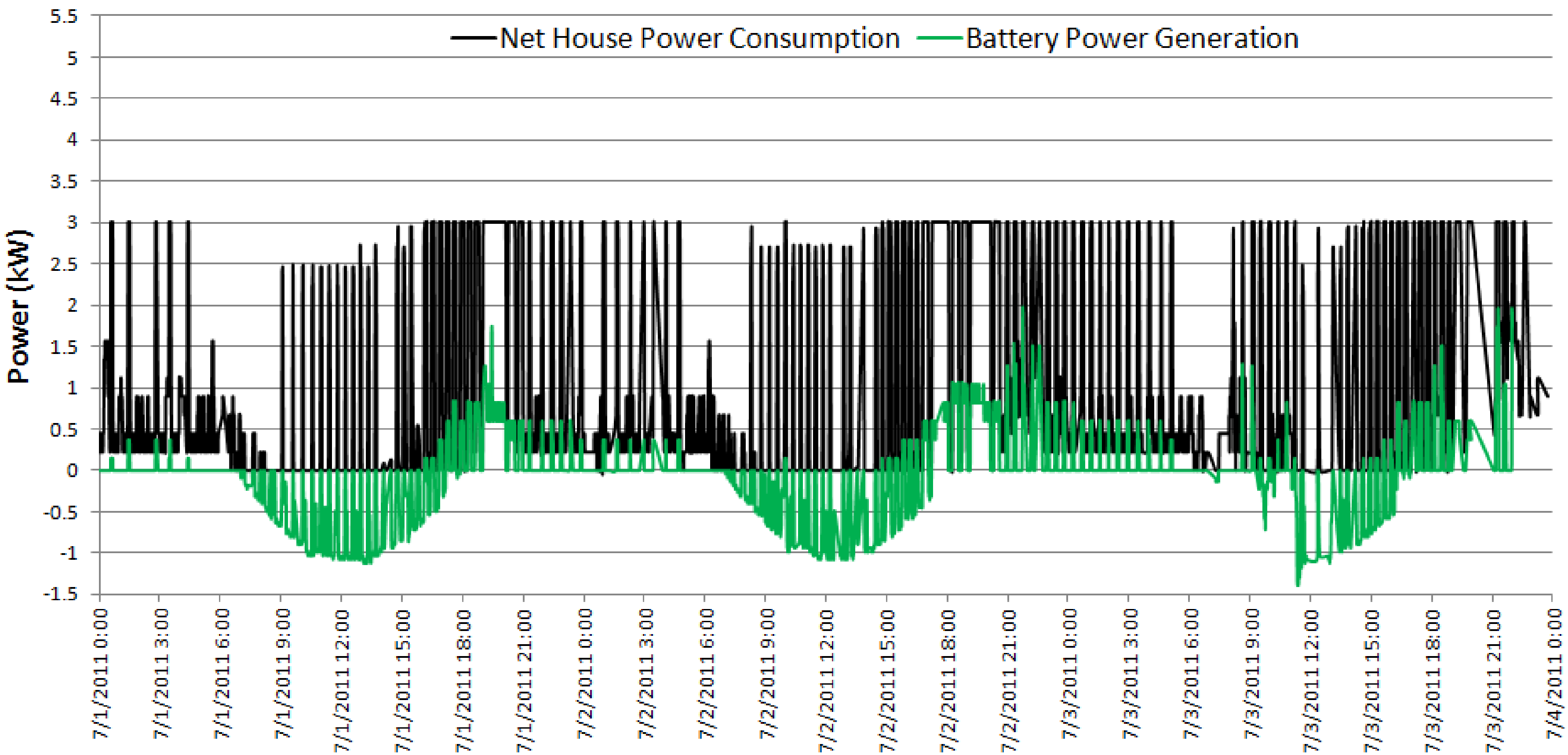
Application 1: Customer enrolled in TOU pricing

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



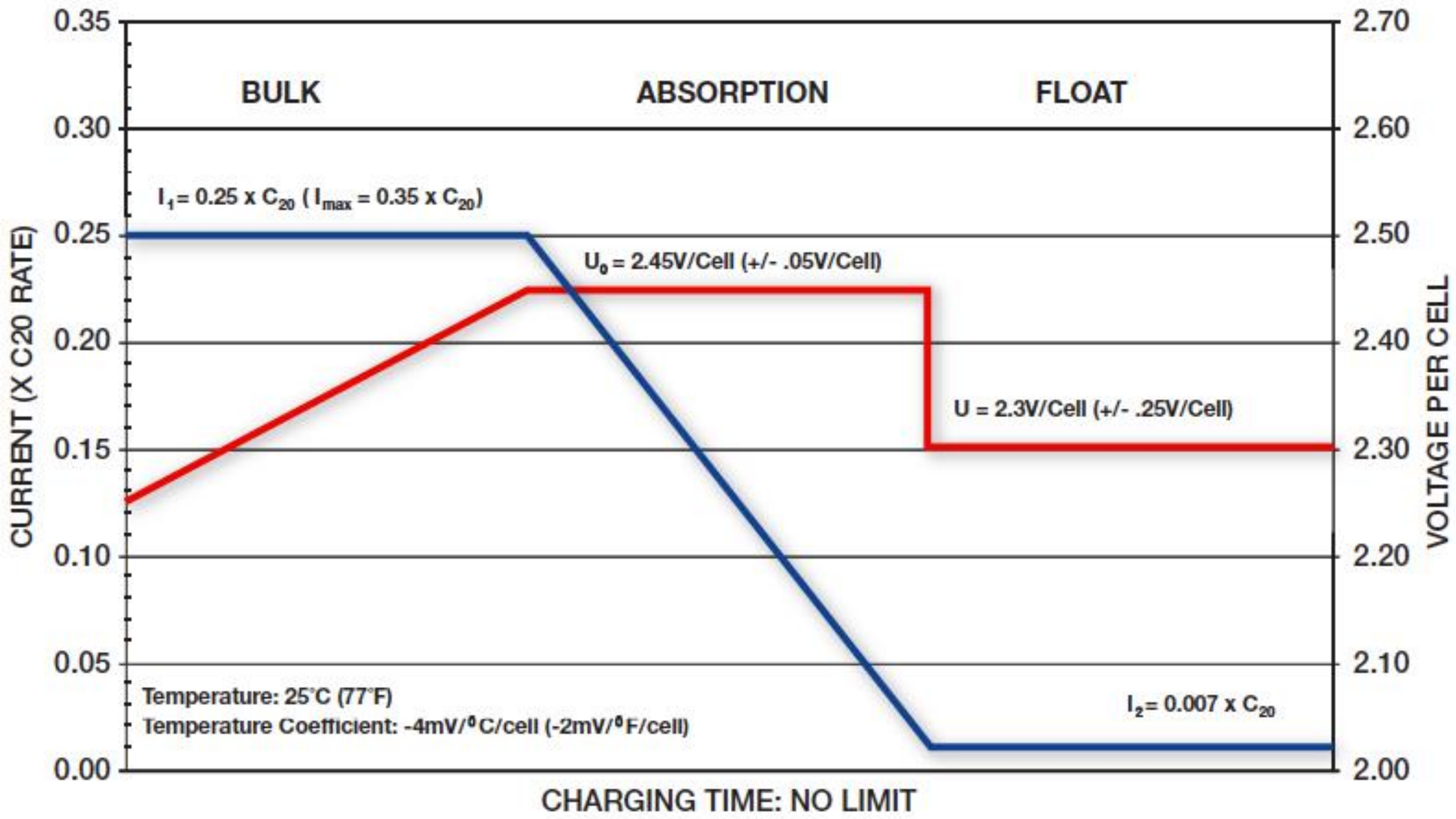
Application 2: Keep Maximum Demand Below 3 kW

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



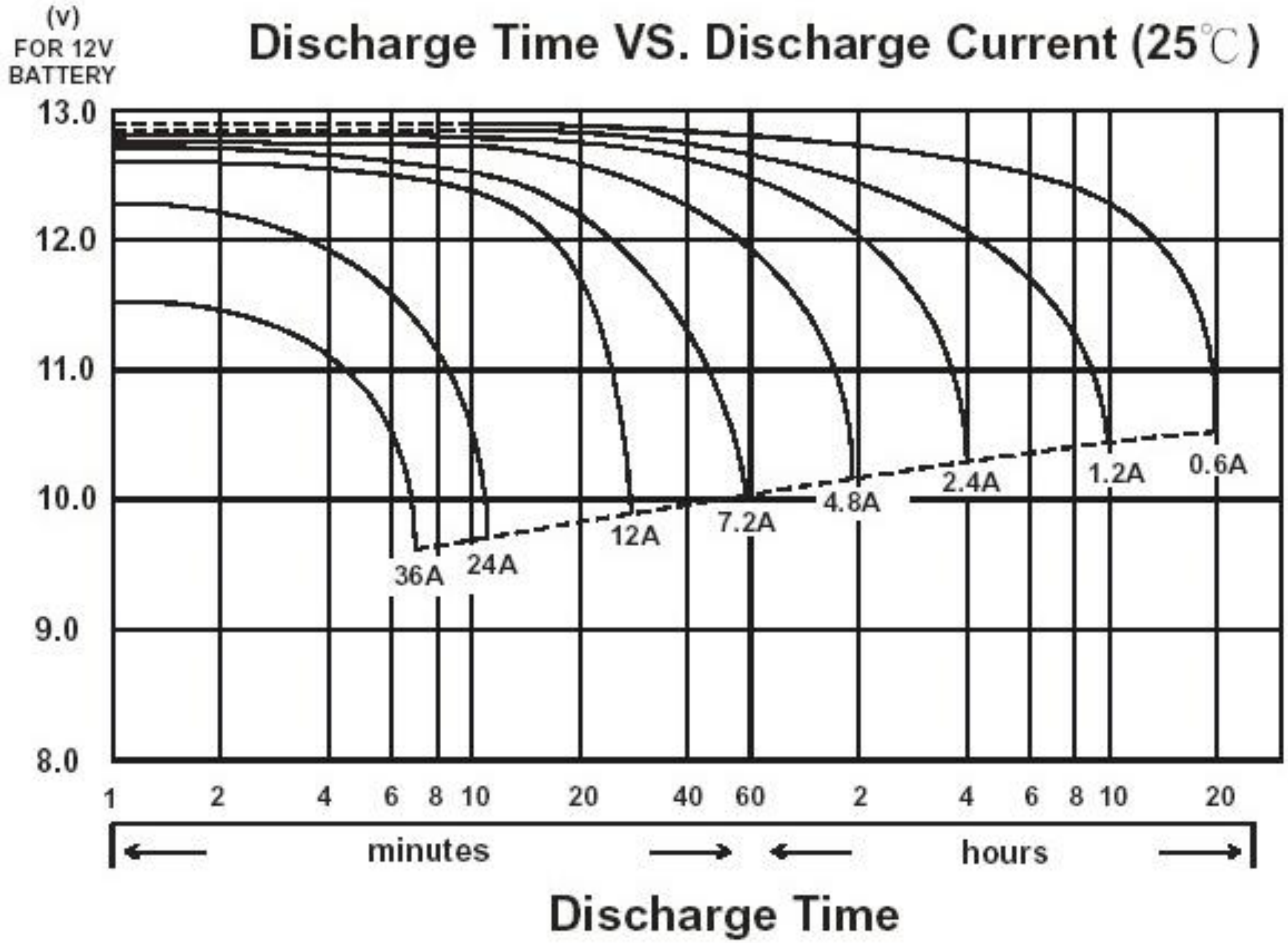
Typical battery charging curve

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



Battery discharge curves

- Battery capacity under variable discharge rate?



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

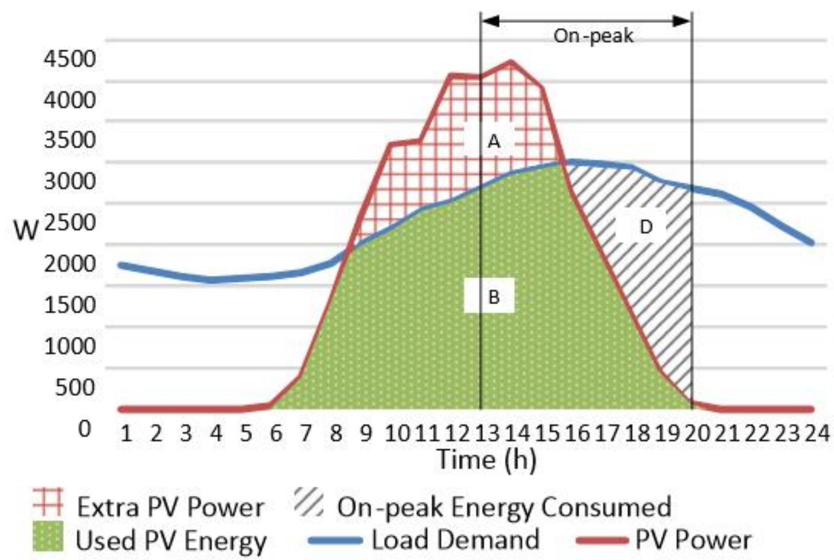


Figure 2. Daily PV energy distribution

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

Related Articles (2017)

1. Dynamic Distribution Network Reconfiguration Considering Travel Behaviors and Battery Degradation of Electric Vehicles
2. Battery Energy Storage Sizing for Commercial Customers
3. Effects of Battery Degradation on Economic Viability of Energy Storage Systems Participating in Regulation Markets
4. Battery Energy Storage Sizing With Respect To PV-Induced Power Ramping Concerns in Distribution Networks
5. Coupling a Small Battery with a Datacenter for Frequency Regulation
6. BESS Control on an Microgrid with Significant Wind Generation
7. Energy Storage Control for Dispatching Photovoltaic Power