Energy Storage Is More Than Batteries And Capacitors

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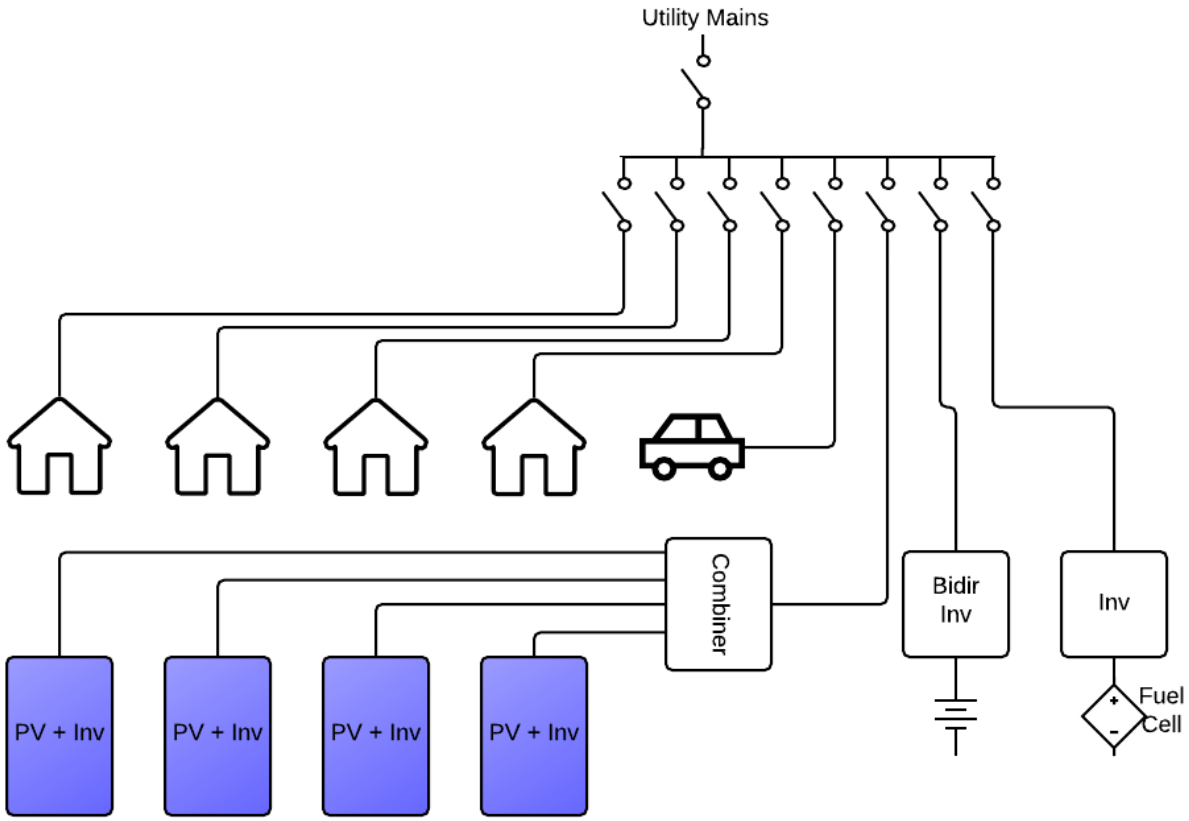
Context

- Renewable energy sources are intermittent
- Loads are stochastic
- An islanded system must maintain power balance AND energy balance
- Most grid resources have limited ramp rate and regulation capabilities

Solar Village

- Missouri S&T has competed in US Solar Decathlon five times
- Houses from 2002, 2005, 2007, 2009 form a village
  - 2013, 2015 houses in new village
- All four houses in the village are rented and occupied

Microgrid


Utility Mains
Combiner
Bidir Inv
Inv
Fuel Cell
PV + Inv
PV + Inv
PV + Inv
PV + Inv

General Specifications

- Four houses, each ~750 sq. ft.
- Total 21 kW PV
- 5 kW Fuel Cell
- 60 kWh, 50 kVA max, 22 kW continuous $LiFePO_4$ battery

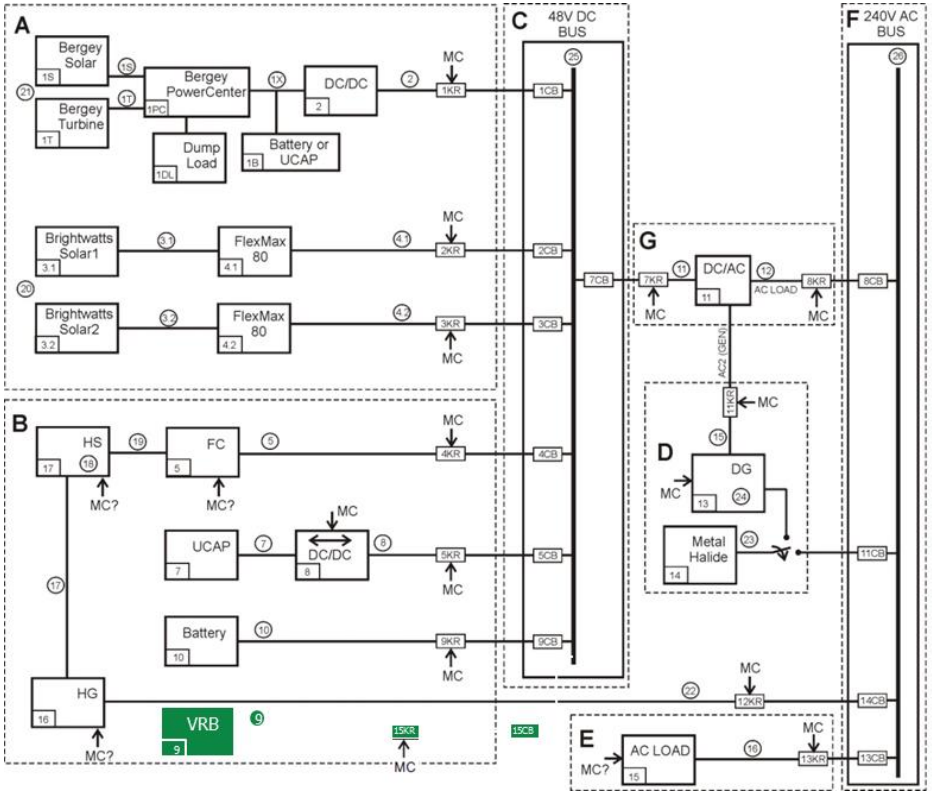
Why?

- Buy energy at retail, sell at avoided cost rate
  - Better to store energy than to sell it!
- Possibility of operating islanded
  - Power quality, availability

Microgrid @ FLW

- Fort Leonard Wood has a demo forward operating base
- Microgrid project to demo generation, storage concepts

System Architecture

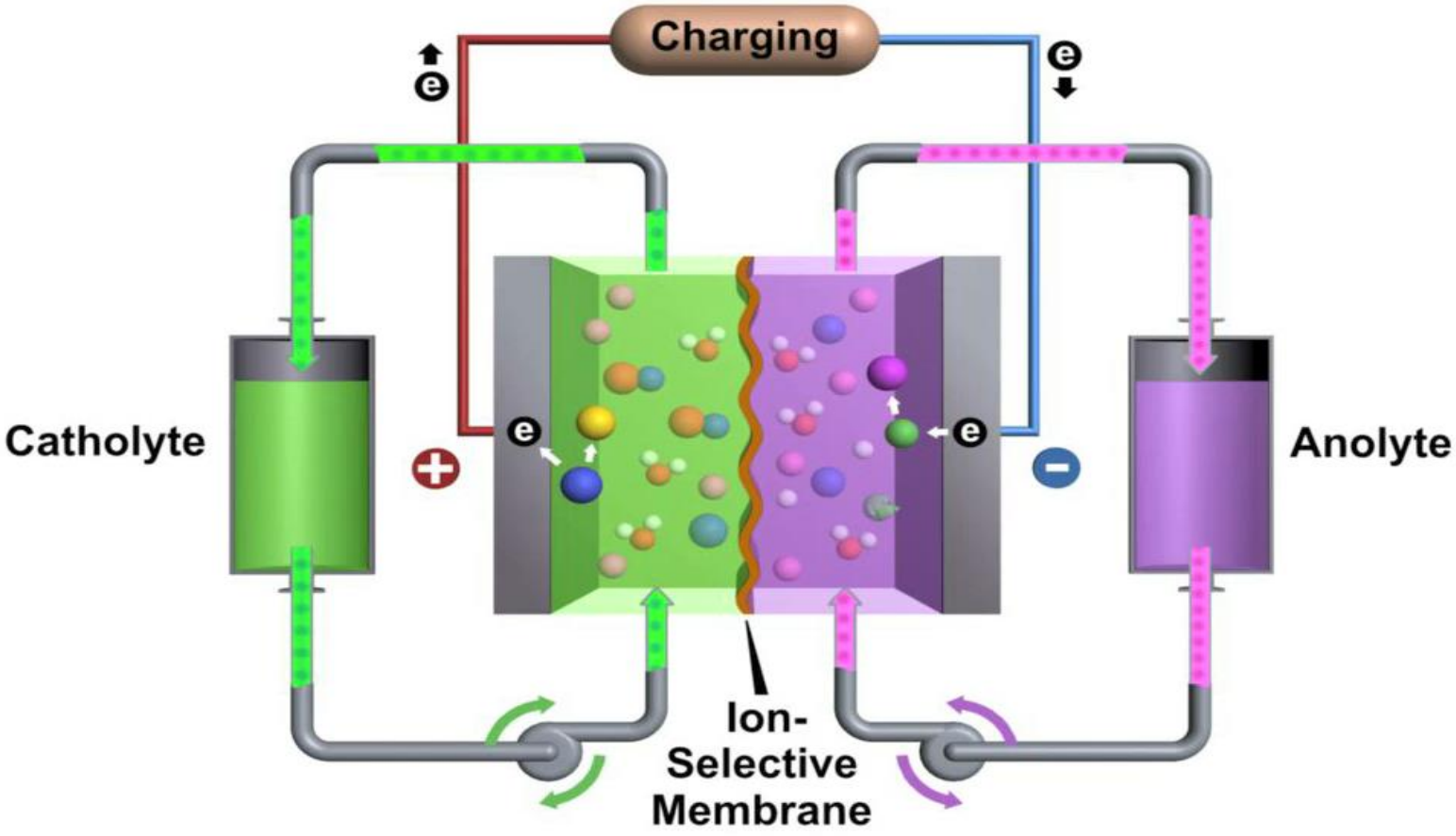


Legend

Zone A: Renewable Sources	MC: MicroController Signal
Zone B: Energy Storage	CB: Circuit Breaker
Zone C: 48V DC Bus	KR: Relay/Contactor, controlled by a 3 to 32 VDC signal, or 24VDC
Zone D: Diesel Gen and 4kW Metal Halide	○ Point of Measurement
Zone E: AC Loads	□ Component #
Zone F: 240V AC Bus	
Zone G: Inverter	

#	Equipment	Description
1S	500W Bergey Solar Array	3 x 28V / 8A
1T	1kW Bergey Turbine	1kW, 24V/42A Rated (Max Running Current 60A)
1PC	Bergey Power Center	Charges battery using turbine and/or PV energy available
1DL	3.5Ω, 1kW power resistor	Extra energy is dissipated here (smallest value is 0.5Ω)
1B	Energy Storage	2 x 15V 58F UCAPs
2	Zahn CH6390-SU Converter	48VDC output, 12 to 61VDC input variation, 2kW
3.1	13 Brightwatts Solar Panels	26.6V @ 7.51A typical power, or 2.6kW
3.2	13 Brightwatts Solar Panels	26.6V @ 7.51A typical power, or 2.6kW
4.1	FlexMax 80 Charge Controller	Needs at least 10.5VDC input, set to 48VDC output
4.2	FlexMax 80 Charge Controller	Needs at least 10.5VDC input, set to 48VDC output
5	Fuel Cell	
7	4 Ultra Capacitors (Parallel)	165Farad and 48VDC, 150A max continuous current per Ucap
8	Bidirectional converter	-->UCAP 48VDC/80ADC -->BUS 48VDC output w/26 to 46VDC input variation/154 to 87ADC
9	VRB	Heartland Alternative Energy; 42V to 57V, 175A (max discharge < 120us)
10	4 x 258Ahr batteries	Sun-Xtender PVX-2580L
11	Xantrex XW6048-120/240-60	6kW, 120/240VAC, 60Hz, 44 to 64VDC input range
13	6kW Diesel Generator	6kW Diesel Generator (240VAC/30A twistlock recept, 120VAC/20A recept)
14	4kW Metal Halide Lights	
15	AC Load	Lights, computers, misc.
16	HOGEN	Hydrogen Generation unit
17	Hydrogen Storage	

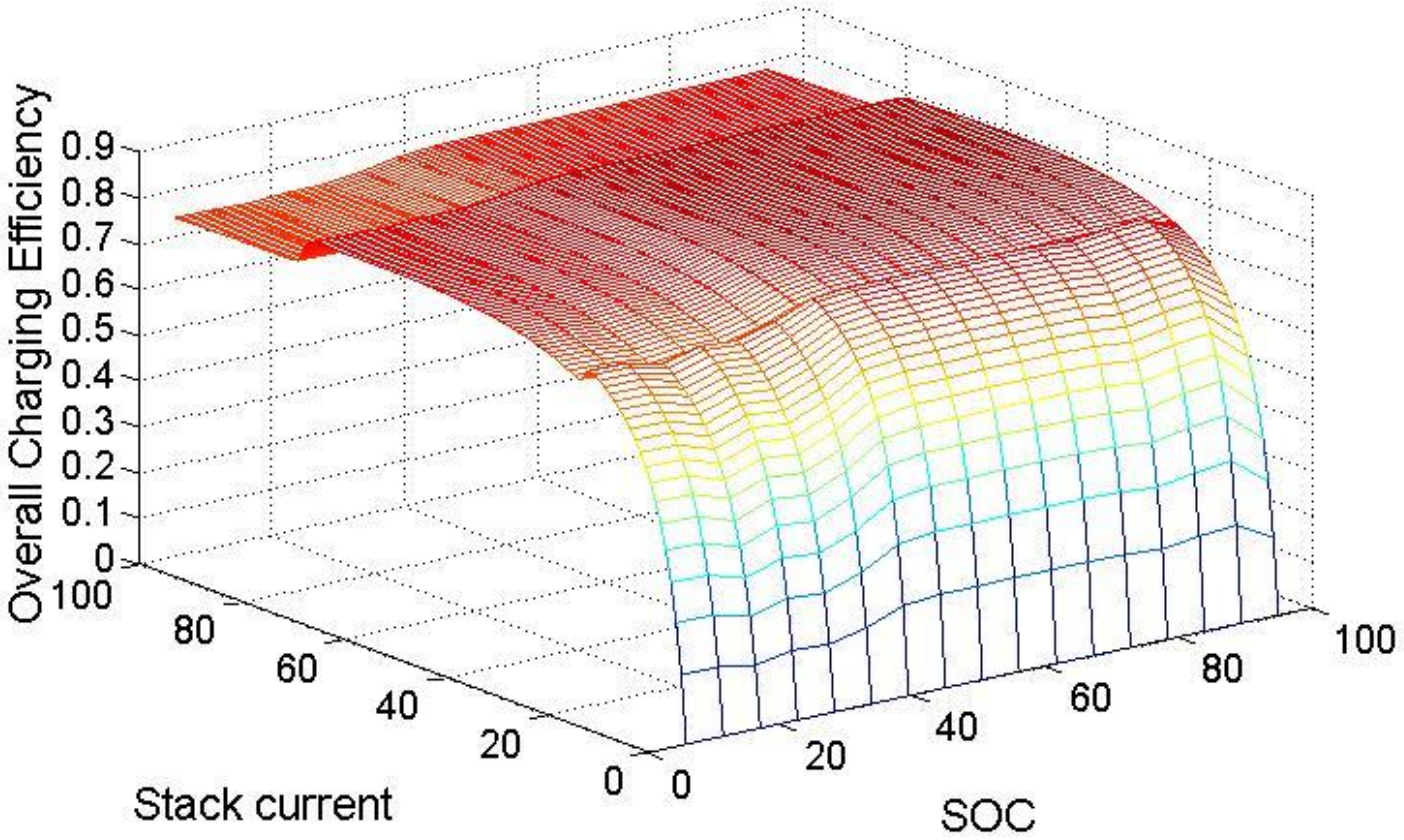
Vanadium Redox Flow Battery



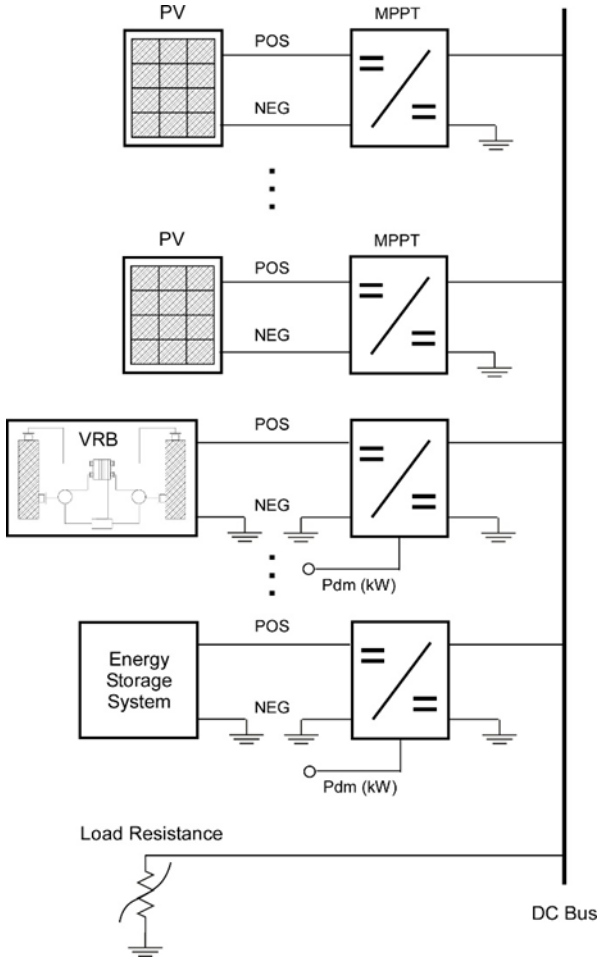
Vanadium Redox Flow Battery

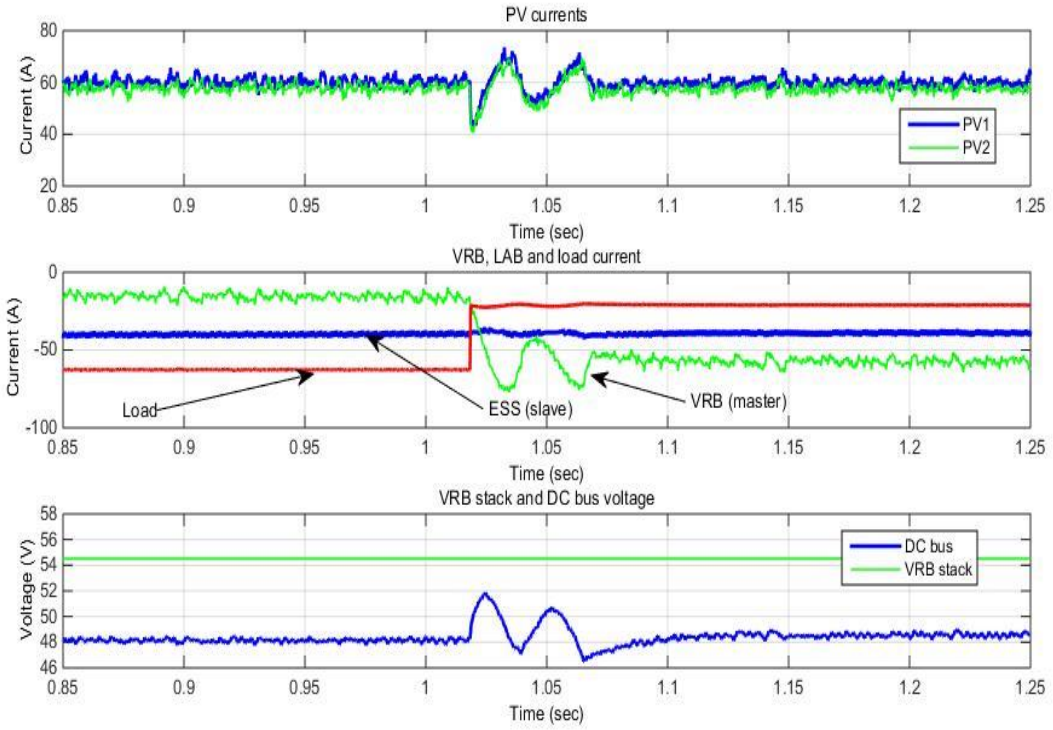
- Energy scales with tanks, power with reaction cell
- Efficiency Factors:
  - Inverter
  - Parasitics (no-load losses)
  - Environmental Controls

Charging Efficiency

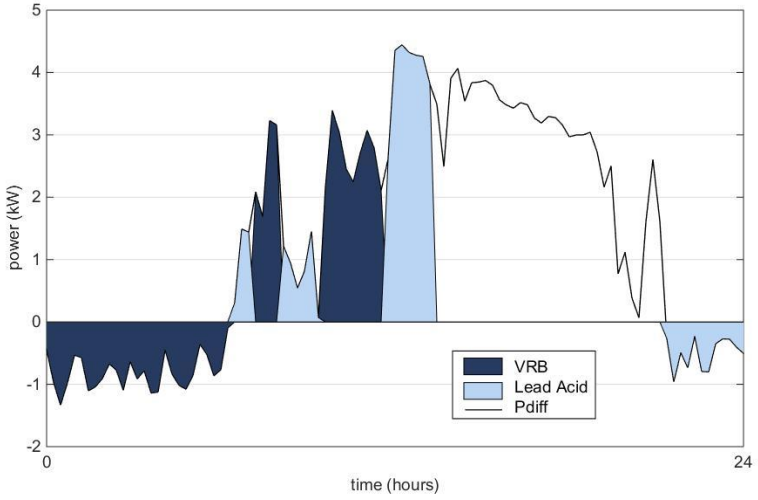


Each ESS must be independently controllable



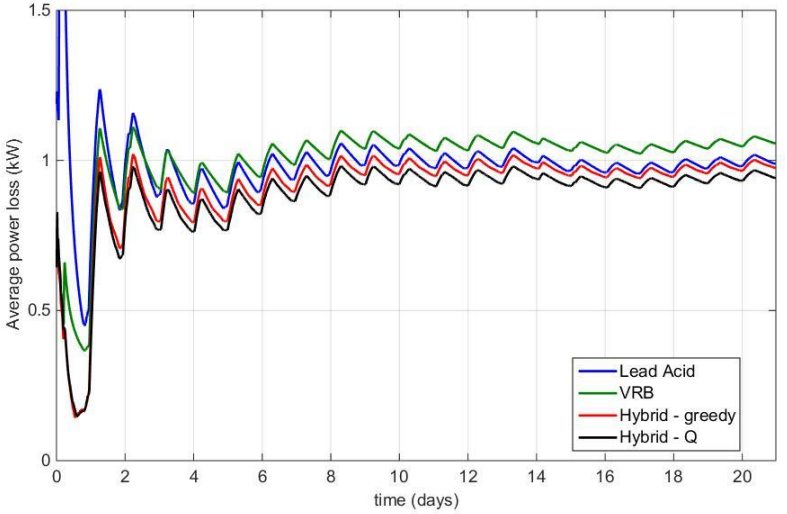


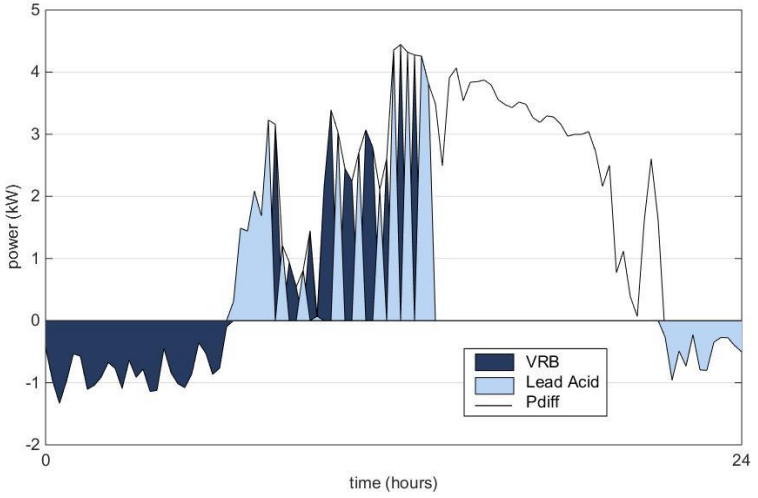
The VRB (master) assumes the load change while the battery (slave) remains constant



Greedy scheduling

System losses





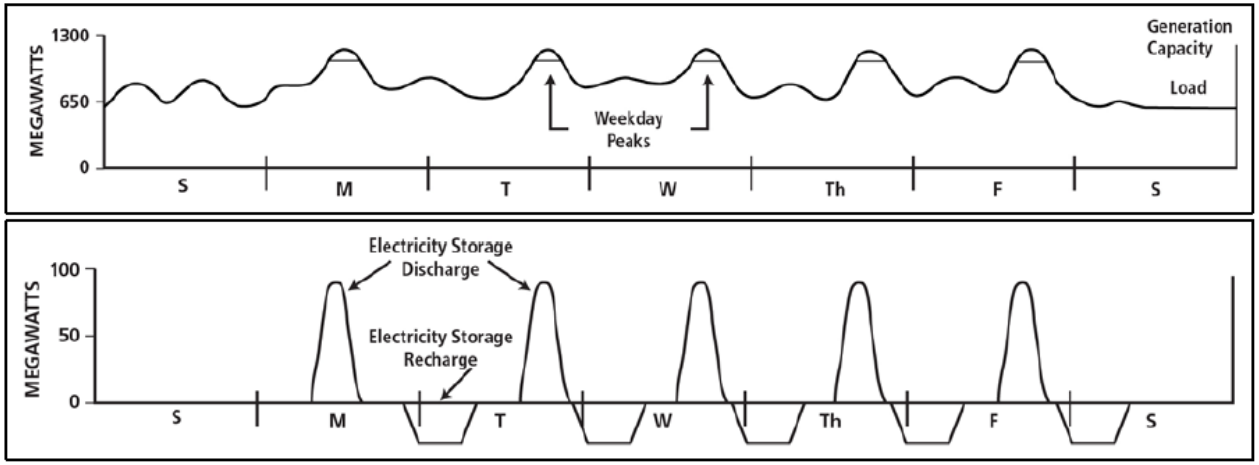
Adaptive learning scheduling

This is still early in the learning process – transitions become smoother as time progresses

Ancillary Services

- Scale up to a larger system
- What problems do utilities face that we can solve?

Supply Capacity



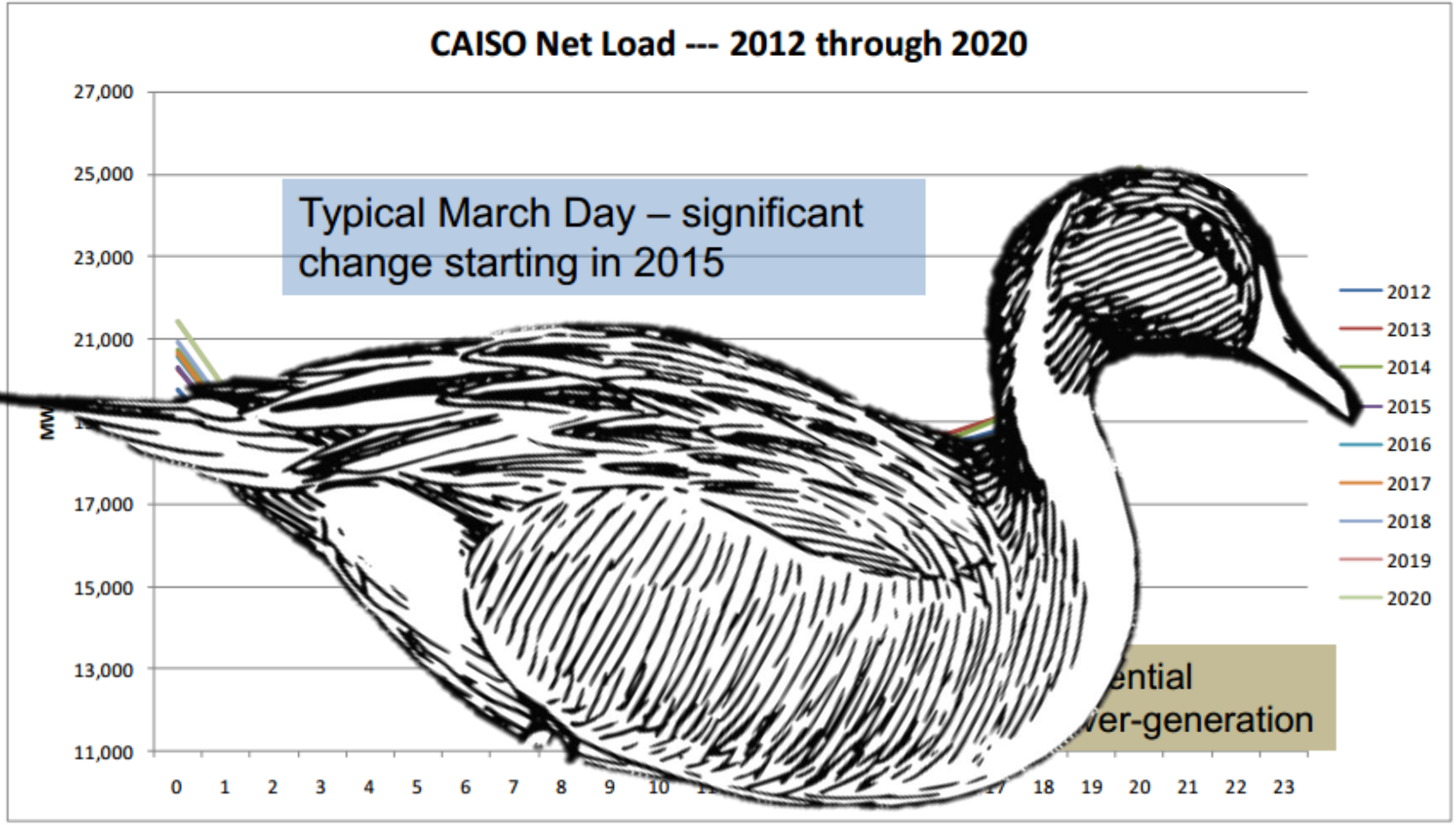
Technical Considerations

Storage System Size Range: 1 – 500 MW

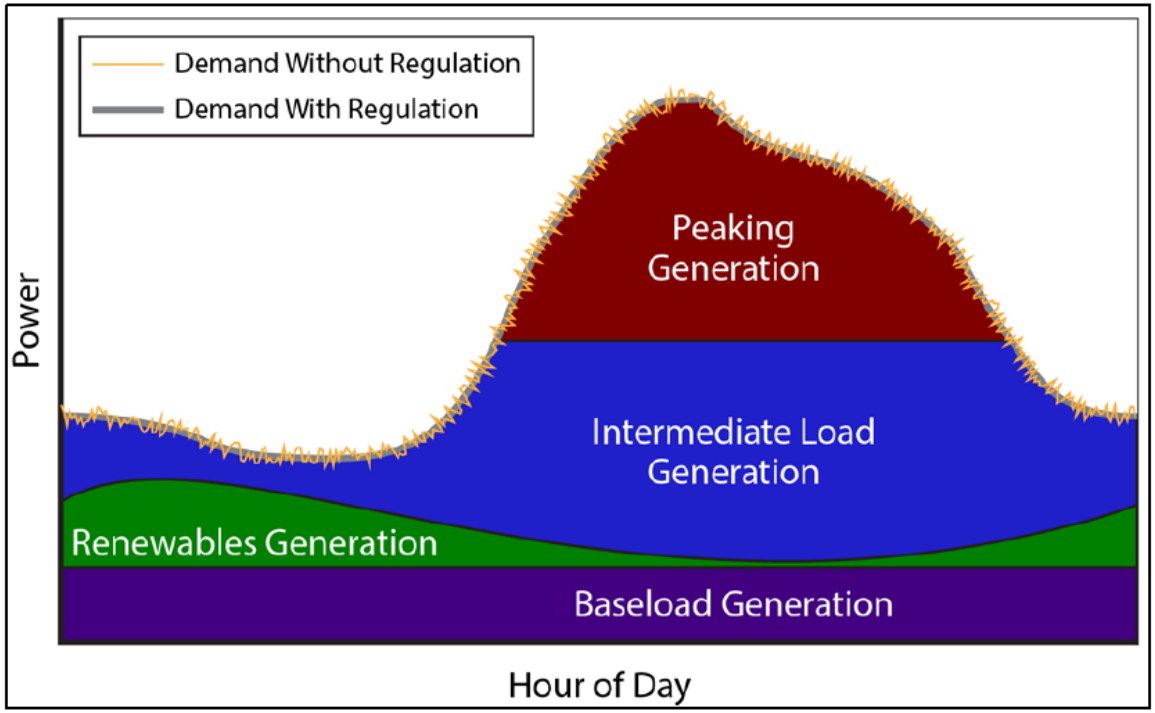
Target Discharge Duration Range: 2 – 6 hours

Minimum Cycles/Year: 5 - 100

The (In)Famous "duck curve"



Regulation

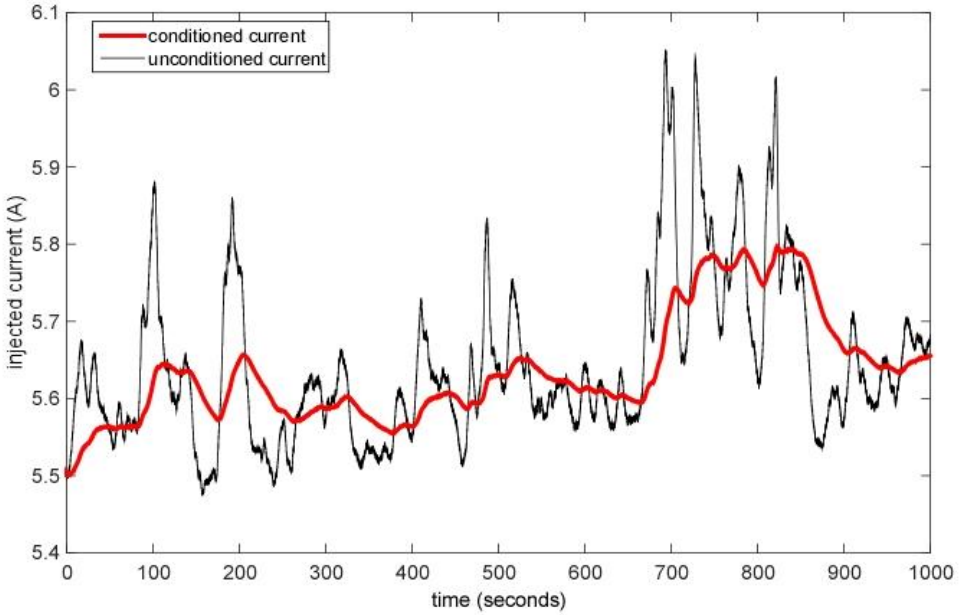


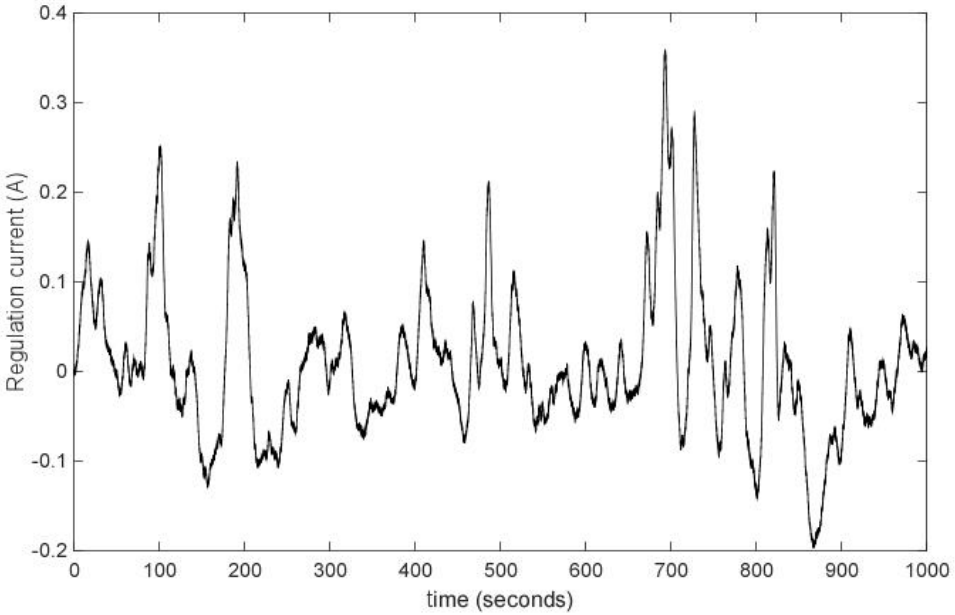
Technical Considerations

Storage System Size Range: 10 – 40 MW

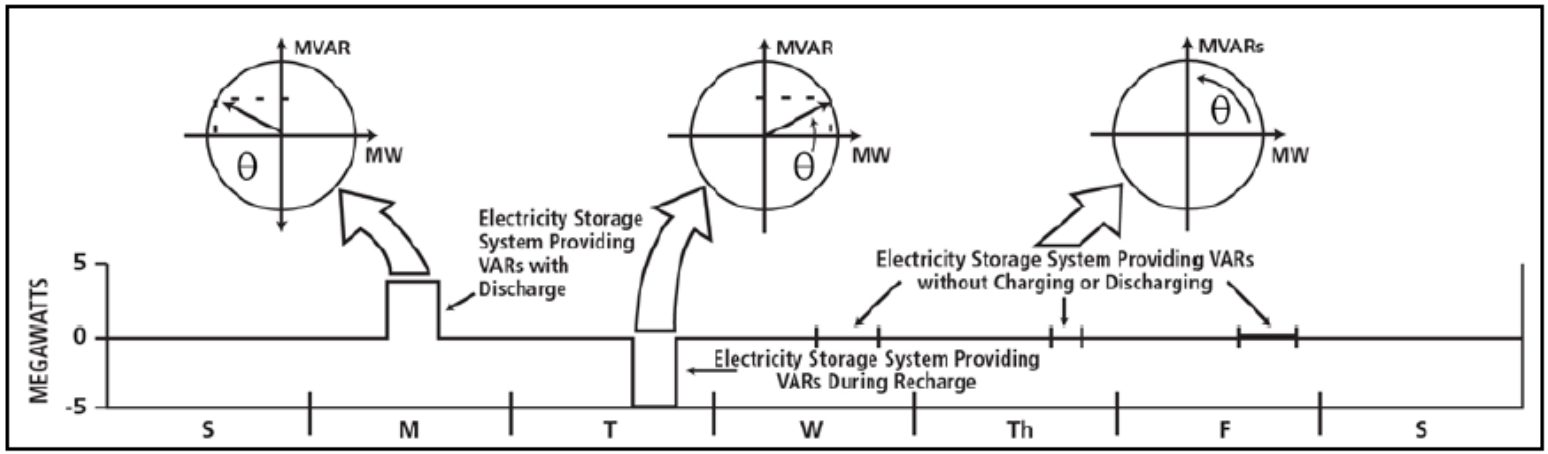
Target Discharge Duration Range: 15 minutes to 60 minutes

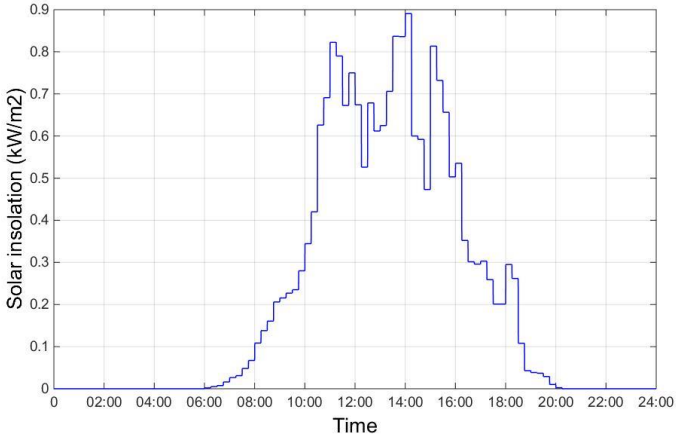
Minimum Cycles/Year: 250 – 10,000

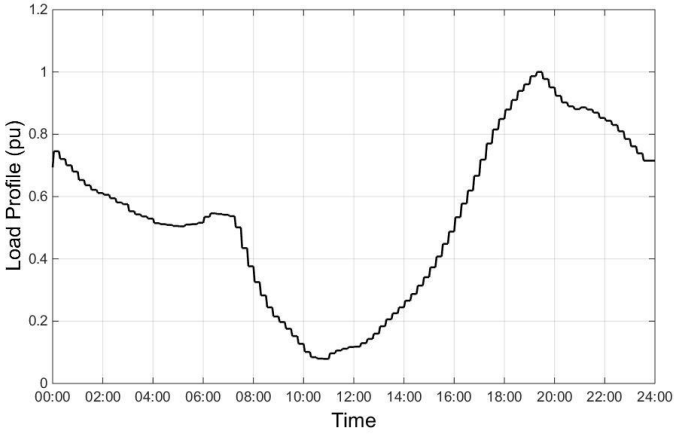

conditioned current
unconditioned current
injected current (A)
time (seconds)
6.1
6
5.9
5.8
5.7
5.6
5.5
5.4
0
100
200
300
400
500
600
700
800
900
1000

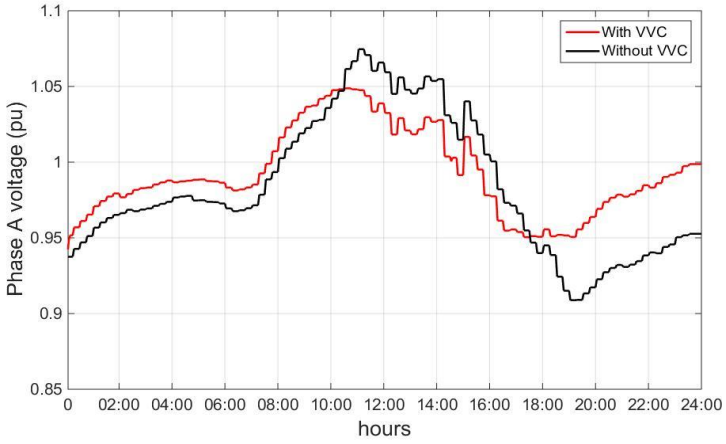

Regulation current (A)
time (seconds)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
100
200
300
400
500
600
700
800
900
1000

Voltage Support

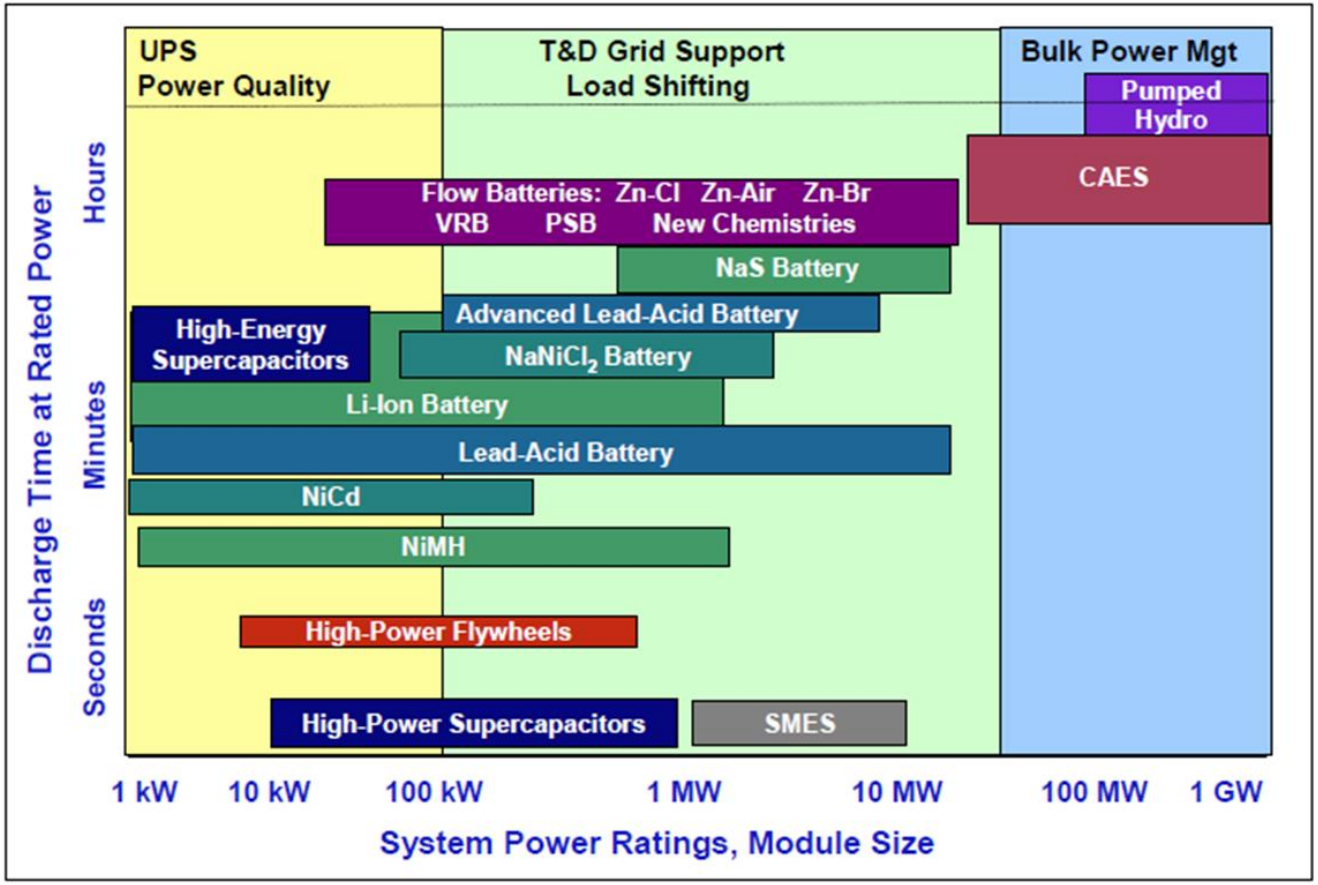



Solar insolation (kW/m2)
Time
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
24:00


Load Profile (pu)
Time
0
0.2
0.4
0.6
0.8
1
1.2
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
24:00


With VVC
Without VVC
Phase A voltage (pu)
hours
0.85
0.9
0.95
1
1.05
1.1
0
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
24:00

Energy Storage Technologies

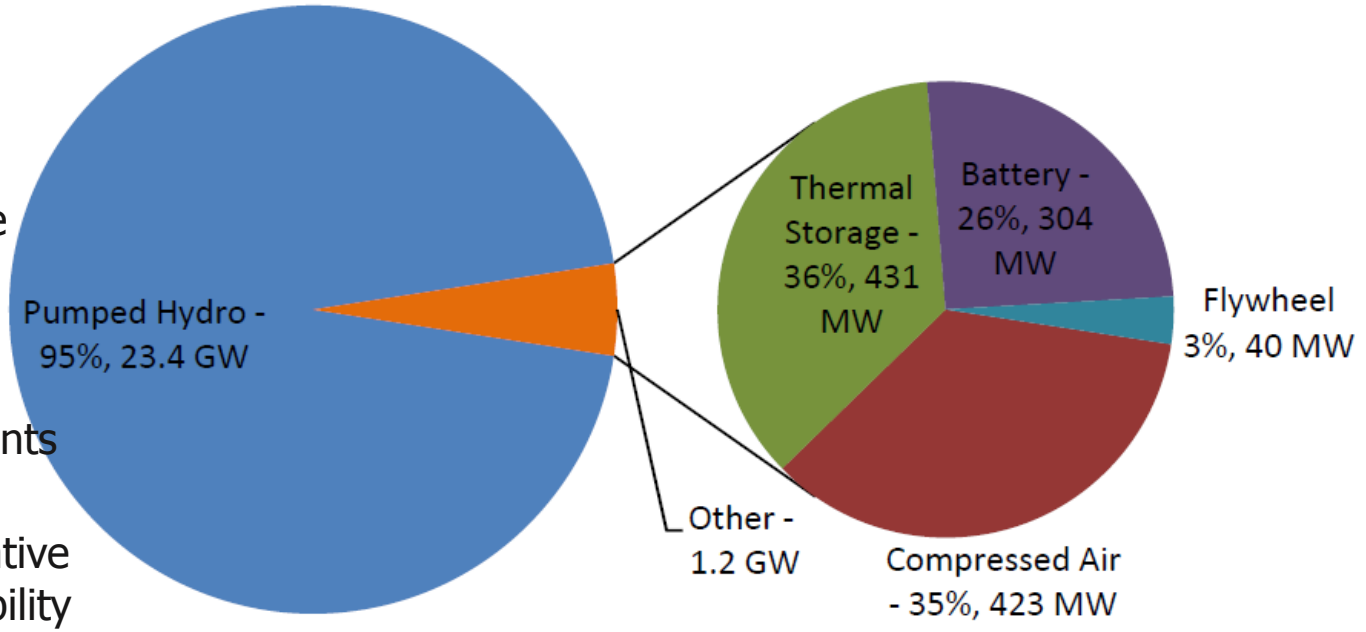


Large-Scale Energy Storage

Current mix of U.S. DER storage technologies

202 U.S. storage system deployments

24.6 GW Cumulative operational capability



DOE Global Storage Database, 2013
http://www.energystorageexchange.org/

Summary

- Microgrids need energy storage of a variety of sizes and technologies
- Energy storage is crucial to expansion of renewable energy on the grid
- Sophisticated controls enable mix of power, energy capabilities

Acknowledgments

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