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ENERGY

Review of Testing on 1MW Lithium-Ion Battery at Reese Technology Center

Presentation to DOE/OE Program Peer Review

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DNV-GL Strategic Research & Innovation

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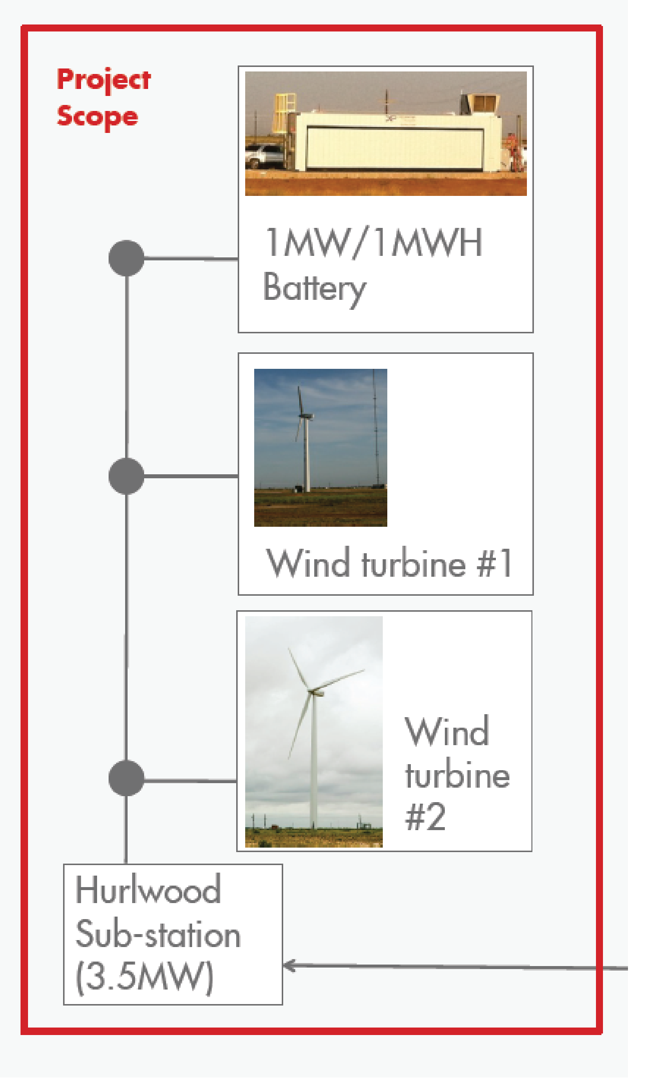
Project Scope and Team

- **Shell International Exploration & Production (US) Inc.**
- **Group NIRE - TTU**
- **DNV-GL**
- **Sandia National Labs**



Project Purpose

- Utilize the co-location of high power, utility scale wind and power energy storage devices to evaluate services
  - Review of previous testing and utilization
  - Wind integration
  - Dual Application
  - Battery Sizing

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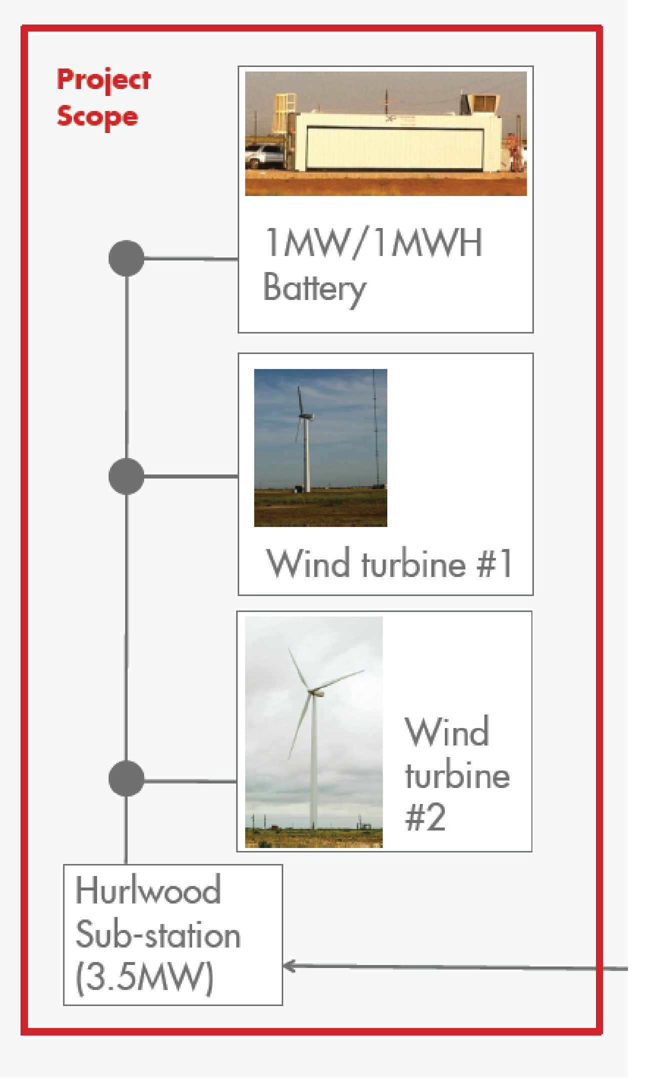

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Battery System & Presentation Overview

- Battery managed by Group-NIRE, operating on South Plains Electric Cooperative (SPEC)
- Testing program to be deployed Q4 2015
- This presentation to review analysis conducted on previous test data
  - Battery performance
  - Efficiency Assessments
  - Applications Analyses
    - Demand Response
    - Frequency Response
    - Wind Ramp Control

1MW / 1MWh Lithium-Ion Battery at Group NIRE, Reese Technology Center

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1MW / 1MWh Lithium-Ion Battery at Group NIRE, Reese Technology Center

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Battery Performance Baseline Shows Consistent Performance in Demand Response Activity

- SOC calculation indicates a average total capacity of 1,088 kWh
- Maximum temperature is consistent 33°C (average 8° above ambient)

Time Period	#	Discharge Power (kW)	Initial SOC (%)	Final SOC (%)	Discharge Time (hrs)	Energy Out (kWh)
July 16-18	1	478	100	9.0	2.08	988.95
	2	**484**	**100**	**7.7**	**2.10**	**1,001.3**
July 20-23	1	475	100	25.1	1.75	827.65
	2	477	100	5.0	2.48	1,039.4
Aug 12-15	1	975	90	9.6	0.93	876.70
	2	965	88	9.0	0.95	823.18
	3	970	91.9	7.8	1.22	907.98
Aug 19-21	1	**965**	**88**	**1.0**	**0.97**	**948.27**

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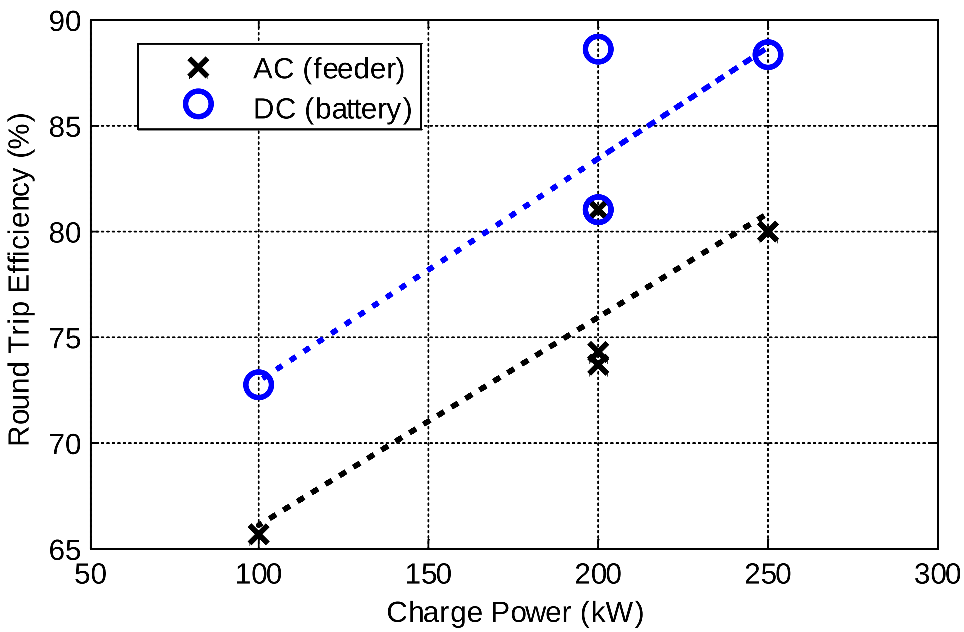
Efficiency of Demand Response Activity is Dependent on Power

- Round trip efficiency calculated as ratio of total discharge energy to total discharge energy
- Average AC efficiency (measure at feeder) **7.4%** less than DC efficiency
- Tests selected for minimal time between charge/discharge & constant power

Date	Charge Power	Discharge Power	AC Efficiency (%, feeder)	DC Efficiency (%, battery)
August 12 2014	**200**	1000	73.70	81.01
August 13 2014	**100**	1000	65.68	72.72
August 19 2014	**200**	1000	74.27	80.99
August 11 2015	**250**	1000	79.96	88.35
August 12 2015	**200**	1000	80.97	88.60

Efficiency of Demand Response Activity is Dependent on Power

- All discharged under same conditions (1,000 kW, full power, 1C)
  - Using round trip efficiency as metric with same discharge conditions
  - Efficiency of charging **increases** at lower power, which **lowers** total, round trip efficiency
- Evaluating round trip efficiency at same charge/discharge power hides these trends



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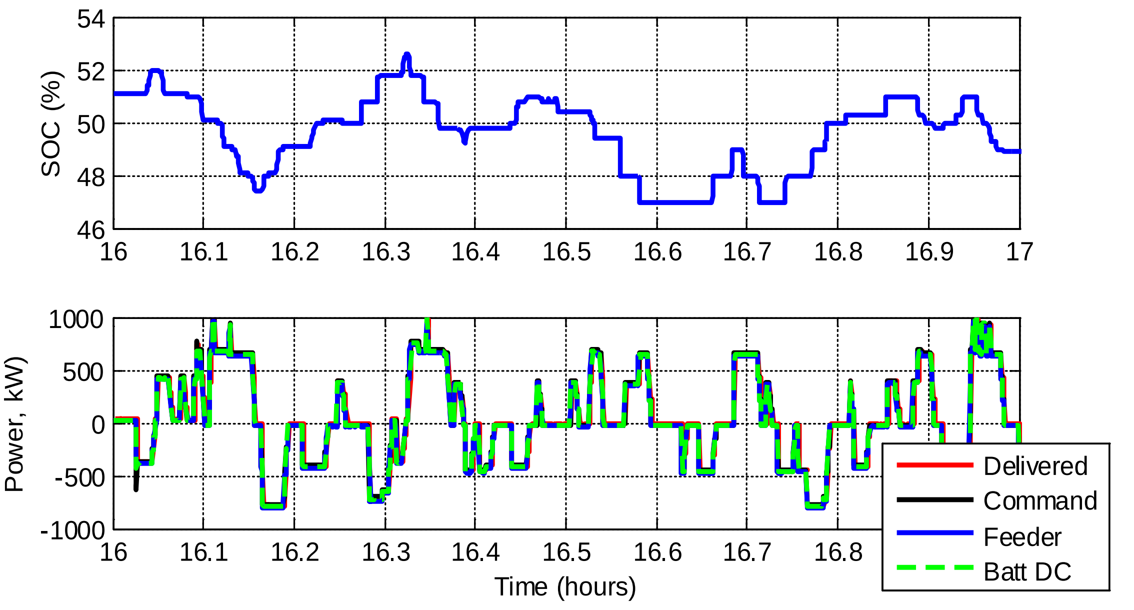
Aggressive Frequency Response Activity Shows High Round Trip Efficiency

- ERCOT fast regulation market (FRRS)
- Lots of higher-power activity, large SOC movement
- Efficiencies very similar in scale to demand response activities



Date	Function	AC Efficiency (feeder)	DC Efficiency (battery)
Sept 4	FRRS	74.02	80.82
Sept 9	FRRS	73.97	81.16
Sept 10	FRRS	74.48	80.27

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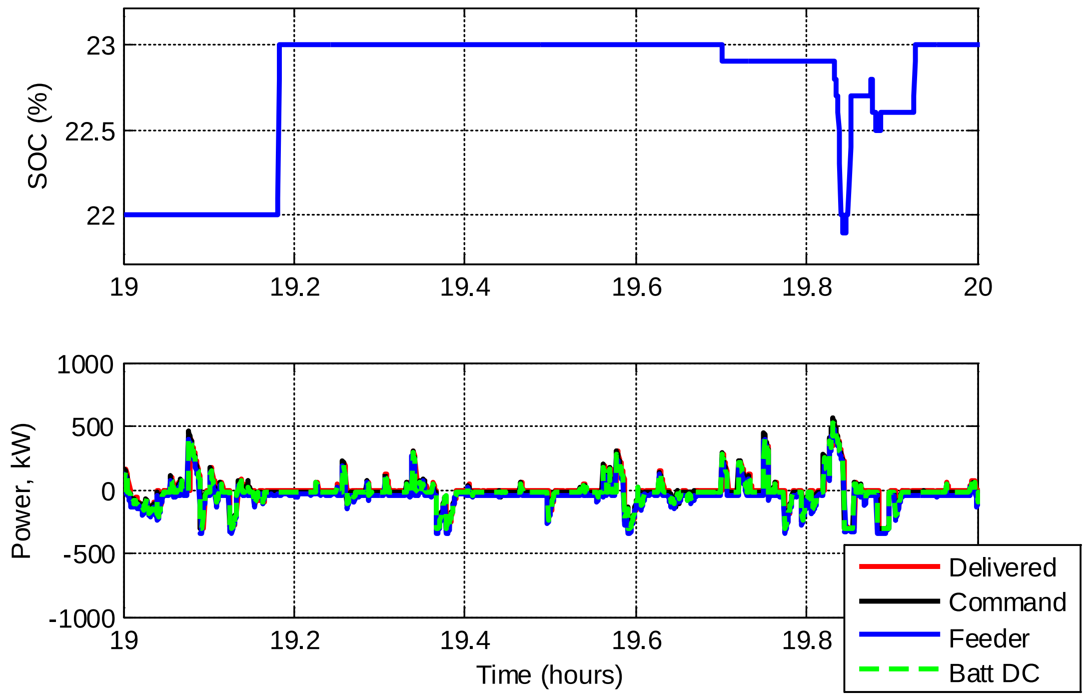
Local Wind Ramp Support and Frequency Response Efficiencies

- Inclusion of static load (20-40 kW) has significant impact dependent on time
- Operations much less active than FRRS, parasitic loads dominate efficiency
- Key concern for standby ‘spinning reserve’ applications as well as for guaranteed efficiency contract terms



Date	Function	AC Efficiency (feeder)	DC Efficiency (battery)
Sept 30	Wind+Freq	27.46	33.20
Oct 10	Wind+Freq	21.71	32.43
Oct 11	Wind+Freq	11.24	22.78

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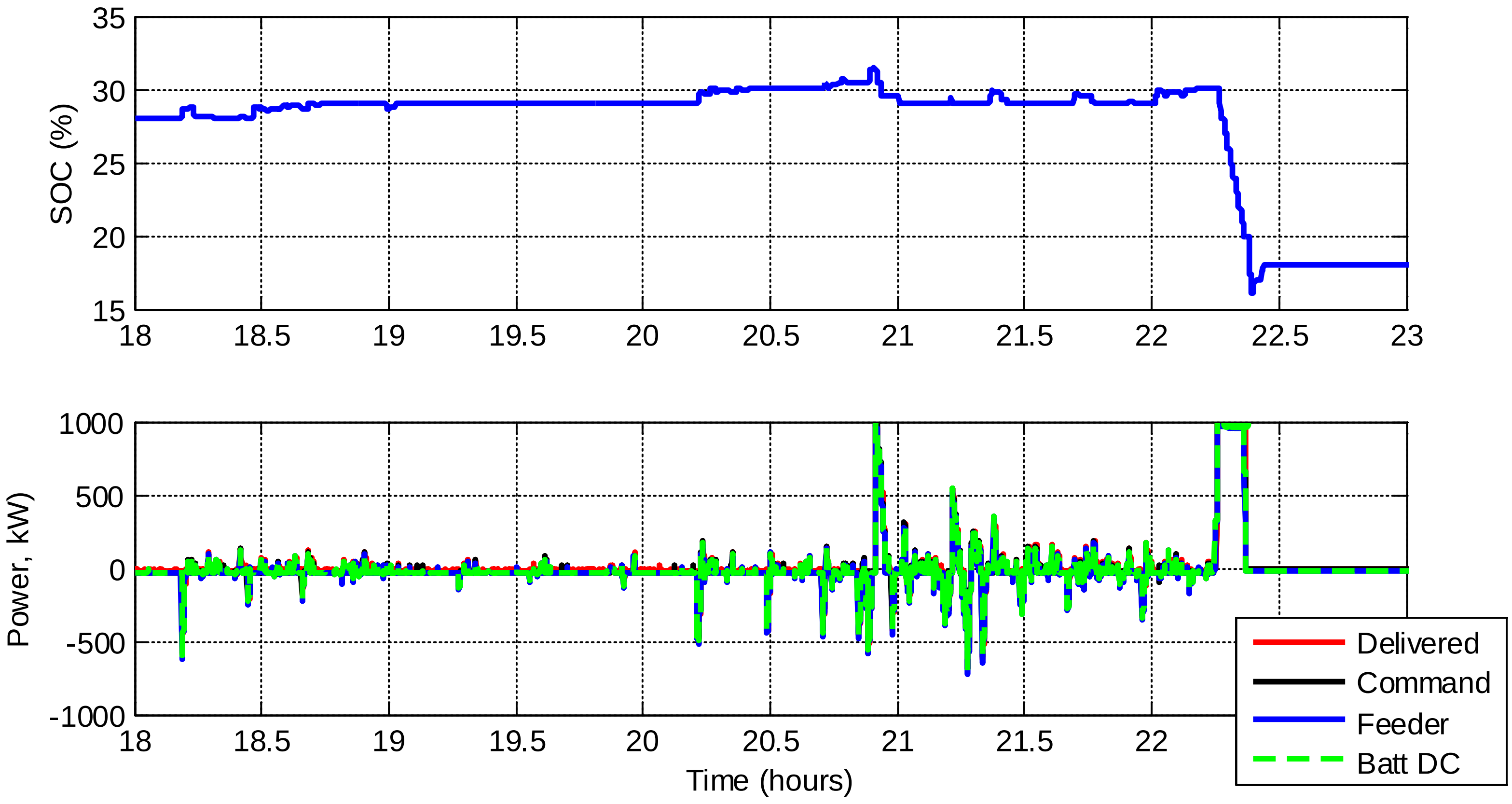
Wind Ramp Support Tests Also Characterized by Low Energy Throughput

- Small power correction followed by large energy compensation
- DC efficiency: 28.7%, AC efficiency: 21.8%



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Additional Profile Characteristics for High Interval Applications

- Quantifying differences in battery application profiles
- Equivalent cycles per day calculated as the number of full 100% DOD cycles that would have resulted based on total energy throughput

Date	Function	ΔSOC (%)	Cycles Per Day	Equivalent Cycles Per Day
August 26	Wind Ramp Support	0.71	158.4	1.12
Sept 4	FRRS	1.71	205.1	3.51
Sept 9	FRRS	2.66	152.7	4.06
Sept 10	FRRS	1.60	152.9	2.44
Sept 30	Wind+Freq	0.44	267.5	1.18
Oct 10	Wind+Freq	0.34	204.0	0.69
Oct 11	Wind+Freq	0.63	135.0	0.85

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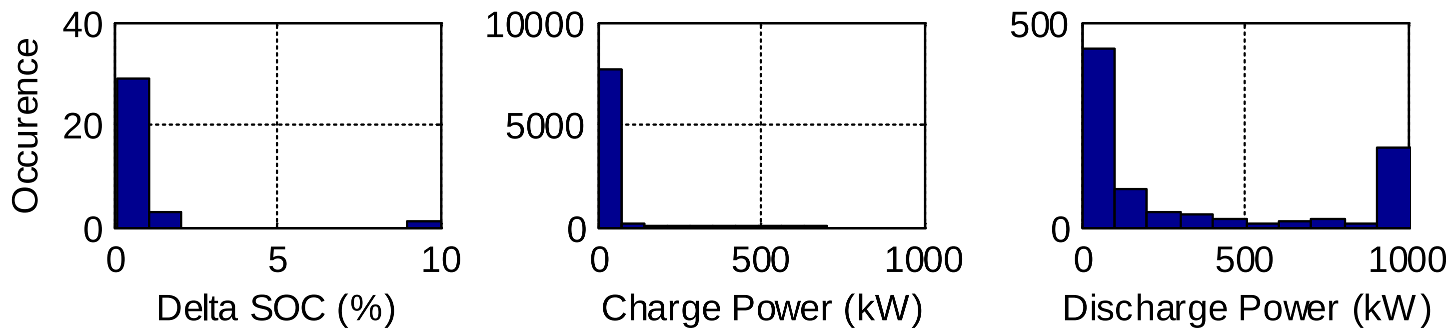
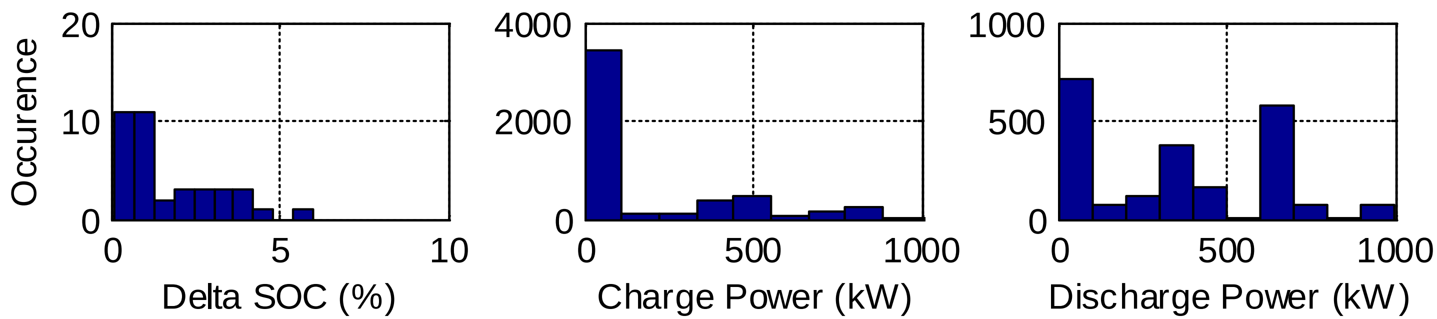
Compare histograms of demand response, FRRS, low interval frequency, wind activity

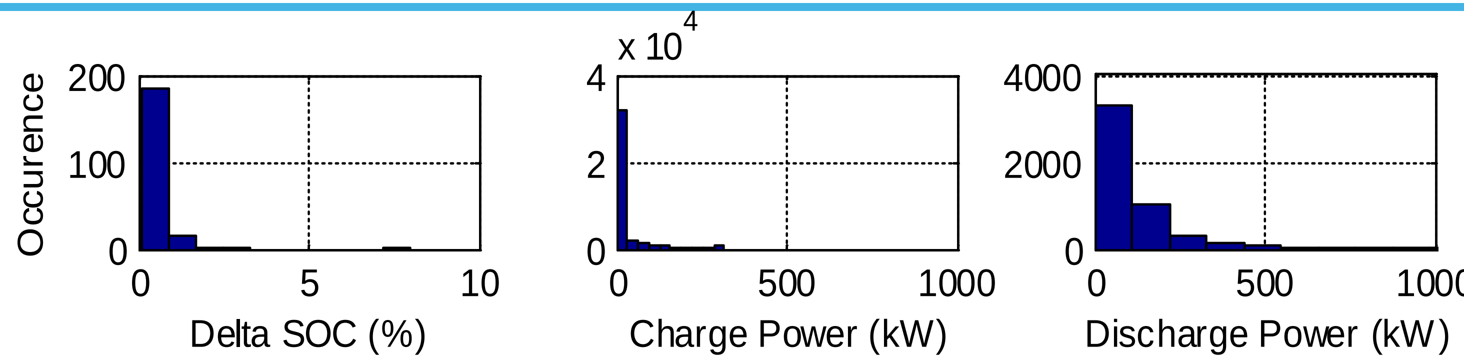
- Wind



- FRRS



- Wind+Freq



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Observations, Insights & Next Steps

Data to date provides significant insights into operational efficiency

- Full system efficiency (AC measured at the feeder) trails DC by 7-8%
- Imbalance of charge / discharge power level can result in at least 15% variation in system efficiency
  - Points to importance of methods for quantifying efficiency
- Low use factors or low energy throughput can result in very low effective system round trip efficiency
  - Points to importance of calculating operational efficiency in contracting
  - Parasitic loads play a dominant role
    - Test procedures for properly measuring standby loads → DOE working group

Next steps – Begin new testing

- Test plan builds on data analysis to further focus on wind integration concepts and efficiency testing and evaluation

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Thank You

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