Wind Integration in West Texas Using Energy Storage

DoE Peer Review Meeting

26-28 September 2016

Washington, DC

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Motivation

- The increase in renewable energy production has introduced novel challenges to the reliable operation of electricity systems. Wind power is the largest non-hydro renewable electricity source in the US.

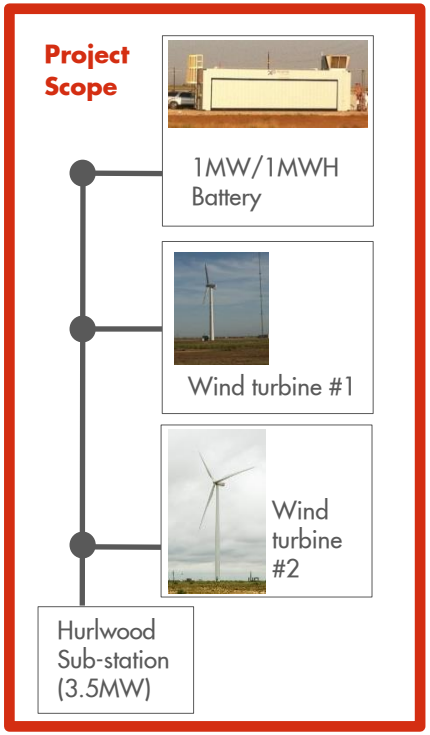
- The purpose of this project is to analyze field-collected information from an energy storage system integrated with wind generation to assess operations of energy storage systems.

- This project is unique due to its combination of MW-scale wind power and battery storage.

Research Program Scope & Location

- Performance observation of grid-connected, utility scale renewable energy assets
  - Single application
    - Constant Power Cycling
    - Frequency Regulation Response
    - Wind Ramp Rate Control
  - Combined application
    - Frequency Regulation & Wind Ramp Rate Control
- Determine how well stationary energy storage performs under a range of wind conditions and functional requirements

- Reese Technology Center, Lubbock, TX
  - 1 MW / 1 MWh lithium-ion (LMO) battery
  - 2 MW wind turbine



Outline

Constant Power Cycling

Frequency Regulation Response

Wind Ramp Rate Control

Frequency Regulation & Wind Ramp Rate Control

Operational battery data for the program

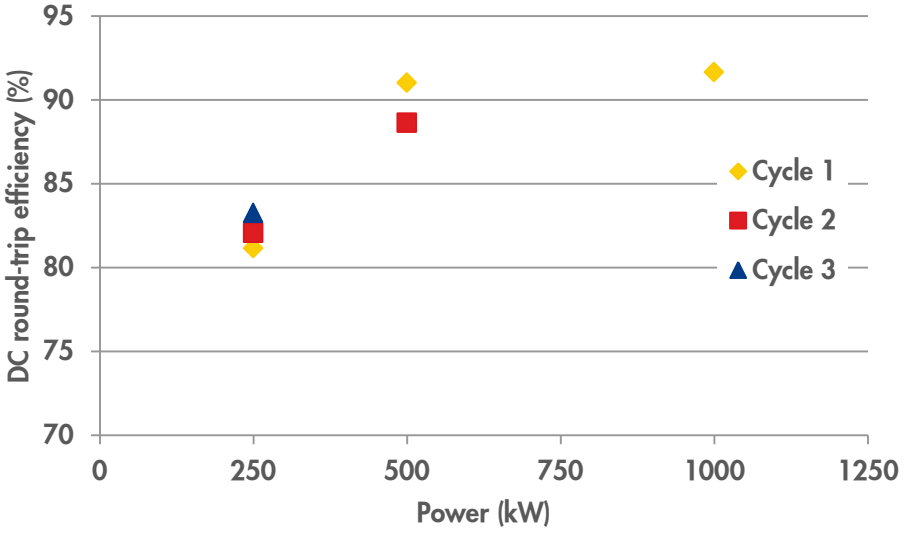
- Battery temperatures observed during testing
  - Average low temperature range: 17-20°C
  - Average high temperature range: 27-28°C
  - Peak temperature observed: 32°C
- The thermal management system uses of air-cooling to maintain ambient temperature of the enclosed battery unit at 21.1°C.
- Auxiliary power loads observed during testing

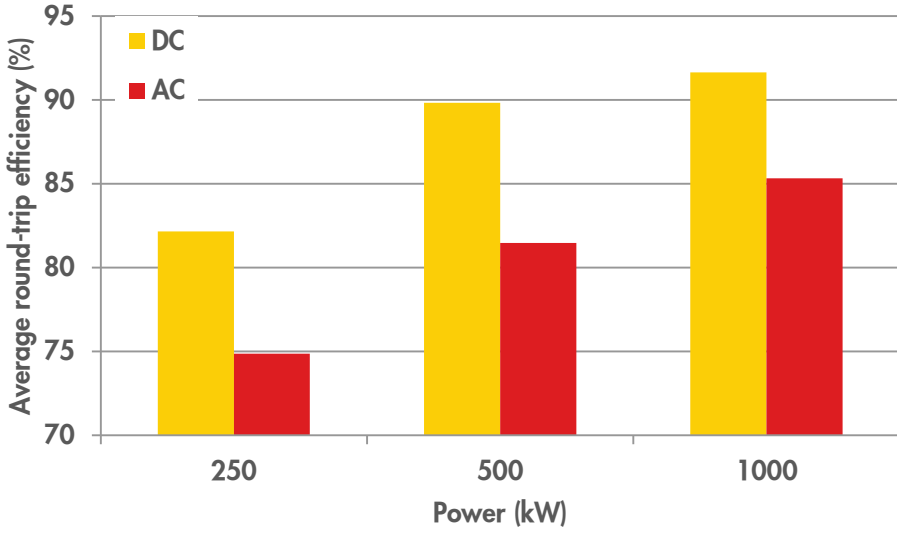
Operational State of Thermal Management System	Measurement Location	Average Power Draw (kW)
ON	DC Load (kW)	23.5
	AC Load (kW)	49.6
OFF	DC Load (kW)	13.6
	AC Load (kW)	20.4

AC load = DC load + inverter + transformer

Constant Power Cycling: Efficiency Assessment

- Objective: evaluate impact of different power levels on round-trip efficiency and temperature rise
- Program was run as a full charge and discharge cycle at the same power level from approximately 10% to 90% SOC.
- Higher round-trip efficiency was observed with higher power levels
  - Less auxiliary power was drawn at higher power levels, due to shorter operation time
  - Higher electrochemical efficiency
- AC losses (including inverter and transformer): 6% - 8% higher than DC





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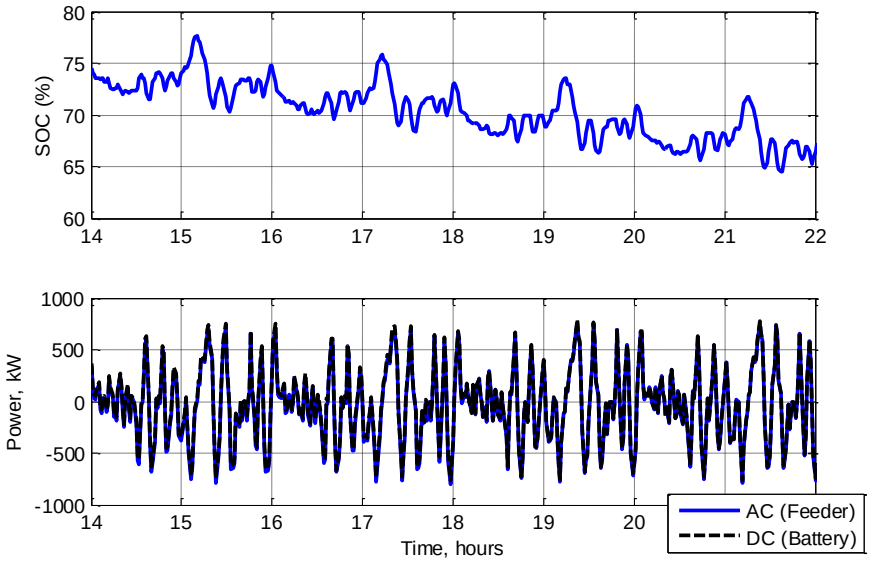
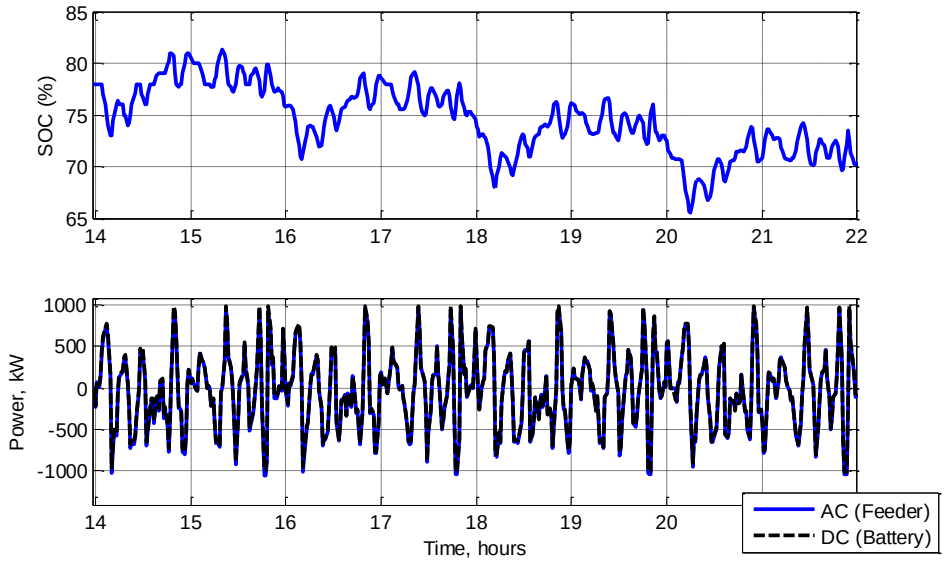
Frequency Regulation Profiles Used in Research Program

- Objective: evaluate system response to varying intensities of frequency regulation signals, using PJM RegD signals as classified by PNNL/Sandia in PNNL-22010 Rev. 1.
- The frequency regulation program was run by repeating the 2-hour profile in the protocol over a period of two days
  - Data shown illustrate 4 cycles in similar SOC ranges
- All frequency regulation tests were conducted with both test profiles
  - The average protocol represents typical operation, while aggressive depicts extreme conditions

Average



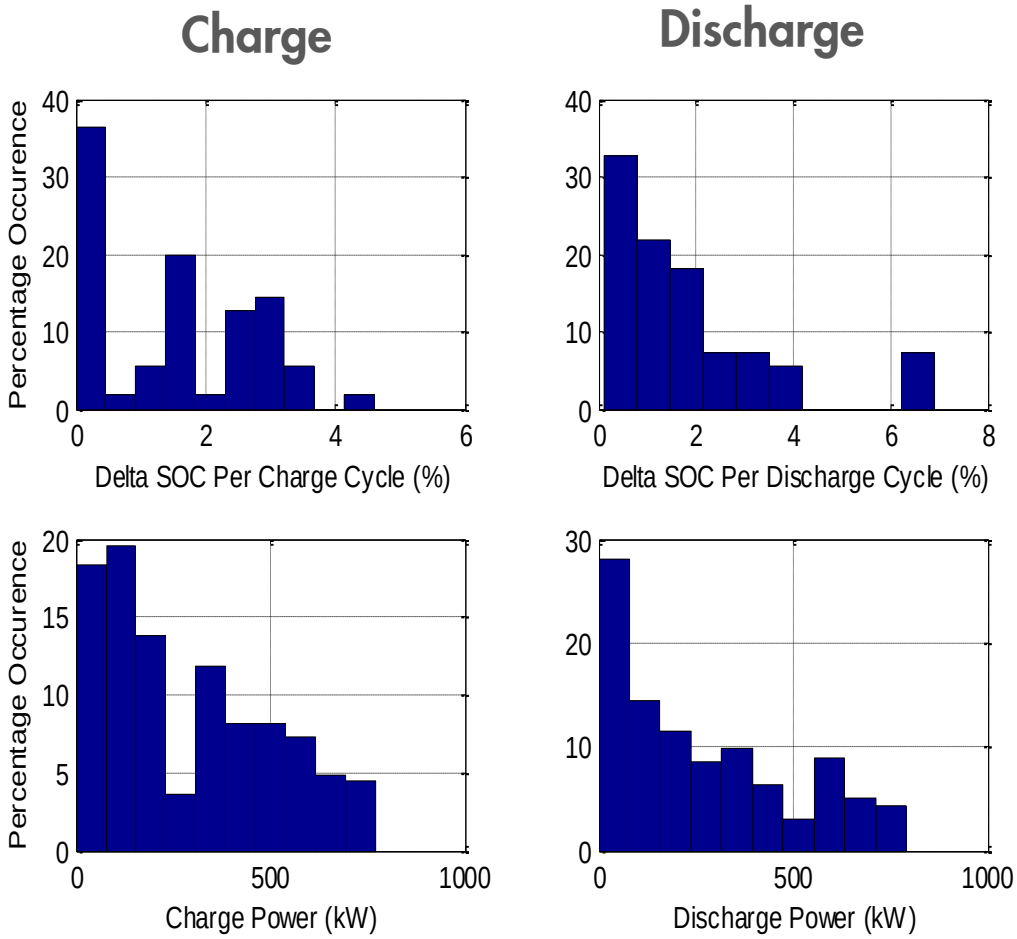
Aggressive



Average profile: System responds precisely with small delta SOC

- The average profile resulted in small cycles
  - Delta SOC <5%, majority <2%
- Maximum power required by this profile was ~750 kW
- Total energy throughput for 4 cycles was 937 kWh

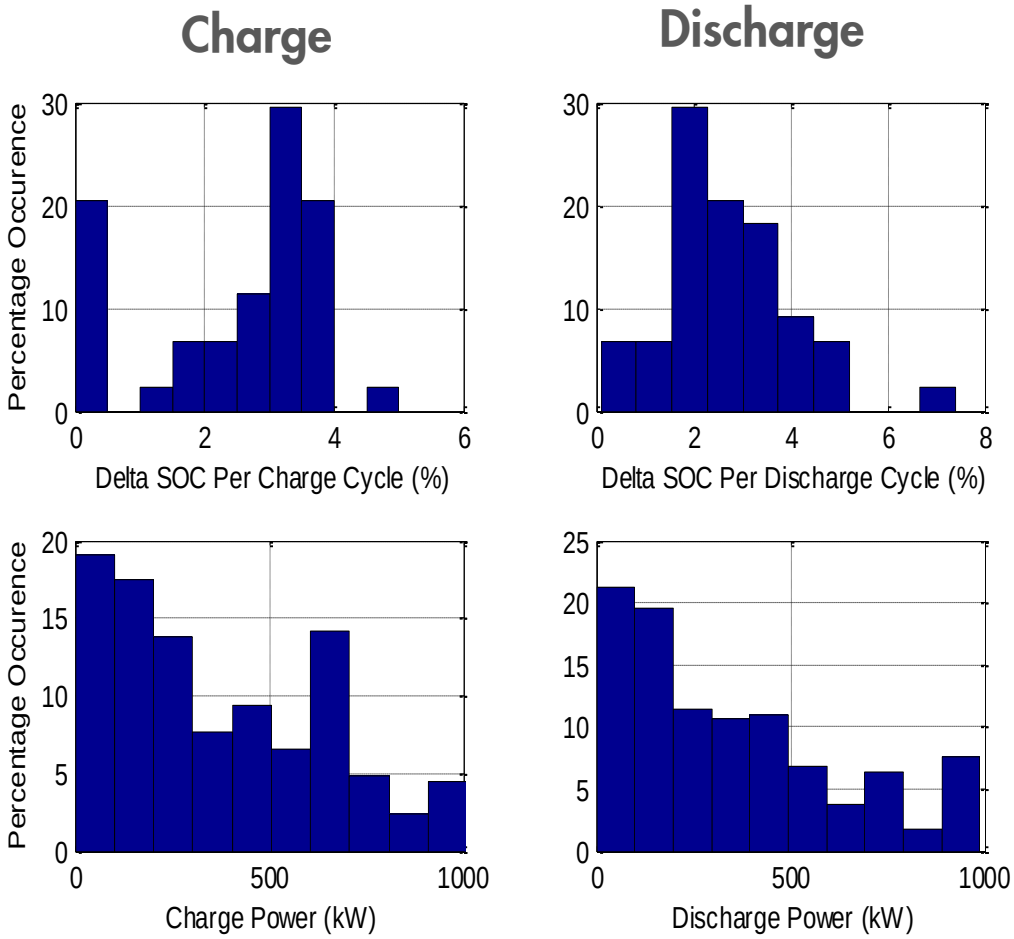
- Average activity: 165 cycles per day at 1.6% delta SOC per cycle
  - 2.64 equivalent full cycles per day
- Performance
  - Average AC efficiency: 72.6%
  - Average DC efficiency: 83.6%
  - PJM Reg D Precision score: 99.74



Aggressive profile: System also responds precisely with small delta SOC

- The aggressive profile resulted in larger cycles
  - delta SOC still <5%, majority between 2% and 4%
- Maximum power required by this profile was 1000 kW (full capacity)
- Total energy throughput for 4 cycles was 1,212 kWh

- Average activity: 131 cycles per day at 2.6% delta SOC
  - 3.40 equivalent cycles per day
- Performance
  - Average AC efficiency: 79.5%
  - Average DC efficiency: 86.4%
  - PJM Reg D Precision Score: 99.64



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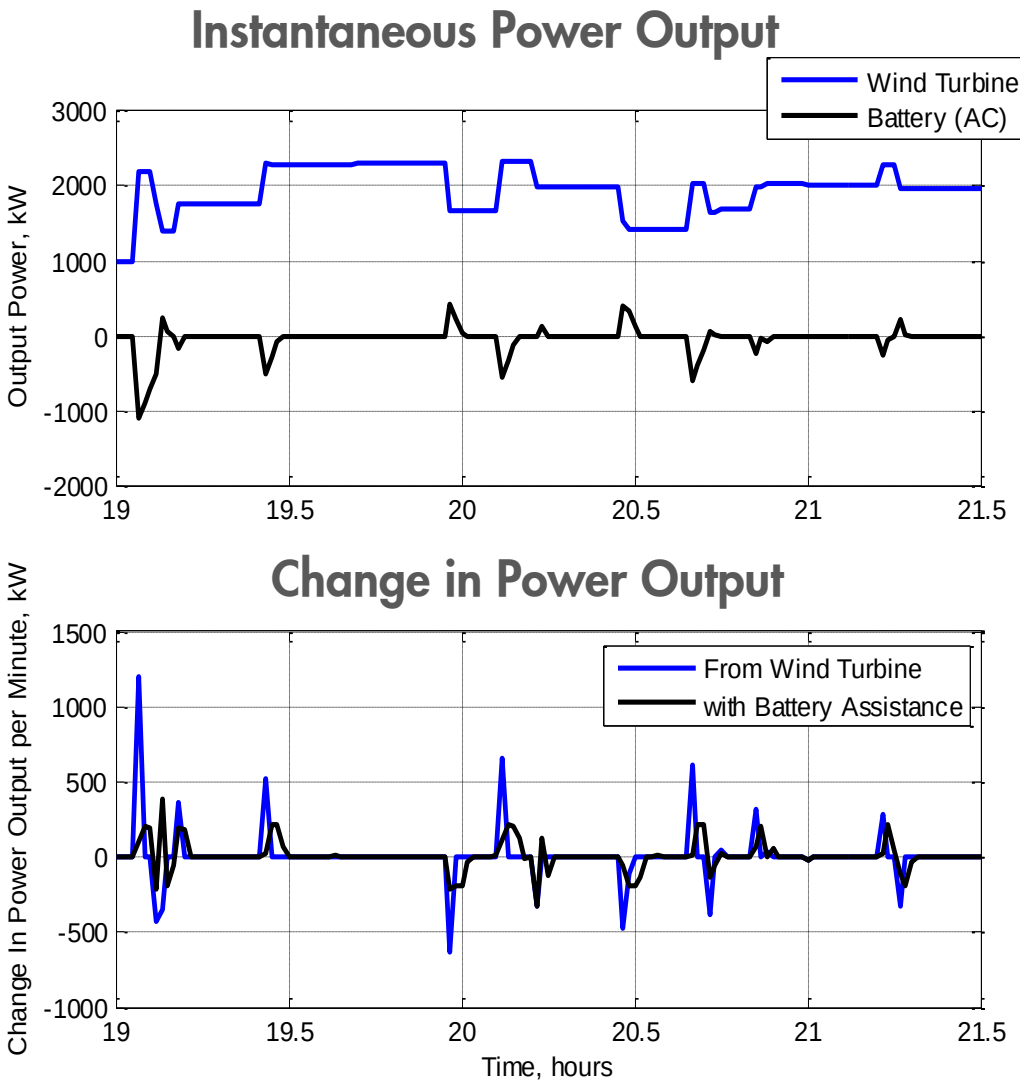
Frequency Regulation & Wind Ramp Rate Control

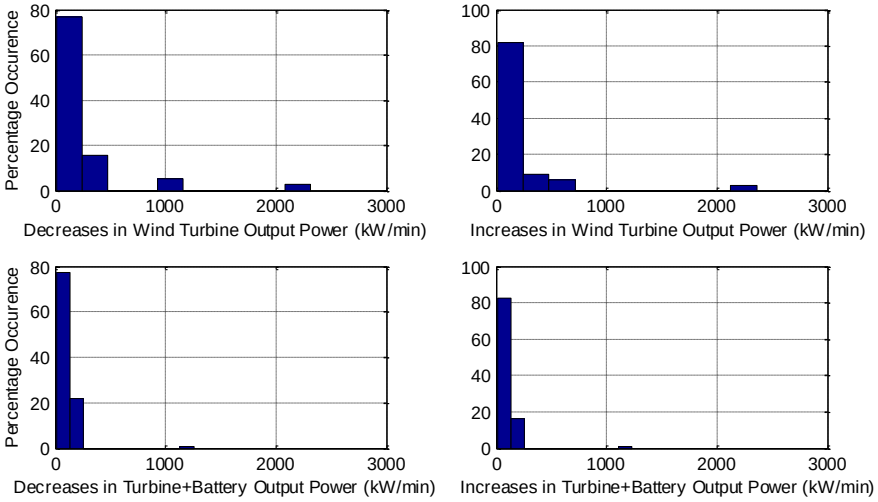
Storage Controls Ramp Rate of Wind Turbine Output

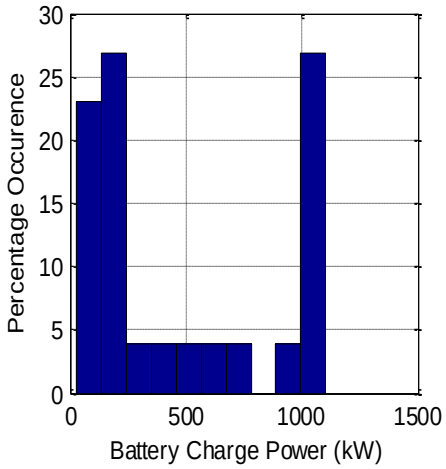
- Objective: minimize amount of fluctuation in wind turbine output power to grid during any given 1-min interval
  - Capability is limited to battery's power of 1 MW
- Battery is called upon to accept or discharge power when turbine output changes up or down
- Program was run ***continuously*** for a full week in order to get a baseline of wind ramp requirements and variation
  - approximately 10 events per day triggered battery response
- The change in power output, shown at right, illustrates quick battery response and effective reduction of the magnitude of changes in power output that can occur from a single wind turbine.

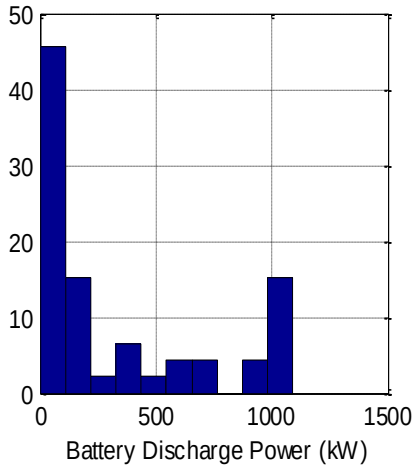


Successful demonstration of ramp rate support by battery

- Power requirements for charge and discharge were very balanced, as was frequency of each (ramp up vs. ramp down)
- Battery successfully demonstrated ability to reduce power output fluctuation by its maximum power level of 1000 kW
- Demonstrated to be predominantly a power application
  - Single extreme case of max power 5 min duration caused delta SOC of 25%
  - Majority of support operations are low power







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Frequency Regulation Response

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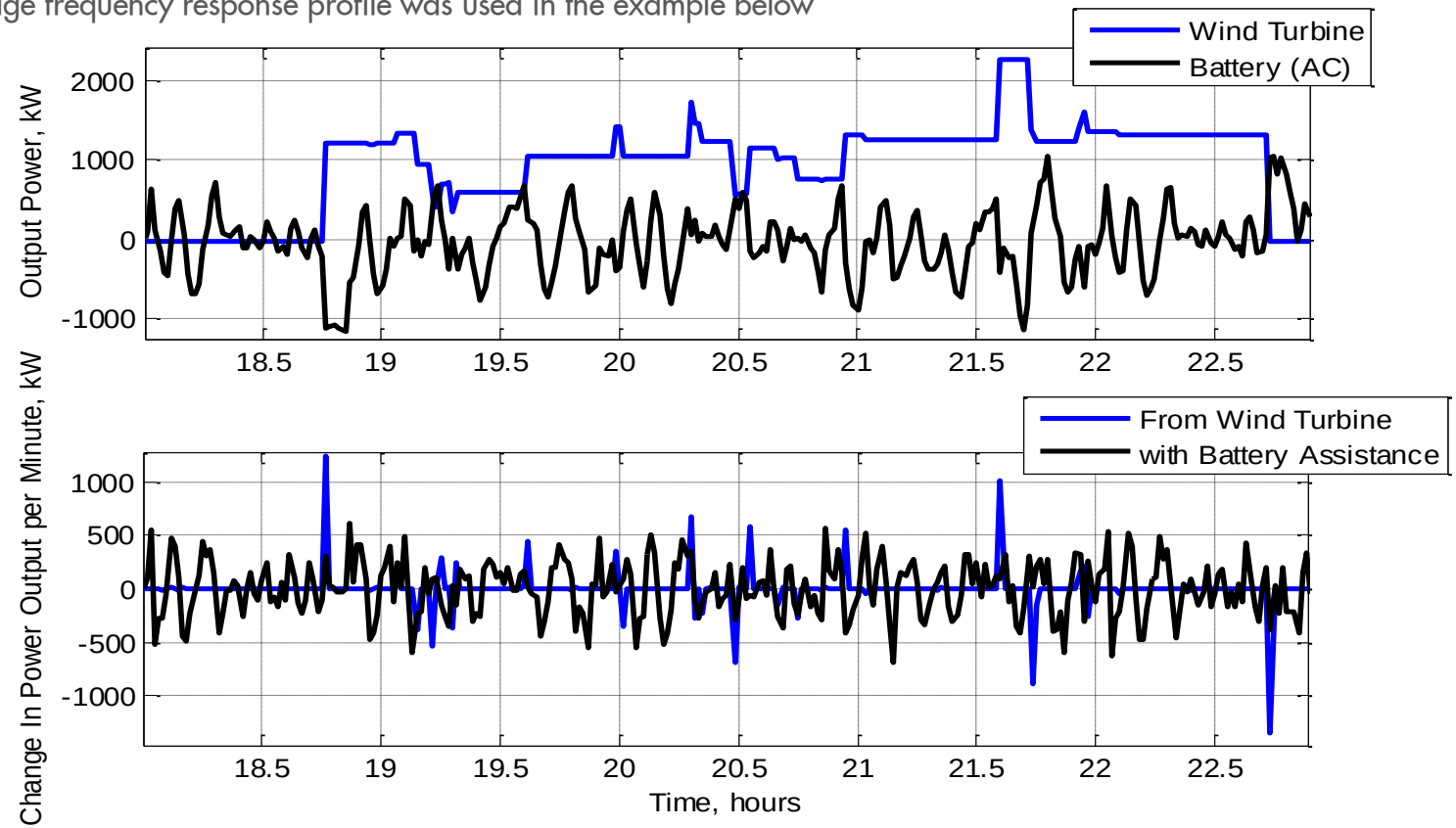
Frequency Regulation & Wind Ramp Rate Control

Combined Frequency Regulation and Wind Turbine Ramp Rate Control

- Objective: minimize amount of fluctuation in wind turbine output power to grid during any given 1-min interval while responding to frequency regulation signal
- The control system prioritized ramp rate control over frequency regulation programming if ramp required full power capacity
  - Average frequency response profile was used in the example below



Battery performs combined applications well

- Program was run continuously for 3 days under both average and aggressive frequency profiles while programmed to respond to wind ramp requirements whenever present
- Observations
  - Single instance when battery unable to provide full power for ramp control during aggressive FR
  - Single instance of frequency response requiring same power as wind, resulting in signals cancelling
  - Highest delta SOC experienced was 25% (1,170 kW for just under 5 minutes)
    - Maximum temperature of 27°C, temperature gradient of 8°C across pack.
  - Battery SOC limits were not a limiting factor in these cases
- Wind turbine ramp support activities were relatively infrequent during the [8 hour] test period; therefore they had minimal effect on the PJM Reg D Precision Score

	Precision Score	
Combined Application Test Number	Average Profile	Aggressive Profile
1	99.11	99.25
2	99.08	99.63
Baseline score for FR only (no wind ramp)	99.74	99.64

Conclusions

The project objective of establishing how well stationary energy storage performs under a range of wind conditions and functional requirements has been met.

Key takeaways

- Round-trip efficiency: 82 - 91% DC-DC; 6-8% lower for AC-AC
  - Higher power levels provided higher RTE
  - Significant impact of HVAC and auxiliary loads which can be up to 50 kW
- Frequency regulation
  - 72 - 86% DC-DC RTE , with higher power corresponded to higher RTE
  - 2.64 (average) and 3.40 (aggressive) equivalent full cycle throughput per day
- Combined application testing is operationally feasible
  - Ramp rate control had minimal effect on the PJM Reg D precision score compared to frequency regulation testing alone
- Frequency regulation and wind ramp support are ‘power’ applications, which lithium-ion storage technology
  - Peak power requirements are a key consideration in system sizing; minimizing size will constrain energy applications

Acknowledgements

We would like to thank the following groups and individuals for their support of this project.

- The DOE **Office of Electricity** and Dr. Imre Gyuk, Program Manager of the Electrical Energy Storage Program
- GroupNIRE
- Sandia National Laboratories
- DNV GL

Thank you!

Questions?

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