Protocol for Measuring and Expressing Performance for Energy Storage Systems

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Problem Statement

- The energy storage market is expanding, with a variety of storage technologies available
- The lack of a uniform way to evaluate energy storage system (ESS) performance is causing confusion in the market
- Without an accepted basis for comparing ESS performance, the application and use of storage technology will be hampered

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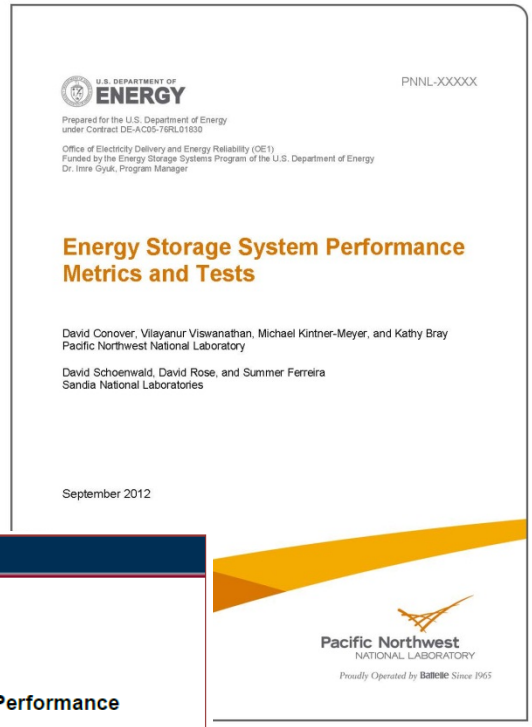
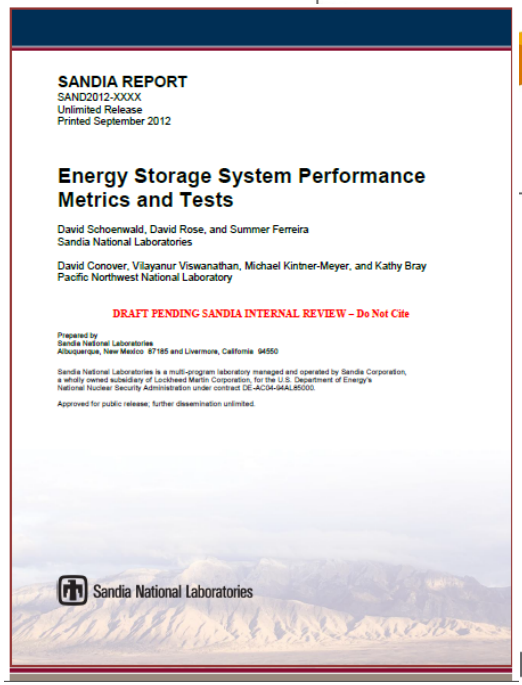
Accomplishments

- Engaged over 60 entities/organizations in a collaborative way to develop a protocol to measure and express energy storage system performance
- Completed a protocol to address peak shaving and frequency regulation applications that can be used by industry and as a basis for a consensus standard
- Established a firm collaborative foundation upon which to foster use of and future enhancement to the protocol to cover additional applications and performance metrics





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Participants (Working Group and ***Sub-Groups***)

- ✓ ***A123 Systems***
- ✓ ***AEP***
- ✓ AES Energy Storage
- ✓ ALABC
- ✓ Altairnano
- ✓ Axion Power
- ✓ ***BPA***
- ✓ ***Clarkson University***
- ✓ CEC
- ✓ CESA
- ✓ Coda Energy
- ✓ Con Ed
- ✓ ***Deka Batteries***
- ✓ Dresser-Rand
- ✓ Duke Energy
- ✓ Eaton Yale
- ✓ Emerson
- ✓ ***EnerVault***
- ✓ ***EOS Energy Storage***
- ✓ EPRI
- ✓ ERCOT
- ✓ ***ESA***
- ✓ First Energy Tech
- ✓ GE Energy Storage
- ✓ ***HDR/DTA***
- ✓ ICE Energy
- ✓ Ioxus
- ✓ Intertek
- ✓ ISO-NE
- ✓ ***K2 Energy Solutions***
- ✓ ***KEMA***
- ✓ LADWP
- ✓ Lux Research
- ✓ ***Maxwell Technologies***
- ✓ ***MISO Energy***
- ✓ ***Mustang Prairie, LLC***
- ✓ ***NEMA***
- ✓ NGK
- ✓ NRDC
- ✓ NRECA
- ✓ ***NEC Labs America***
- ✓ Nichicon America
- ✓ ***Nemtzow and Associates***
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- ✓ PJM
- ✓ ***PNM Resources***
- ✓ ***Powin Energy***
- ✓ Premium Power
- ✓ Primus Power
- ✓ ***Prudent Energy***
- ✓ SAFT
- ✓ SAIC
- ✓ S&C Electric
- ✓ ***SEEO***
- ✓ ***Solar Grid Storage***
- ✓ Solon
- ✓ So Cal Edison
- ✓ Southern Company
- ✓ ***Steffes Corp***
- ✓ SUNY
- ✓ Velkess
- ✓ Xtreme Power

Section 1.0 - Purpose

- A set of “best practices” for characterizing energy storage systems and measuring and reporting on their performance
- A basis for assessing how individual energy storage systems will perform with respect to key performance attributes relevant to different applications
- Intended to provide a valid and accurate basis for the comparison of different energy storage systems
- Enable more informed decision-making in the selection of energy storage systems for various stationary applications

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Section 2.0 - Scope

- Defines test and measurement criteria with which to express and report performance
- Energy storage systems are used for energy intensive stationary applications (peak shaving) and/or power intensive stationary applications (frequency regulation)
- Includes the storage device, any power conversion systems installed with the storage device and may also include any battery management systems
- Agnostic with respect to the storage technology and the size and rating of the energy storage system
- Does not apply to single use storage devices and storage devices that are not coupled with power conversion systems
- Does not address safety, security or operations and maintenance of energy storage systems
- Does not provide pass/fail criteria

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Protocol Overview

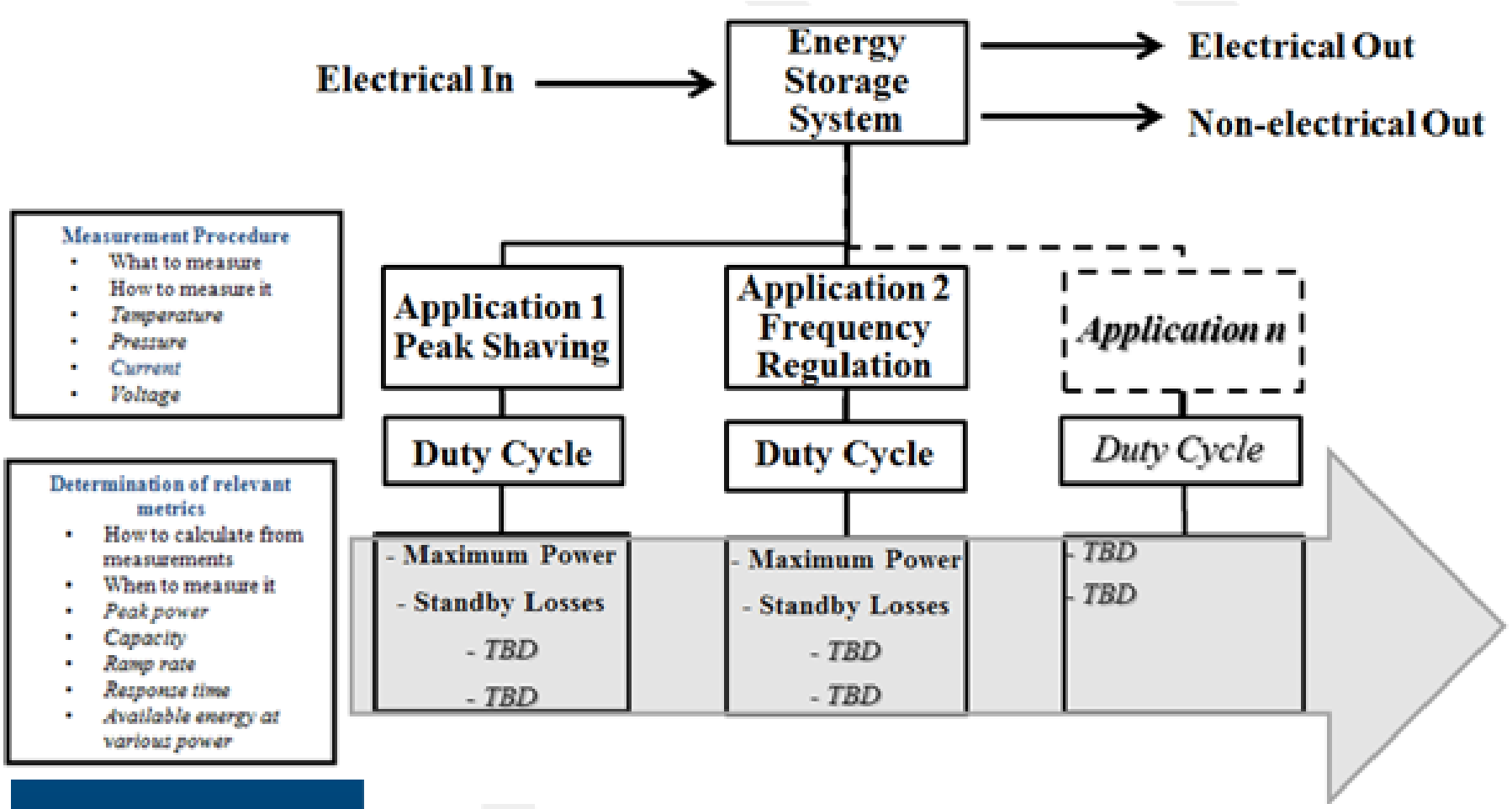

Figure 4-1 Protocol Overview

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Summary of Technical Criteria

- **Applications**
  - Frequency regulation
  - Peak shaving
- **Duty cycle established**
- **Metrics**
  - Round trip efficiency at rated power
  - Round trip efficiency using duty cycle for fixed duration
  - Response time
    - Time to respond after signal receipt
    - Ramp rate
- **Reference Performance**
  - Measure energy capacity before and after subjecting to fixed duration duty cycle
- **Definitions**
  - Energy storage system
  - Rated power
  - Energy capacity
  - Response time
  - Ramp rate
  - Round trip efficiency

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Frequency Regulation

- Area regulation used by BA to meet NERC BA Performance Control Standards
- ESS subjected to PJM duty cycle
- Round trip efficiency @ rated power = disch energy/charge energy
- Round trip efficiency during duty cycle measured by subjecting ESS to duty cycle from desired initial SOC and bringing ESS back to initial SOC after duty cycle
  - Round trip efficiency = total discharge energy/total charge energy
- Response time measured at extreme SOC – time from no load to full discharge rated power, no load to full charge rated power
- Response time includes time to respond to signal + time to ramp to desired power
- Ability of ESS to track signal $\Sigma(P_{signal}-P_{ess})^2$, $\Sigma|P_{signal}-P_{ess}|$, $\Sigma|E_{signal}-E_{ess}|$ - % total tracking also reported

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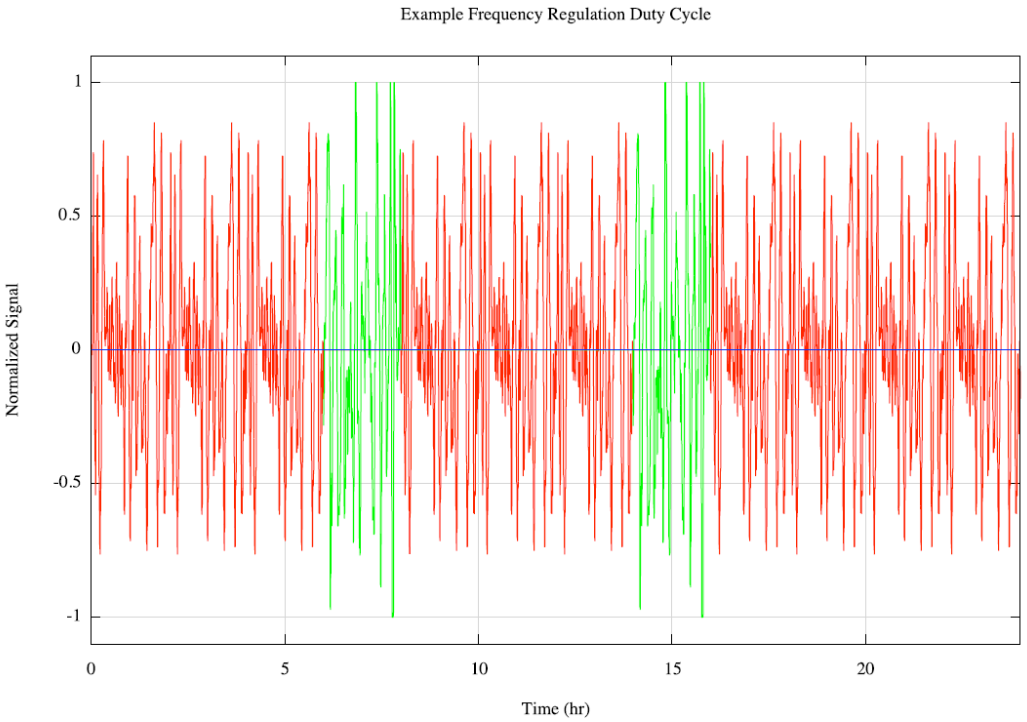
Frequency regulation duty cycle

- Duty cycle determined from PJM balancing signal for year 2011
- Standard deviation over a 24-hour period used as metric for signal aggressiveness
- Signals grouped into low, average and high standard deviations
- Representative 2-hour intervals with average standard deviation and 1-hour intervals with high standard deviation chosen
  - each being energy neutral
- Duty cycle consisted of three 2-hour average standard deviation (SD) signals followed by two 1-hour high SD signals, three 2-hour average standard deviation (SD) signals followed by two 1-hour high SD signals and four 2-hour average SD signals



Peak Shaving

Peak Shaving Applications defined in Protocol

Application	Expected Range of Required Discharge Duration	Projected Power Range of Installations
Energy Time Shift (Arbitrage)	3-7 hours	1-500MW
Supply Capacity	4-6 hours	1-500MW
Load Following	2-4 hours	1-500MW
Transmission Congestion Relief	3-5 hours	1-100MW
Distribution Upgrade Deferral	3-6 hours	0.2-20MW
Transmission Upgrade Deferral	3-6 hours	1-100MW
Retail Demand Charge Management	4-6 hours	0.05-10MW
Wind Energy Time Shift (Arbitrage)	3-6 hours	0.2-500MW
Solar Energy Time Shift (Arbitrage)	3-5 hours	0.2-50MW
Renewable Capacity Firming	2-3 hours	0.1-500MW
Baseload generation time shift*	4-6 hours	10MW-500MW

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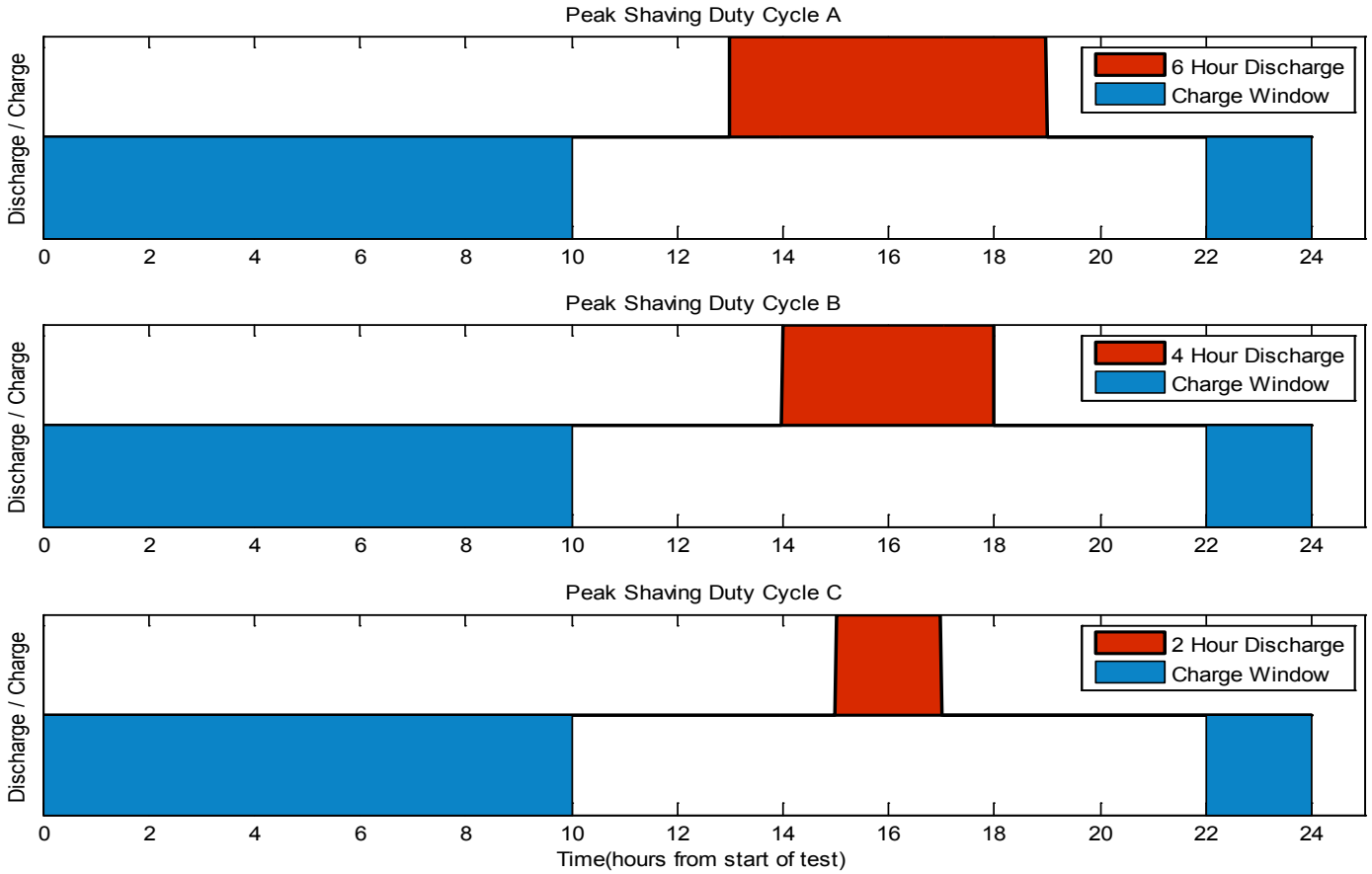
Peak Shaving Duty Cycles

Peak Shaving Duty Cycles as Defined in the Protocol



Discharge duration is primary differentiator between peak shaving applications

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Next Steps

- Application of the initial protocol by the industry and use of results by storage technology customers
- Further refinement based on its application and use
- Use as a basis for consensus standards by US and/or international standards developing organizations (SDOs)
- Development of new provisions to address additional applications and performance metrics
- Application and use of new provisions, further refinement and transition through the protocol to US and/or international SDOs
- Continue to strengthen and broaden our unique public-private collaborative process

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