Energy Storage Performance Test Protocols Development for Multiple Grid Applications

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Project Overview

Energy Storage Challenge

- How do we compare performance of different storage technologies on an apples to apples basis? Huge challenge for the end user to evaluate various technologies.

Project Objective

- Develop an approach to determine performance of energy storage to help stakeholders evaluate multiple storage technologies for various applications.

Accomplishments

- Completed 7 applications to date, and nearing completion on the 8^{th}
- Two “Performance Protocol” documents released, with a 2^{nd} Revision slated for end of FY2015
- Protocol has been adopted/adapted by IEC TC120 Metrics & Performance Working Group
- Protocol has been adopted/adapted by EPRI ESIC Metrics & Performance Working Group
- Multiple users have used test driven the protocol to evaluate storage systems
- There is acceptance in the US and internationally about the importance of this work as a standard bearer for evaluation of storage performance.

Overview

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Purpose

- ✓ Overview of protocol - status
- ✓ How to use the protocol
- ✓ What the metrics mean
- ✓ Experiences to date applying the protocol
- ✓ Current activities

Expected outcome

- ✓ Allow apples to apples comparison of various ESS technologies

Project Status

- Initiated March 2012, first protocol released November 2012, first revision released June 2014, second revision to be released end of FY15
- Has been test driven by multiple users to report system performance
- Currently being used as a basis for US (NEMA and ASME) and International (IEC) standards covering energy storage system performance
- Eight applications have been completed

Protocol Overview

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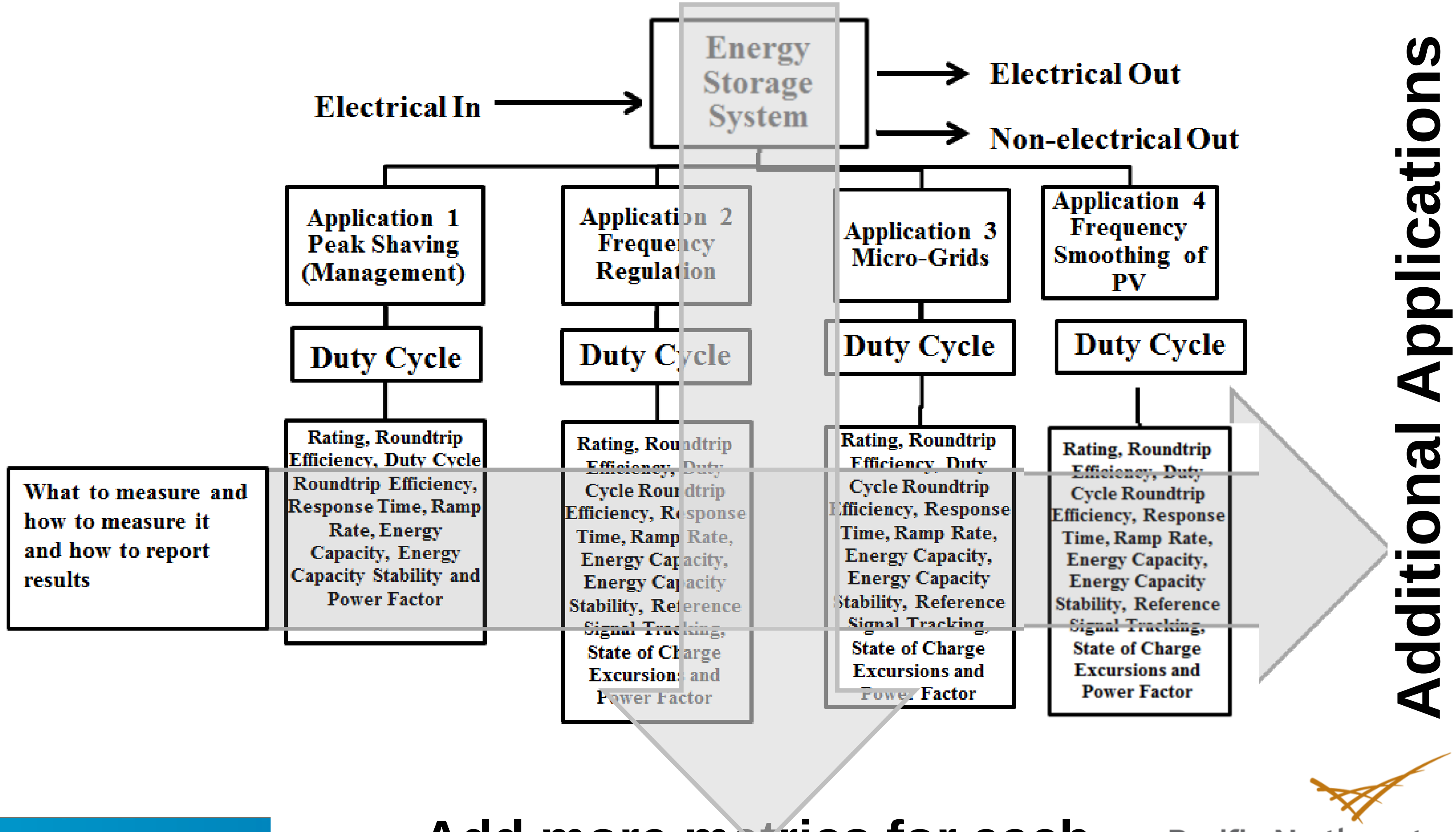

Add more metrics for each application as relevant

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Current Applications and Metrics

- Applications
  - Peak shaving
  - Frequency regulation
  - Islanded micro-grids
  - *Volt-Var*
  - *Power Quality*
  - *Frequency Control*
  - *PV Smoothing*
  - *Renewable firming / load following*

What the Metrics Mean

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- Rating – rated power performance of the system for a particular application (this is a specification, not a metric)
- Roundtrip efficiency from stored energy capacity (%) – useful energy output divided by energy input over a cycle under normal operating conditions
- Duty cycle roundtrip efficiency (%) – the energy removed from a system at a given power by the energy required to recharge the system over the application specific duty cycle
- Response time (sec) – time it takes a system to reach 100% of rated power during charge or to discharge 100% of rated power during discharge (from an initial at rest measurement)
- Ramp rate (MW/min or %/min) – rate of charge of power (real or reactive) delivered to or absorbed by a system over time

What the Metrics Mean

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- Energy capacity (Btu or Wh) – the amount of energy the system can store at rated electrical or thermal power
- Energy capacity stability (% of initial performance) – stored energy capacity divided by the initial stored energy capacity
- Reference signal tracking (%) – the ability of the system to respond to a reference signal as % of time the signal is tracked
- State of charge excursions – continuous monitoring during required testing and integrating the current with respect to time for each half-cycle (current and power are of the same sign)
- Energy lost (or gained) after Volt-VAR support

Applications addressed in FY15

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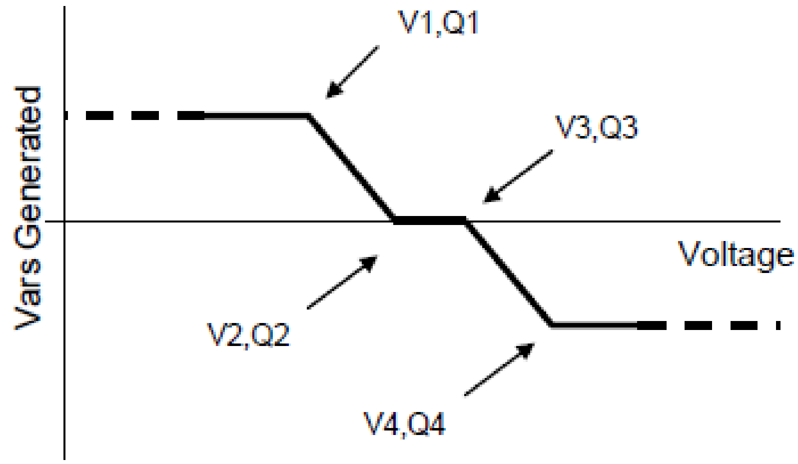
- Volt/VAR support
- Power quality
- Frequency control
- PV Smoothing
- Renewable (wind or solar) firming & load following over 24 hours)
- Identified new metrics that are relevant and needed

Volt-VAR Overview

- Various VAR control approaches - Unity power factor (PF), Fixed PF, Variable PF, Volt-VAR
- Protocol developed for ESS doing ONLY Volt-VAR
- Available reactive power = rated power
- ESS absorbs reactive power when grid voltage too high
- ESS sources reactive power when grid voltage too low
- Mainly used in distribution grids
  - 120V, 240V residential
  - ~ 5kV commercial
  - 25-50 kV industrial
- Various functional relationships of ESS reactive power as a function of grid voltage are available *(Smart Inverter Working Group SAND2013-9875, EPRI)*

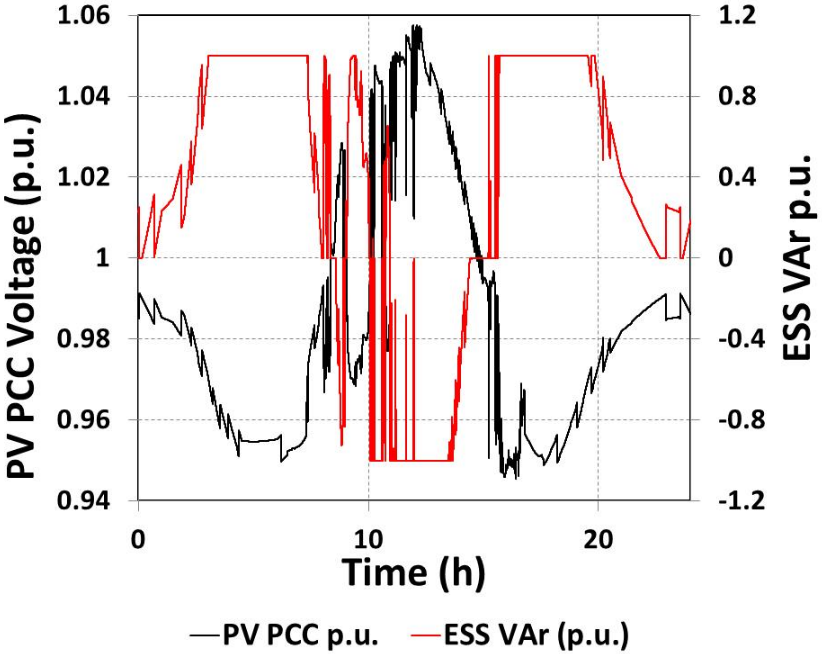
Volt-VAR Overview

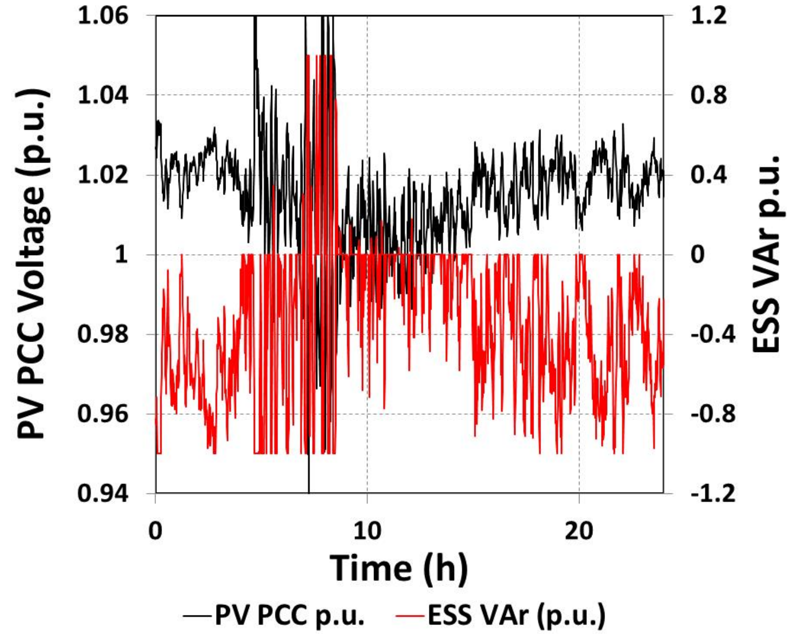
- The reactive power Q varies as a function of the ESS terminal voltage V
- A deadband Q2-Q3 exists around the nominal voltage.
  - Q1 and Q4 are 100% of ESS rated power, while V1 is 97% of nominal grid voltage, and V4 is 103% of nominal grid voltage



- Developed for smart PV inverters but easily adapted for ESS
- For only Volt-VAR support, reactive power = ESS rated power in MVA
- 24-hour duty cycle

Volt-VAr duty cycle





- For PV PCC at the end of a California 4 kV feeder.
- Voltage simulated in OpenDSS for highest load day on the feeder (12/20/2012)
- Received from Jay Johnson of Sandia
- Aggressive duty cycle for PCC voltage varying between 0.94 to 1.06 p.u.

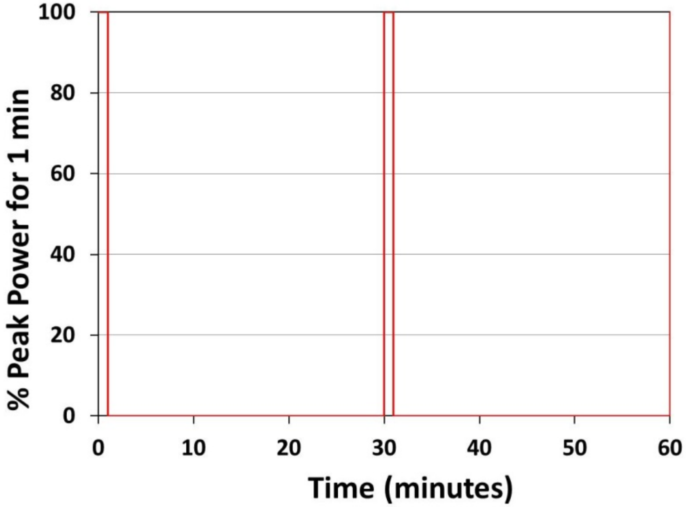
- IEEE 8500 node system replicated and validated in GridLAB-D™
- Actual utility radial circuit, heavily loaded and has voltage control issues along feeder.
- Residential PV added to houses
- GridLabD simulation done by Jason Fuller and Sri Gourisetti of PNNL
- Used aggressive duty cycle

Volt-VAR Metrics

- Round trip efficiency
- Energy capacity and energy capacity stability
- Duty cycle specific metrics
- Duty cycle RTE - duty cycle round trip efficiency supposed to be since no real power being exchanged
- Reference signal tracking
- Reactive power response time
- Reactive power ramp rate at 50% SOC
- New metric - Loss or gain of energy after 24-hour duty cycle
  - How to measure? Bring ESS to desired starting SOC. After 24-hour duty cycle, discharge to 0% SOC to determine capacity – then compare with starting SOC to determine loss or gain of capacity (this measurement also yields SOC excursion)
- State of charge excursion

Power Quality Overview and Metrics

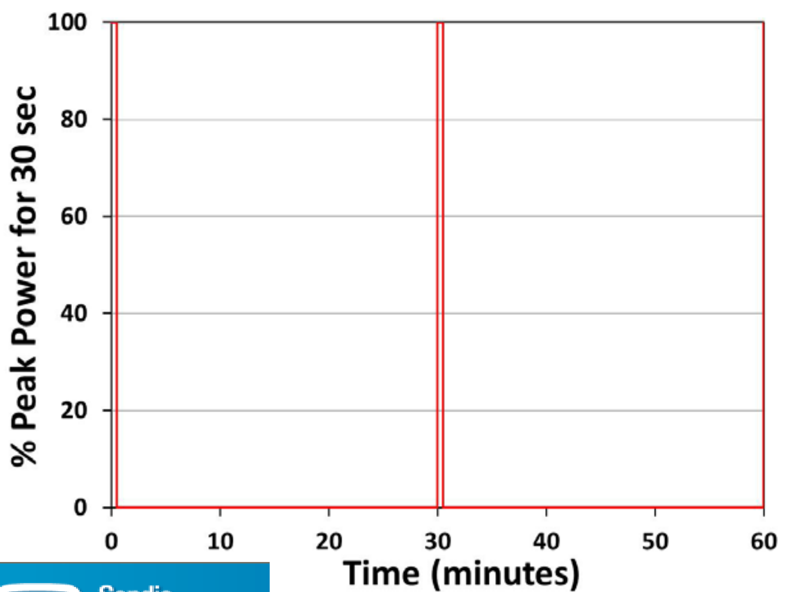
- A sag or interruption in voltage can cause power disturbances that negatively impact power quality (more common in distribution systems)
- The duty cycle consists of continuous discharge at peak (max.) power for
- 1 min (24-h)
- 5 min (12-h) and
- 10 min (6-h)



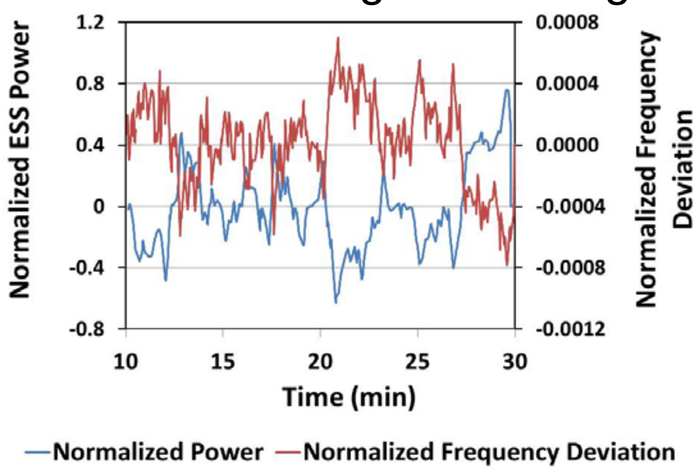
- Metrics
  - Round trip efficiency
  - Response time and ramp rate
  - Energy capacity and energy capacity stability
  - Duty cycle specific metrics
  - Peak power for 1 min, 5 min, 10 min
  - Duty cycle round trip efficiency. Reference signal tracking
    SOC excursion

Frequency Control Overview and Metrics

- Sudden loss of generation – needs injection of real power for 30 sec (primary frequency control); injection for 20 min (secondary frequency control)
- Duty cycle (charge for sudden loss of lead)
  - Discharge at 30-s peak power for 30 sec (primary freq control)
  - Discharge @ rated power for 20m (secondary freq control)



- Metrics
  - Round trip efficiency
  - Response time and ramp rate
  - Energy capacity and energy capacity stability
  - Duty cycle specific metrics
  - Peak power for 1 min
  - Duty cycle round trip efficiency Reference signal tracking



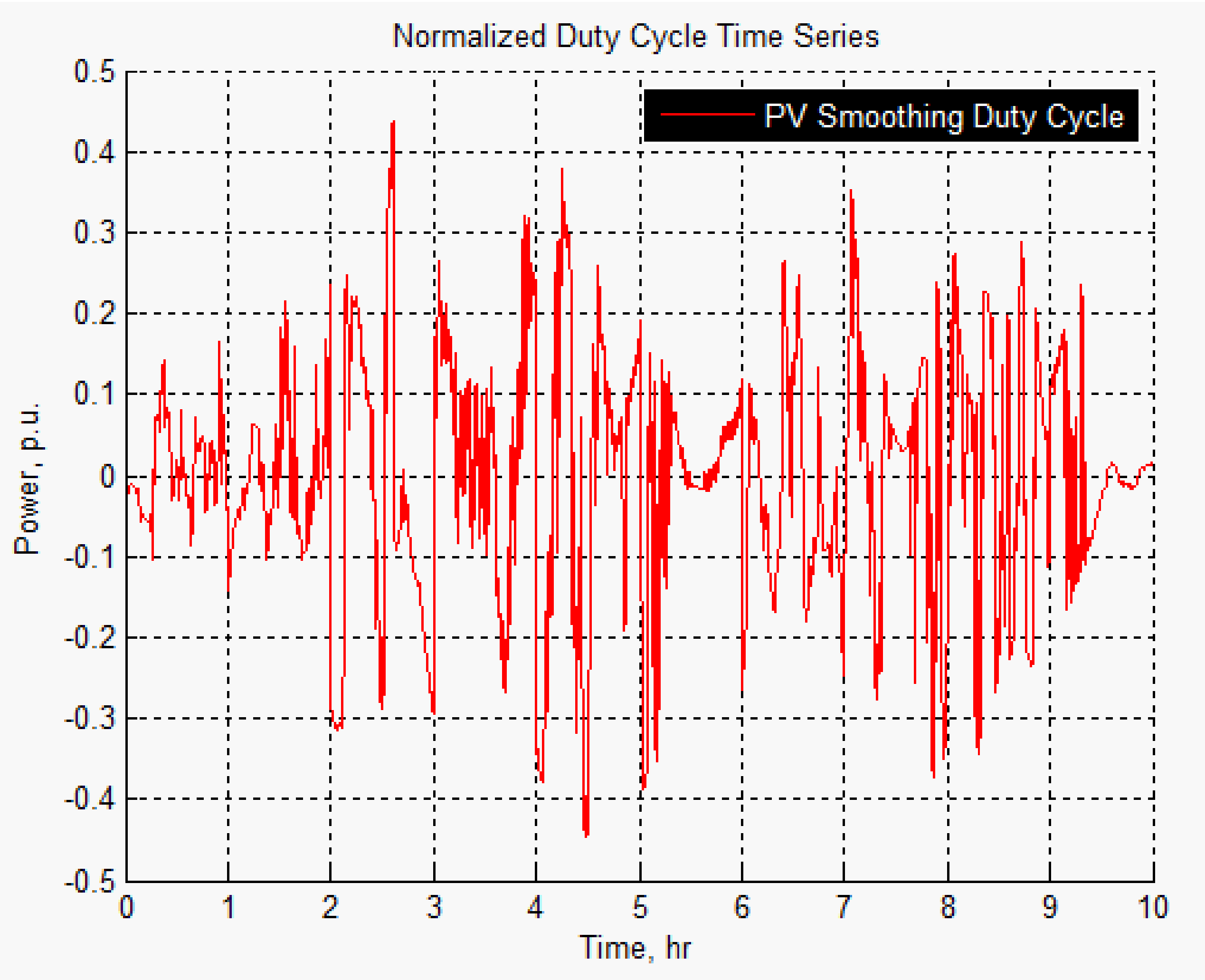
Dynamic frequency control

Didier Colin et al ERDF/SAFT/Schneider Electric and others – Venteea 2 MW 1.3 MWh battery system. Lyon France 15-18 June 2015

PV Smoothing Overview

- The use of an ESS to mitigate **rapid fluctuations** in PV power
- Primary uses:
  - Mitigate frequency variation and voltage stability issues that can arise from **high penetration PV**
  - Meet ramp rate requirements
  - Distribution – Mitigate voltage flicker and voltage excursions outside desired bands
  - Transmission – Reduce the need to set aside additional operating reserve
- Basic Operation:
  - ESS absorbs or supplies power at appropriate times as determined by a control system resulting in a less variable composite power signal

PV Smoothing Duty Cycle



Duty Cycle Features:

- 10 hour signal
- Corresponds to a day with high variability of PV irradiance
- Signal is normalized and approx. zero mean ➔
- Power intensive
- Not Energy intensive

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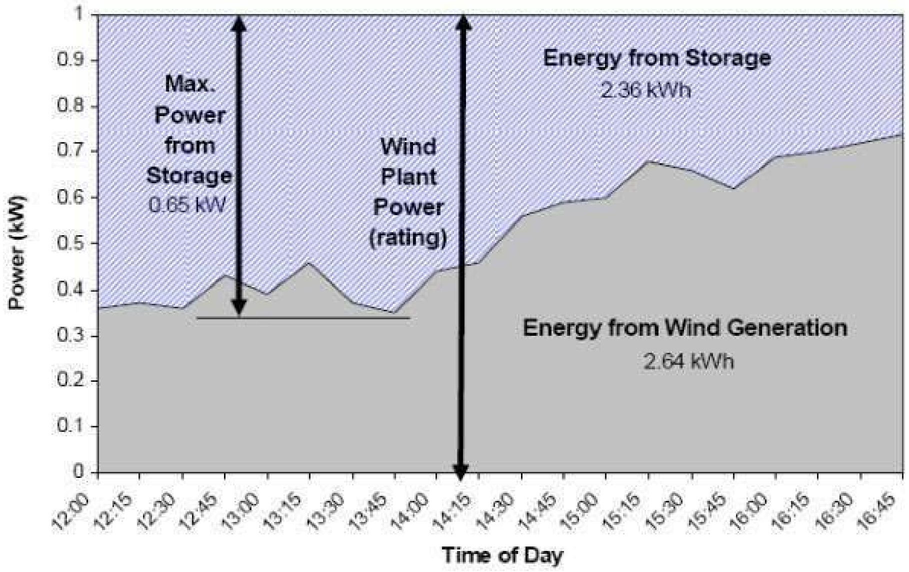
Renewable (Wind or Solar) Firming

- Overview
  - The use of ESS power to supplement renewable generation such that their combination produces steady power output over a desired time window.
  - Often, the ESS is used to compensate for the forecast uncertainty in actual renewable generation during this time window.

Key difference from smoothing:

- **Smoothing** is attempting to limit ramp rate ➔ one second to one minute durations.
- **Renewable firming** is more concerned with 15 minute to multiple hour time periods.



From: Elisabeth Lemaire, Nicolas Martin, and Per Norgard, “European White Book on Grid Connected Storage,” European Distributed Energy Resources Laboratories Report No. R-003.0, 2011.

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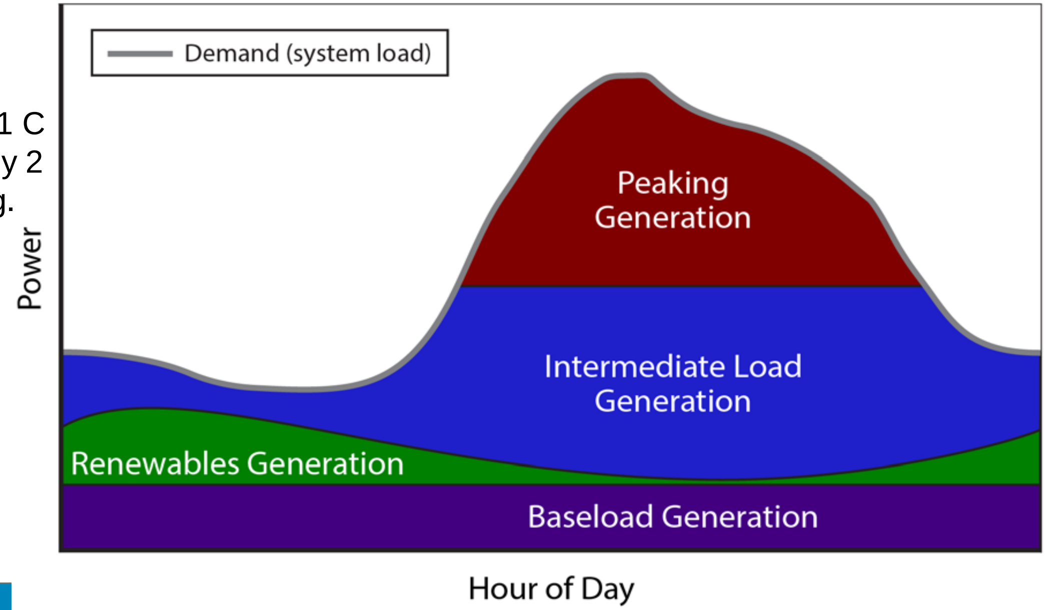
Load Following over 24 Hours

- Overview
  - The use of ESS output power to achieve a balance between electric supply and end-user demand within a specific area, over a 24 hour time window.
  - Method: ESS supplies power during time periods in which load exceeds generation and absorbs power during periods in which generation exceeds load. These time periods are typically about 15 minutes.

Assume 1 hour of discharge duration at 1 C provides approximately 2 hours of load following.



Technical Considerations:
Storage Size Range: 1 – 100 MW
Discharge Duration: 15 minutes – 1 hour

From: A. A. Akhil et al, DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA, SAND2013-5131, July 2013.

Metrics for PV Smoothing, Renewable Firming, and Load Following Applications

- System Rating – @ ambient conditions
- Roundtrip Energy Efficiency – for entire ESS
- Duty-Cycle Roundtrip Efficiency – for entire ESS
- Response Time of ESS in responding to a command signal – does not include communication delay times
- Ramp Rate
- Energy Capacity
- Energy Capacity Stability
- Reference Signal Tracking – how well does ESS track the reference signal: |reference signal power – ESS power|^2
- State-of-Charge Excursions
- Maximum Ambient Temperature

Users of the protocol

- Multiple BESS vendors
  - Have provided mostly positive feedback
- PNNL/Powin Energy for BPA funded project (among the first users)
- GridSTAR (Penn State) Philadelphi Naval Shipyard Mcirogrid
- IEC TC120 working group 2 (Performance) has co-opted this work (International impact)
- EPRI-ESIC working group 2 (Performance) has co-opted this work (National and International impact)
- PNNL is working with 3 utilities on 5 BESS and using this work for baseline testing (Washington Chamber of Commerce Clean Energy Funds)

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Technical Specifications Being Added

A new category of information in the protocol that is 'blind' as to intended application, provides relevant information on any ESS for any application and is self-reported where manufacturers and integrators can provide values they measure and use those in the market

- Storage Temperature and Humidity Range
- Temperature Operating Range
- System Dimensions and Weight
- Startup time
- Shut down time
- Control power UPS back-up time
- Overload reactive/real power
- Power curve capability

Summary

- The protocol is available for application and use by anyone and is being used as a basis for formal US and International Standards
- The protocol forms the basis for technical communication between proponents and users of energy storage systems
- The protocol is being updated to address market needs associated with additional system applications, new metrics relevant all applications and the inclusion of system specifications
- This is a live document - enhancement to current metrics is also underway based on market needs and experiences using the protocol
- National and International impact

Questions and Contact Information

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www.pnnl.gov/main/publications/external/technical_reports/PNNL-22010Rev1.pdf - 1030k - 2014-06-24

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- External Contributors
  - Various working groups for each application
  - Performance metrics measurement working group
  - EPRI ESIC (WG1, WG2, WG3
  - Smart Inverter Working Group (Volt-VAR)
    - PV PCC voltage data received from Sandia National Laboratory
  - SGIP DRGS SubGroup C - Microgrids
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