Energy Storage Technology Advancement Partnership (ESTAP) Webinar:

Measuring Energy Storage System Performance: A Government/ Industry-Developed Protocol

June 30, 2016

Hosted by Todd Olinsky-Paul
ESTAP Project Director
Clean Energy States Alliance

Housekeeping

All participants are in “Listen-Only” mode. Select “Use Mic & Speakers” to avoid toll charges and use your computer’s VOIP capabilities. Or select “Use Telephone” and enter your PIN onto your phone key pad.

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This webinar is being recorded.

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www.cesa.org/webinars

State & Federal Energy Storage Technology Advancement Partnership (ESTAP)

Todd Olinsky-Paul

Project Director

Clean Energy States Alliance (CESA)

Thank You:

Dr. Imre Gyuk
U.S. Department of Energy,
Office of Electricity Delivery and
Energy Reliability

Dan Borneo
Sandia National Laboratories

ESTAP is a project of CESA

Clean Energy States Alliance (CESA) is a non-profit organization providing a forum for states to work together to implement effective clean energy policies & programs:

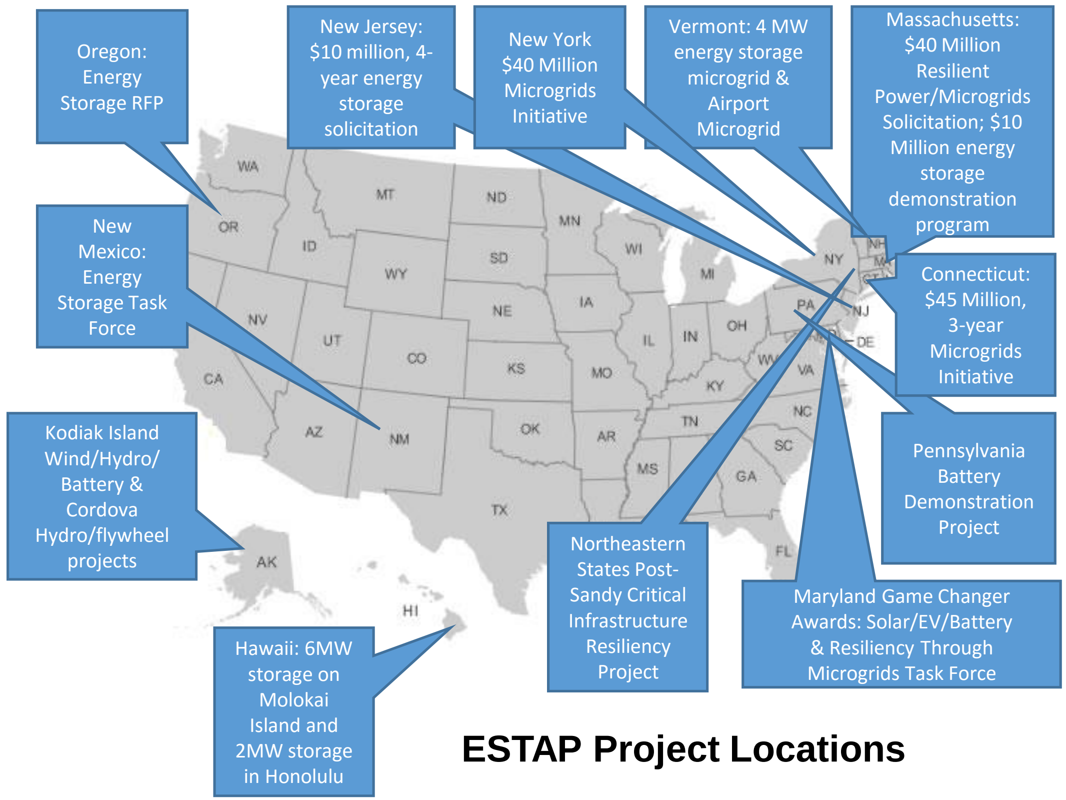
State & Federal Energy Storage Technology Advancement Partnership (ESTAP) is conducted under contract with Sandia National Laboratories, with funding from US DOE.

ESTAP Key Activities:

1. Disseminate information to stakeholders
   - ESTAP listserv >3,000 members
   - Webinars, conferences, information updates, surveys.

2. Facilitate public/private partnerships to support joint federal/state energy storage demonstration project deployment

3. Support state energy storage efforts with technical, policy and program assistance



ESTAP Project Locations

Clean Energy States Alliance

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

Energy Storage Technology Advancement Partnership

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Overview

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Project Director: Todd Olinsky-Paul

Contact: Todd Olinsky-Paul, Todd@cleanegroup.org

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The Energy Storage Technology Advancement Partnership (ESTAP) is a federal-state funding and information sharing project, managed by CESA, that aims to accelerate the deployment of electrical energy storage technologies in the U.S.

The project's objective is to accelerate the pace of deployment of energy storage technologies in the United States through the creation of technical assistance and co-funding partnerships between states and the U.S. Department of Energy.

ESTAP conducts two key activities:

1) Disseminate information to stakeholders through:

- The ESTAP listserv (>2,000 members)
- Webinars, conferences, information updates

NEW RESOURCES

October 14, 2015

Resilience for Free: How Solar+Storage Could Protect Multifamily Affordable Housing from Power Outages at Little or No Net Cost

By Clean Energy Group

September 30, 2015

Webinar Slides: Energy Storage Market Updates, 9.30.15

UPCOMING EVENTS

December 16, 2015

ESTAP Webinar: State of the U.S. Energy Storage Industry,

More Events

LATEST NEWS

November 30, 2015

Massachusetts Takes the Lead on Resilient

Today’s Guest Speakers

- **Dr. Imre Gyuk**, Program Manager, Energy Storage Research, Office of Electricity Delivery & Energy Reliability, U.S. Department of Energy
- **David Conover**, Senior Technical Advisor, Pacific Northwest National Laboratory
- **Vilayanur Viswanathan**, Senior Engineer, Pacific Northwest National Laboratory
- **David A. Schoenwald**, Principal Member Technical Staff, Sandia National Laboratories

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Putting Energy Storage Performance on a more Objective Basis

IMRE GYUK, PROGRAM MANAGER
ENERGY STORAGE RESEARCH, DOE

Performance-based Standards of Measurements for Energy Storage Systems

8 Specific Use Cases

Protocol Represents Industry Consensus

Will Provide Basis for fair Comparisons between different Technologies

Promotes Consumer Confidence, May lead to Product Improvement, Allows tracking Performance, Improves Performance Guarantees, Allows better Insurance Deals, Clarifies the Value Proposition …..

Measuring and Expressing the Performance of Energy Storage Systems

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Update on and Overview of Revision 2 to the PNNL/SNL Protocol

June 30, 2016

PNNL-SA-118995/SAND2016-6155 PE

Purpose and Expected Outcome

Purpose

Provide an update on enhancements to the *Protocol for Measuring and Expressing Energy Storage System Performance*

Expected Outcome

An understanding of the new metrics, applications and improved format in the protocol leading to increased application and use of the protocol

Background

Problem prior to 2012 - lack of a uniform and repeatable method for determining and expressing system performance

- March 2012 – project initiated under DOE OE ESS Program to involve all interested stakeholders in the development of a protocol/pre-standard for immediate use and as a basis for US and international standards
- November 2012 – first version of the protocol completed (2 applications 7 performance metrics)
- June 2014 – second version completed (added 1 more application and enhanced selected provisions)
- April 2016 – third version completed (added 5 more applications, more metrics and revised format for ease of use)

Protocol Overview

- Describe ESS (boundary and system content) – 4.2
- Identify ESS Application(s) – 4.3
- Specifications and Performance Metrics – 4.4
- Measurements and Determination of Performance Metrics – 4.5
- Reporting of Results – 4.6

Applications Addressed

- Peak shaving
- Frequency regulation
- Islanded microgrids
- Volt/Var support NEW
- Power quality NEW
- Frequency control NEW
- PV Smoothing NEW
- PV Firming NEW

- Work for each new application
  - ✓ Describe and define the application
  - ✓ Develop appropriate duty cycle(s)
  - ✓ Confirm which existing metrics are applicable and if necessary adjust them for the application
  - ✓ Identify new metrics that are relevant and needed

General Information and Tech Specs

NEW

Table 4.4.1 General Information and Technical Specifications

Subject	Description
Enclosure Type	A description of the system enclosure, including any enclosure supplied with the system, provided as a part of the site installation and/or comprised of building assemblies associated with the installation.
Equipment Footprint	L x W of system including all ancillary components (sq. ft.).
Height	Equipment height plus safe clearance distances above the equipment (ft.).
Weight	Weight of each individual sub-system (PCS, ESS, accessories, etc.), including maximum shipping weight of largest item that will be transported to the project site (lbs.).
Grid Communication Protocols/Standards	List of communications related protocols and standards with which the ESS is compliant.
General Description of the Energy Storage System	Identification of the energy storage technology type (e.g. battery type, flywheel, etc.) used in the ESS.

Table 4.4.1 added in response to and based on input from EPRI ESIC

General Information and Tech Specs

NEW

Table 4.4.1 (Cont.) General Information and Technical Specifications

Subject	Description
Warranty & Replacement Schedule	Warranty inclusions and exclusions, including replacement schedules and timespan of warranty and any limitations.
Expected Availability of System	Percentage of time that the ESS is in full operation performing application-specific functions taking into account both planned and unplanned down-time.
Rated Continuous Discharge Power	The rate at which the ESS can continuously deliver energy for the entire specified SOC range of the storage device that comprises the ESS.
Rated Apparent Power	The real or reactive power (leading and lagging) that the ESS can provide into the AC grid continuously without exceeding the maximum operating temperature of the ESS.
Rated Continuous Charge Power	The rate at which the ESS can capture energy for the entire SOC range of the storage device that comprises the ESS.

Table 4.4.1 added in response to and based on input from EPRI ESIC

General Information and Tech Specs

Table 4.4.1 (Cont.) General Information and Technical Specifications

NEW

Subject	Description
Rated Continuous AC Current (discharge and charge)	The AC current that the ESS can provide into the grid continuously and can be charged by the grid continuously without exceeding the maximum operating temperature of the ESS.
Output Voltage Range	The range of AC grid voltage under which the ESS will operate in accordance with the ESS specification.
Rated Discharge Energy	The accessible energy that can be provided by the ESS at its AC terminals when discharged at its beginning of life (BOL) and end of life (EOL).
Minimum Charge Time	The minimum amount of time required for the ESS to be charged from minimum SOC to its rated maximum SOC.

Table 4.4.1 added in response to and based on input from EPRI ESIC

Reference Performance

Table 4.4.2 Reference Performance

Subject	Description
Stored Energy Capacity (Section 5.2.1)	The amount of electric or thermal energy capable of being stored by an ESS expressed as the product of rated power of the ESS and the discharge time at rated power.
Round Trip Energy Efficiency (5.2.2)	The useful energy output from an ESS divided by the energy input into the ESS over one duty cycle under normal operating conditions, expressed as a percentage.
Response Time (Section 5.2.3)	The time in seconds it takes an ESS to reach 100 percent of rated power during charge or from an initial measurement taken when the ESS is at rest.
Ramp Rate (Section 5.2.3)	The rate of change of power delivered to or absorbed by an ESS over time expressed in megawatts per second or as a percentage change in rated power over time (percent per second).
NEW **Reactive Power Response Time (Section 5.2.3)**	The time in seconds it takes an ESS to reach 100 percent of rated apparent power during reactive power absorption (inductive) and sourcing (capacitive) from an initial measurement taken when the ESS is at rest.

Table 4.4.2 Applies to ALL ESS regardless of intended application(s)

Reference Performance

Table 4.4.2 (Cont.) Reference Performance

	Subject	Description
NEW	**Reactive Power Ramp Rate (Section 5.2.3)**	The rate of change of reactive power delivered to (inductive) or absorbed by (capacitive) by an ESS over time expressed as MVAr per second or as a percentage change in rated apparent power over time (percent per second).
NEW	**Internal Resistance (Section 5.2.3)**	The resistance to power flow of the ESS during charge and discharge.
NEW	**Standby Energy Loss Rate (Section 5.2.4)**	Rate at which an energy storage system loses energy when it is in an activated state but not producing or absorbing energy, including self-discharge rates and energy loss rates attributable to all other system components (i.e. battery management systems (BMS), energy management systems (EMS), and other auxiliary loads required for readiness of operation).
NEW	**Self-discharge Rate (Section 5.2.5)**	Rate at which an energy storage system loses energy when the storage medium is disconnected from all loads, except those required to prohibit it from entering into a state of permanent non-functionality.

Table 4.4.2 Applies to ALL ESS regardless of intended application(s)

Enhancements Related to Reference Performance

- Run reference performance tests ONCE regardless of intended ESS application(s)
- In Rev. 1, the 1st cycle was excluded from cumulative RTE calculation. Included 1st cycle in Rev. 2
- In Rev 1, individual cycle RTE was excluded and it is now included individual RTE
- Added separate equations for the case when auxiliary load is powered by a separate line
- For capacity test the test may begin with charge OR discharge
- Result tables for capacity test specify maximum power and average power during charge and discharge

Duty-cycle Performance

Table 4.4.3(a.) Duty-cycle Performance

Subject	Description
Duty-cycle Round Trip Efficiency DC RTE (Section 5.4.1)	The useful energy output from an ESS divided by the energy input into the ESS over a charge/discharge profile that represents the demands associated with a specific application that is placed on an ESS, expressed as a percentage.
Reference Signal Tracking RST (Section 5.4.2)	The ability of the ESS to respond to a reference signal.
State of Charge Excursions SOCX (Section 5.4.3)	The maximum and minimum SOC attained by the ESS during the execution of the duty cycle.
Energy Capacity Stability ECS (Section 5.4.4)	The energy capacity at any point in time as a percent of the initial energy capacity.

- ***RST does not apply to peak shaving***
- ***DC RTE does not apply to Volt/Var***

Duty-cycle Performance

Table 4.4.3(b.) Duty-cycle Performance – Added Metrics for Volt-var

Subject	Description
SOC_Volt-Vr (Section 5.4.5.1)	The difference between the final and initial SOC shall be reported, along with the initial SOC
SOC_active standby (Section 5.4.5.1)	The difference between the final and initial SOC at the end of an active standby of same duration as Volt-var duty cycle with auxiliary load turned on, with the initial SOC the same as the value at the start of the Volt-var duty cycle shall be reported.
Wh_discharge (Section 5.4.5.1)	The real energy injected (with and without Volt-var duty cycle)
Wh_charge (Section 5.4.5.1)	The real energy absorbed (with and without Volt-var duty cycle)
Wh_net (Section 5.4.5.1)	The net energy (injected or absorbed) (with and without Volt-var duty cycle)

Duty-cycle Performance

Table 4.4.3(c.) Duty-cycle Performance – Added Metrics for Power Quality and Frequency Control

Subject	Description
Peak Power (Section 5.4.5.2 or Section 5.4.5.3 for Power Quality or Frequency Control Applications Respectively)	The peak power the ESS can provide for a specific duration.

Enhancements Related to Duty-cycle Performance

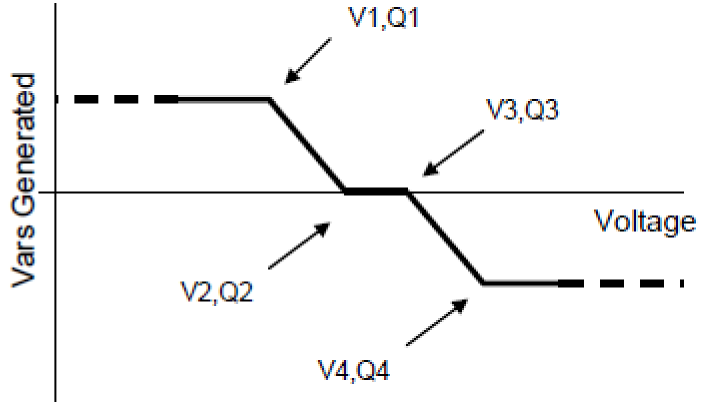
- Run duty-cycle tests in conjunction with reference performance tests
- Use same test set up and data gathering scheme – just run the duty-cycle tests using the duty-cycle for each intended ESS application
- For peak shaving tests, the duty cycle may begin with charge OR discharge
- Result tables for the peak shaving test specify maximum power and average power during charge and discharge
  - For charge, since charge duration is 12 hours, the charge power may taper at some point
  - For discharge at various powers (6h, 4h, and 2h), the power may taper off towards the end

Overview of Volt-Var, Power Quality and Frequency Control

- Various var control approaches
  - Unity power factor (PF), Fixed PF, Variable PF, Volt-var
- This work looks at Volt-var
  - During this operation, ESS does ONLY Volt-var
- Available reactive power = rated apparent power
- Absorb reactive power when grid voltage too high
- Source reactive power when grid voltage too low
- Mainly used in distribution grids
  - 120V, 240V residential
  - ~ 5kV commercial
  - 25-50 kV industrial
- Various functions of reactive power needed as f(grid voltage) available (Smart Inverter Working Group, SAND2013-9875, EPRI)

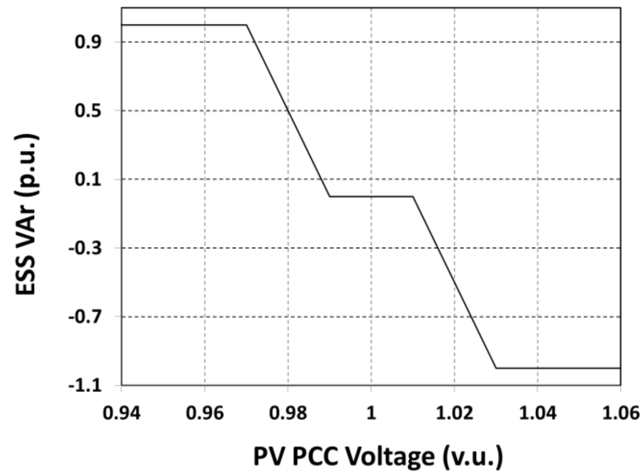
Volt-var

- The reactive power varies as a function of the ESS terminal voltage – this function is a “piecewise linear” between pairs of Qi and Vi, where Qi is ESS reactive power output and Vi is ESS terminal voltage

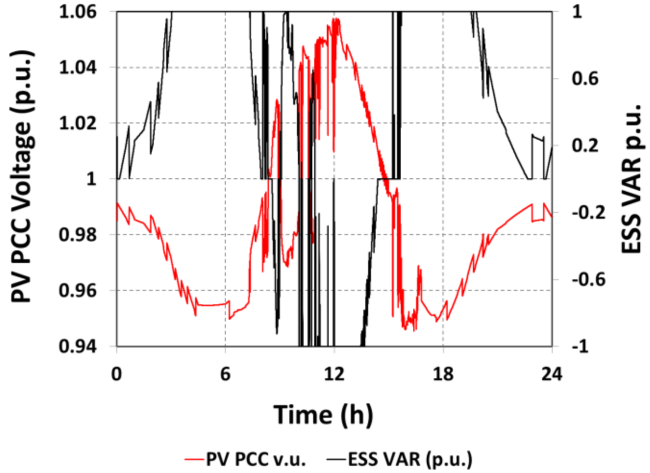


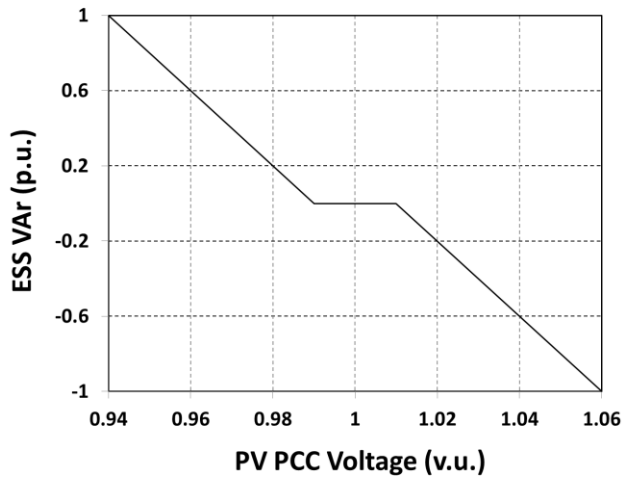
- There is a deadband around the nominal voltage. Q1 and Q4 are 100% of ESS rated power, while V1 is 97% of rated power, and V2 103% of rated power
- While developed for PV inverters, this is easily adapted for ESS - for only Volt-Var the reactive power is simply equal to ESS rated power in MVA
- Repeating this for grid systems with and without PV is expected to cover the range of Volt-var needs
- Testing the ESS for 24 hours continuously is expected to yield a sufficiently stressful test to determine reliability

Volt-var summary ESS power as f(grid voltage)

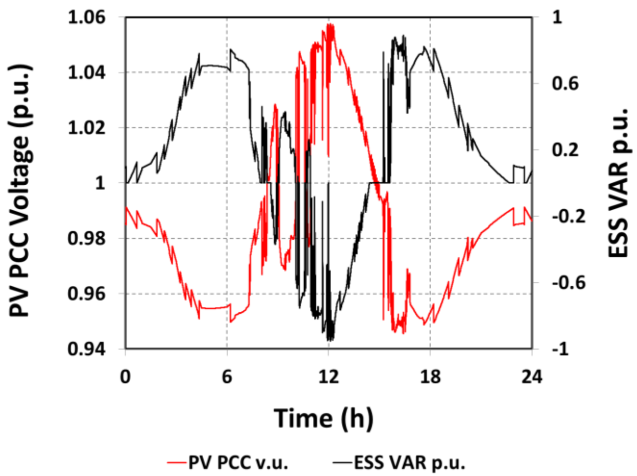


Aggressive case





Moderately Aggressive case



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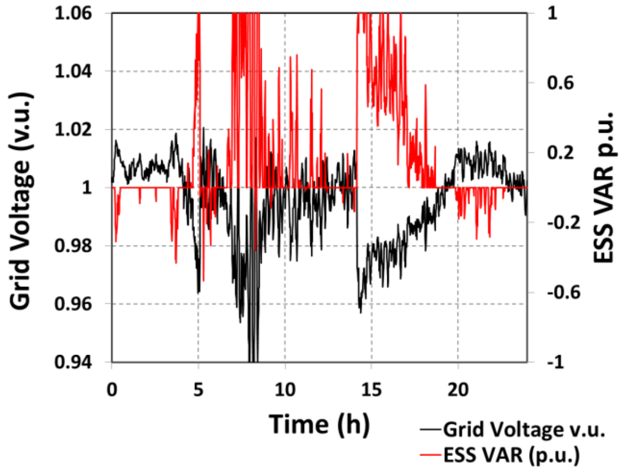
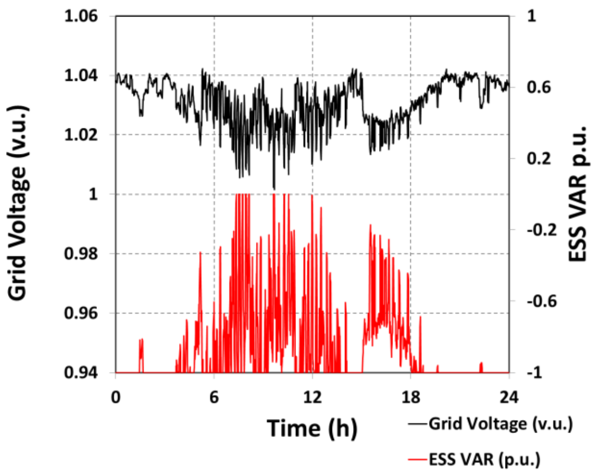
Aggressive Volt-var signal applied to Grid Lab-D generated voltage at 3 different Feeder Locations





Distribution grid feeder voltage with
1) deviations above and below the reference voltage
2) deviation mostly greater than the reference voltage

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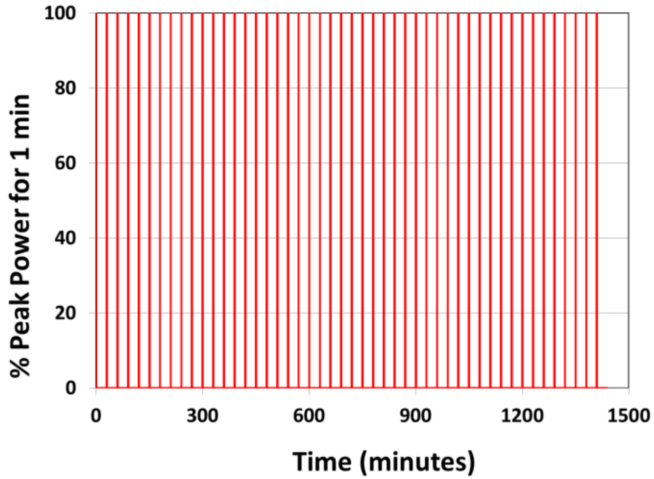
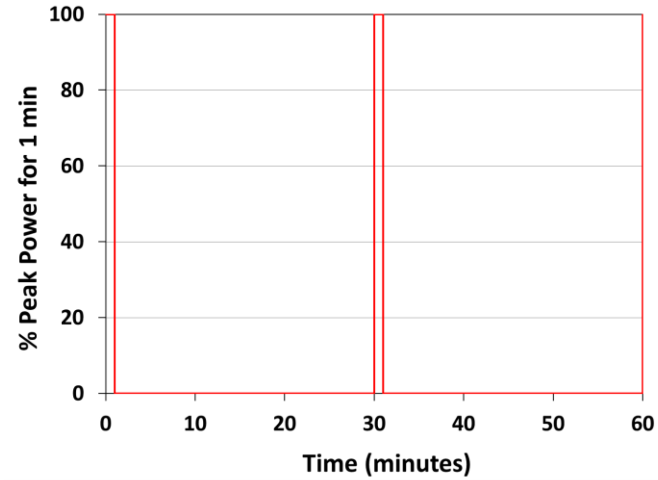
Power Quality

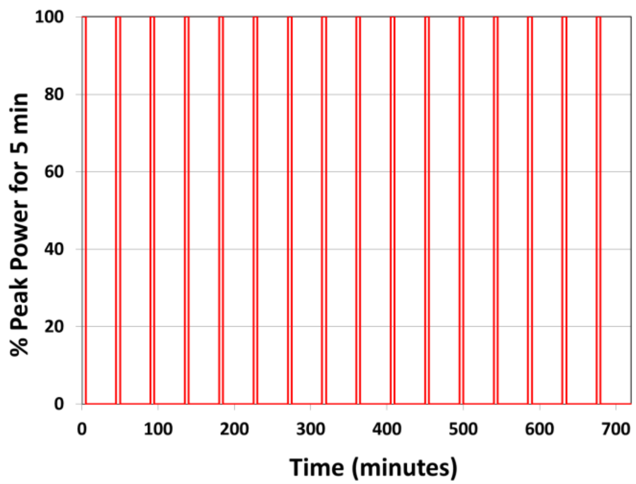
- ESS can mitigate a sag or interruption in voltage that can cause power disturbances that negatively impact power quality (mostly on distribution systems) by injecting real power for up to a few tens of seconds
- This application does not require storage to provide enough power for customers to ride through an outage w/o power loss
- The duty cycle consists of continuous discharge at peak power for 1 min, 5 min, and 10 min, where peak power is defined as maximum power for 1 minute, 5 min, and 10 min.

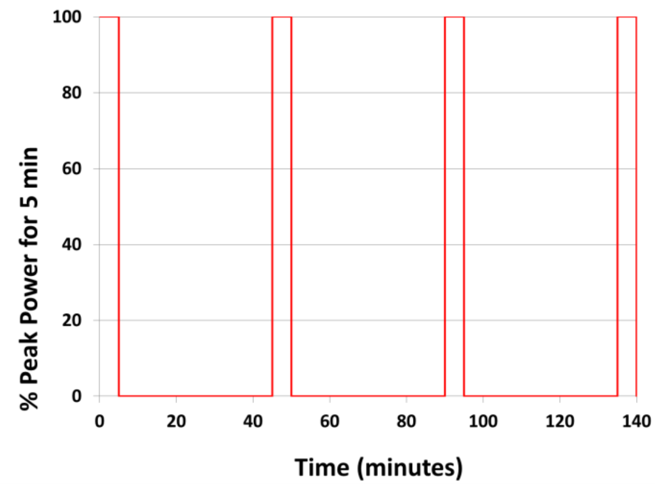
Power Quality Duty-cycle

Left – full duty cycle
Right – zoomed in for clarity





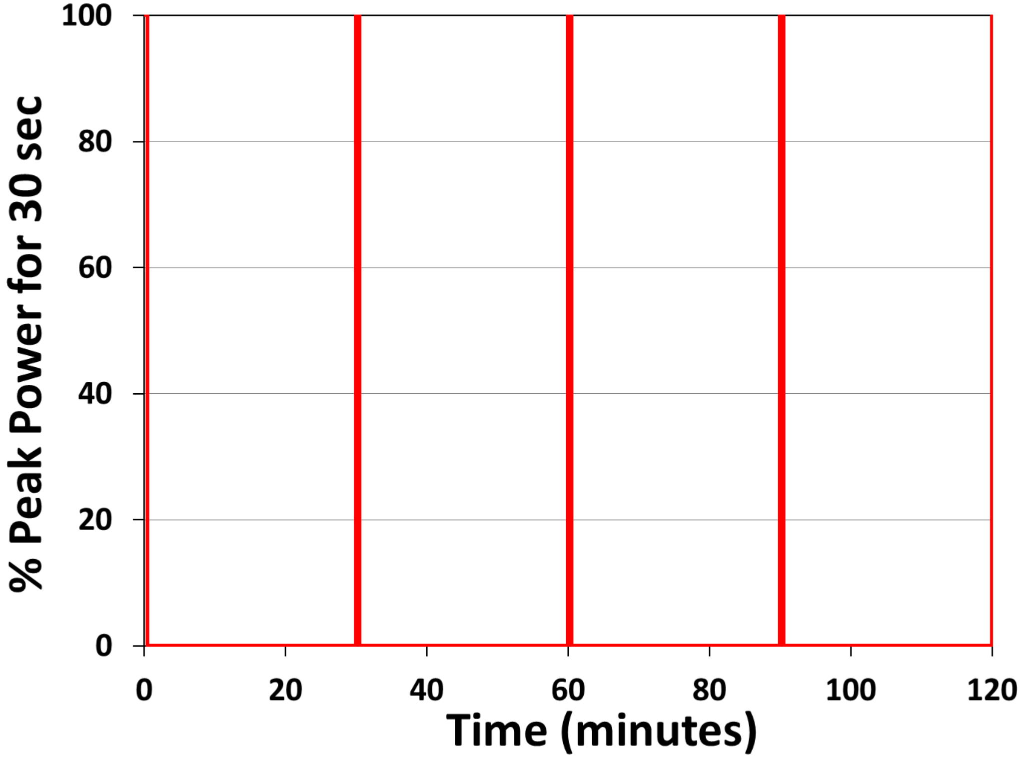




Primary and Secondary Frequency Control

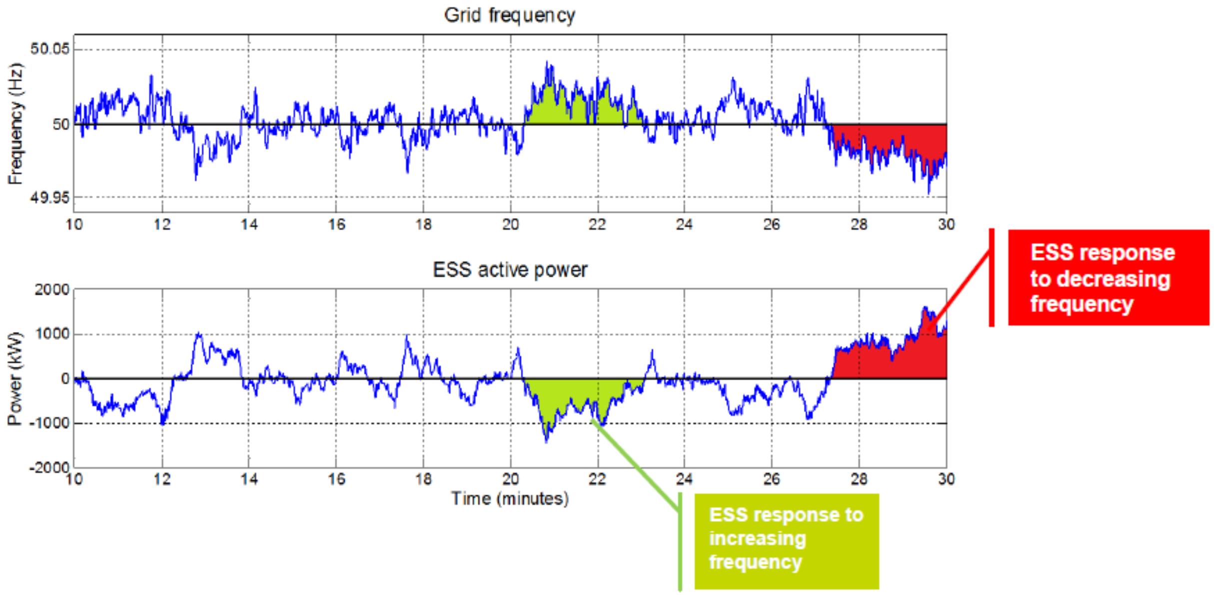
- Sudden loss of load – needs injection of real power for 30 sec (primary frequency control) and injection for 20 min (secondary frequency control)
- Duty cycle (charge for sudden loss of load)
  - Discharge at 30-s peak power for 30 sec (primary frequency control)
  - Discharge at rated power for 20 min (secondary frequency control)

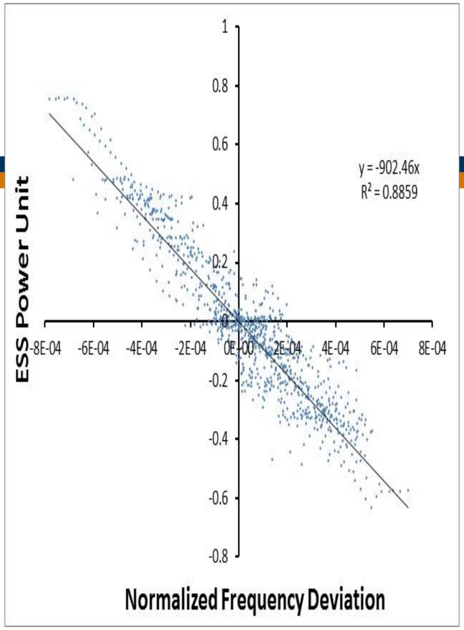
Frequency Control Duty-cycle

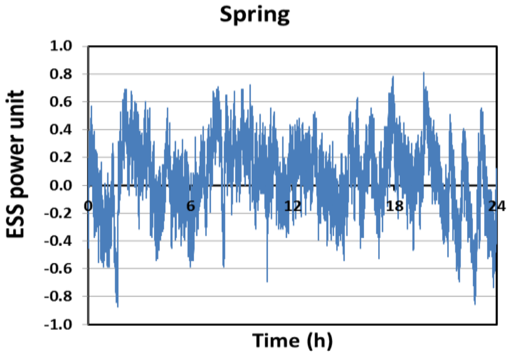


Dynamic Frequency control – Additional Duty Cycles

EXAMPLE: PRIMARY FREQUENCY CONTROL





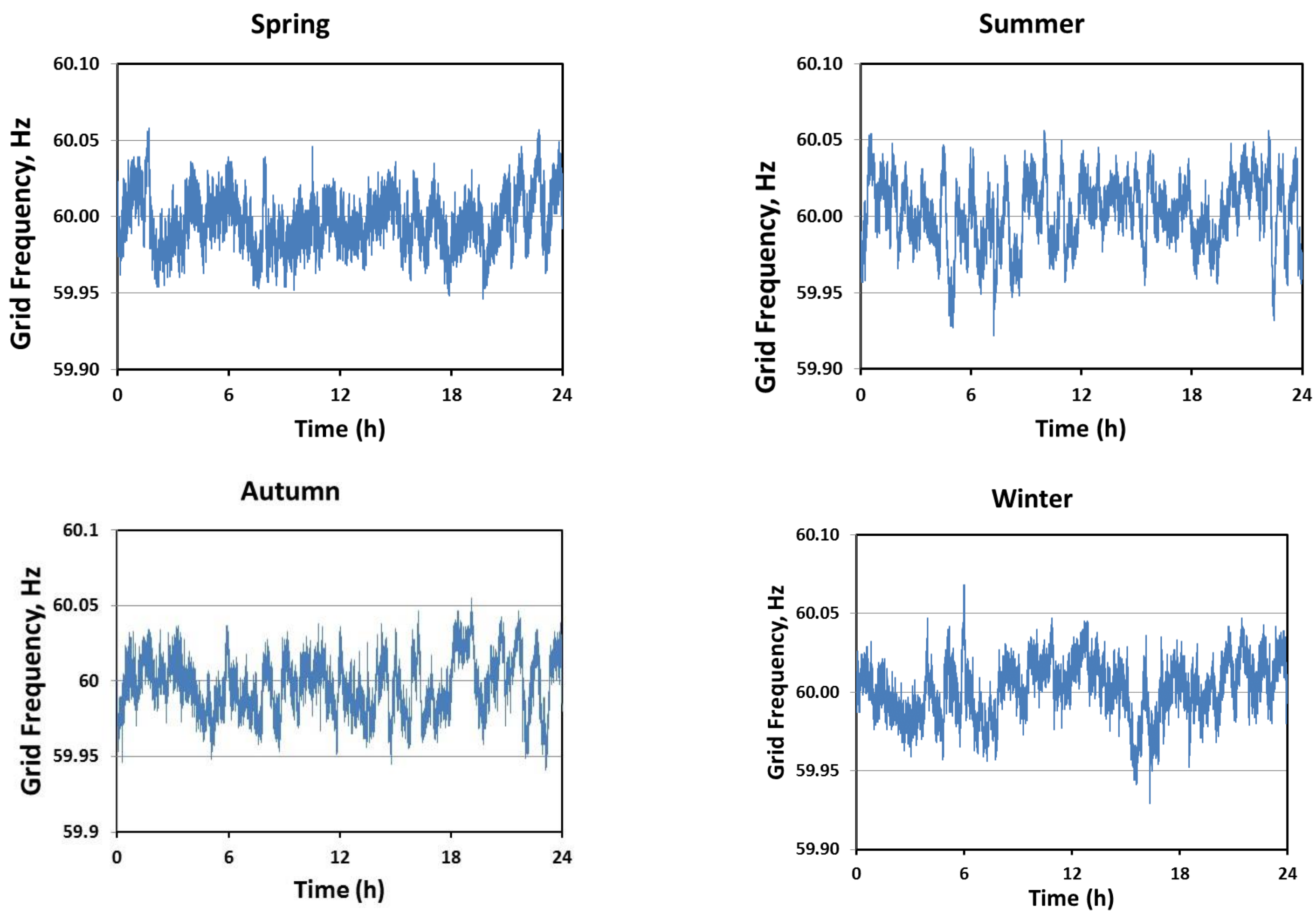


FIELD TESTS: May 2015 to May 2016
GOAL: analyze impacts of seasonal variations of wind generation and load on the operation of the storage system (benefits, grid constraints, etc.)

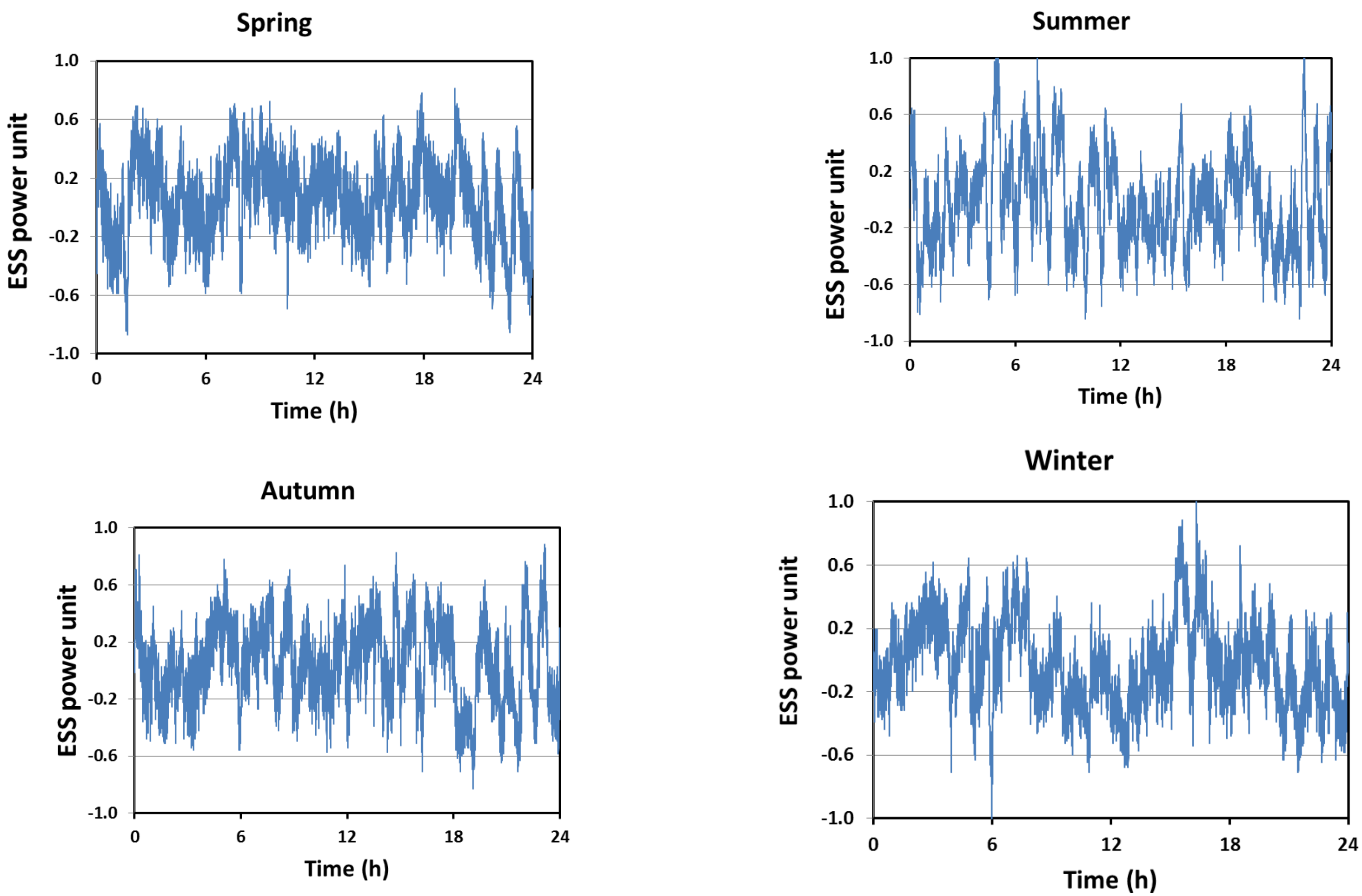
Bruno Prestat (EDF), Chair EPRI-ESIC WG4 Grid Integration. July 10, 2015 presentation Didier Colin et al ERDF/SAFT/Schneider Electric and others – Venteea 2 MW 1.3 MWh battery system. Lyon France 15-18 June 2015

Applied the response signal to a US grid for Spring season

Grid frequency data from a utility for 4 seasons



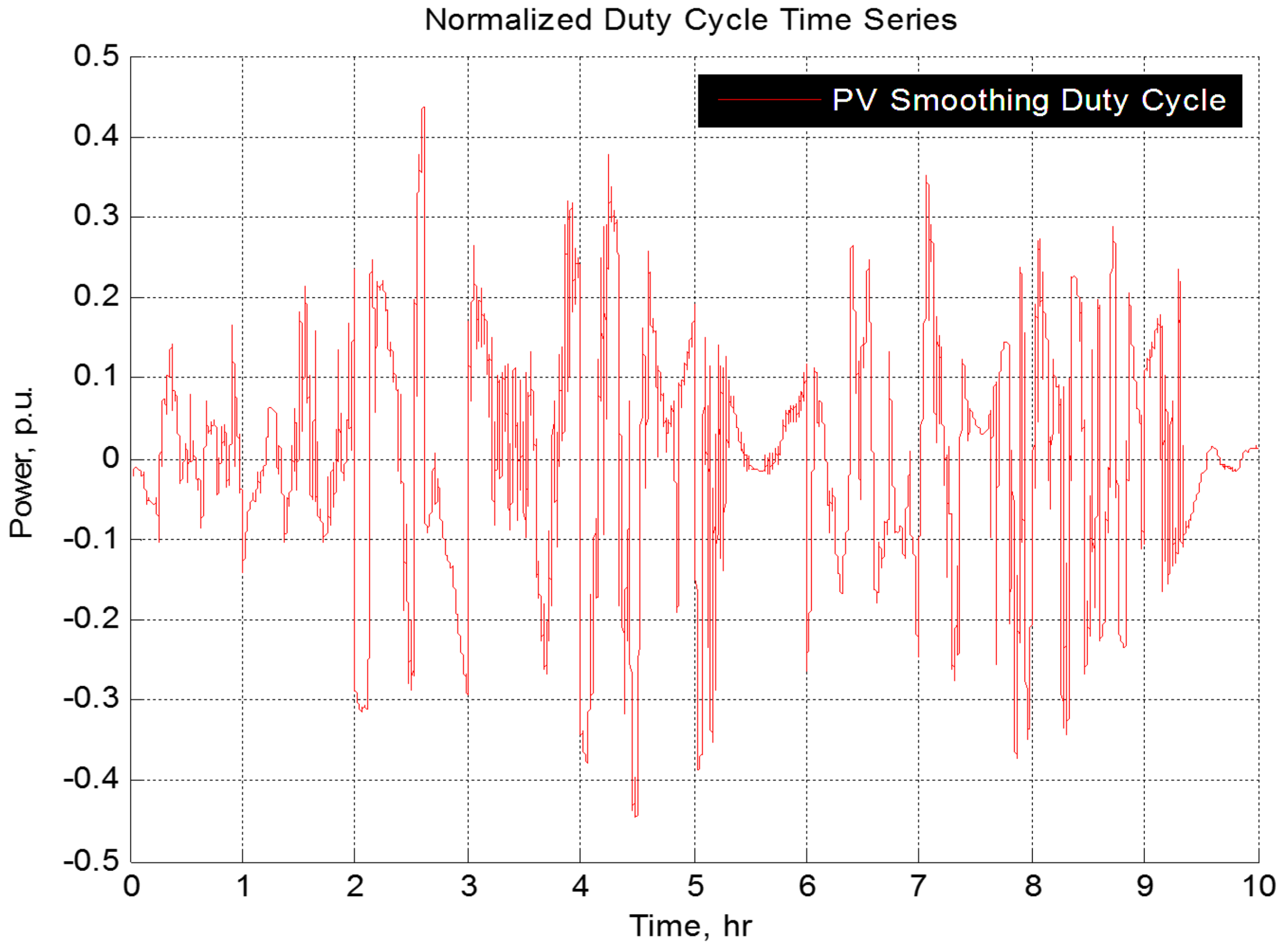
Duty cycle (dynamic frequency control) for BESS from grid frequency data



PV Smoothing

- ESS mitigates the rapid fluctuations in PV power output that occur during periods with transient shadows on the PV array by adding power to or subtracting power from the PV system output to smooth out the high frequency components of the PV power
- Reference performance metrics apply as they are ‘blind’ as to application and duty-cycle
- Duty-cycle performance metrics (Table 4.4.3(a.)) apply with tests for each run using the PV smoothing duty cycle

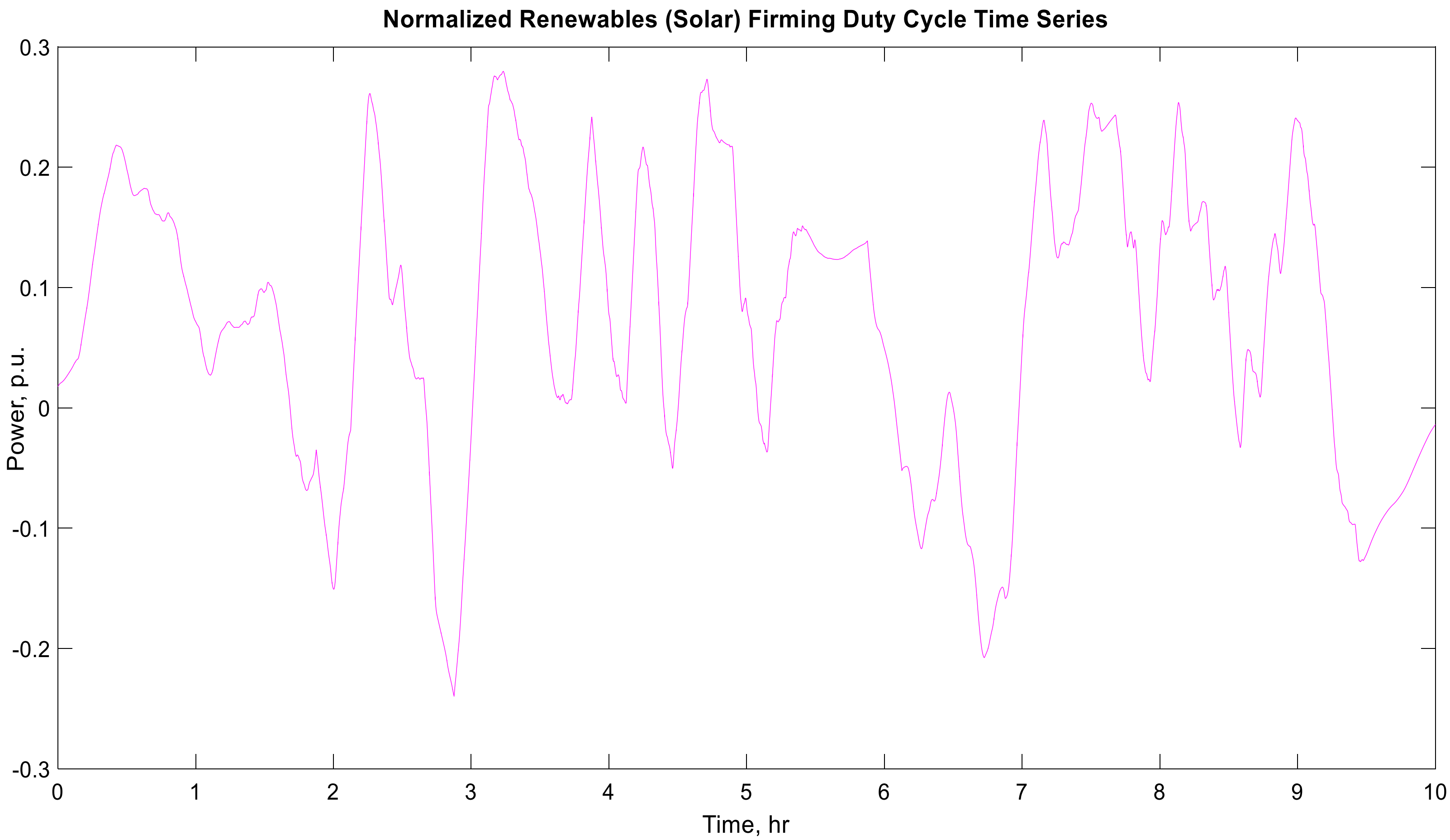
PV Smoothing Duty-Cycle



Renewables (solar) Firming

- ESS provides energy to supplement renewable (solar) generation such that the combination of the stored energy and the renewable generation produces steady power output over a desired time window
- Reference performance metrics apply as they are ‘blind’ as to application and duty-cycle
- Duty-cycle performance metrics (Table 4.4.3(a.)) apply with tests for each run using the Renewables (solar) Firming duty cycle

Renewables (solar) Firming Duty-Cycle



Summary

- ✓ Revision 1 has been used as a basis for US and International (IEC) standards and is being applied by proponents and users of ESS
- ✓ Revision 2 was released April 2016
- ✓ Revision 2 adds key information and technical specifications, new applications, new metrics, and significant formatting and use enhancements
- ✓ All proponents and users of ESS benefit when performance can be measured and expressed with confidence in a uniform, comparable, and consistent manner

Acknowledgement

Dr. Imre Gyuk, DOE-Office of Electricity Delivery and Energy Reliability

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All the participants of the working groups

Thanks

Dave Schoenwald
Summer Ferreira
Sandia

Dave Conover
Vish Viswanathan
PNNL

To participate in future protocol efforts contact
energystorage@sandia.gov

Contact Info

CESA Project Director:
Todd Olinsky-Paul
(Todd@cleanegroup.org)

Sandia Project Director:
Dan Borneo
(drborne@sandia.gov)

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