Paper No: 20PESGM2278

SAND2020-8061C

Sandia National Laboratories

Performance Evaluation of Energy Storage Systems in Wind and Solar Applications

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Outline

- Motivation and Background
- Energy Storage Application: PV Smoothing
- Energy Storage Application: Wind Firming
- Conclusions
- Acknowledgements

Motivation and Background

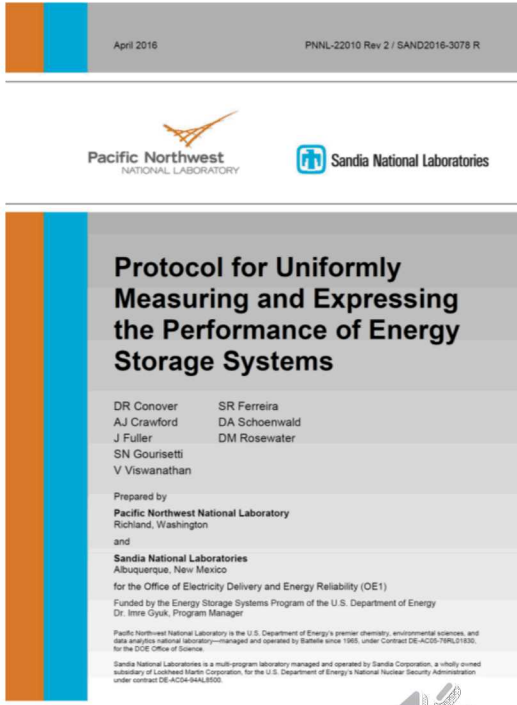
- There is significant interest in the potential value of deploying energy storage systems (ESS) on the grid.
- In the absence of an agreed upon set of criteria for measuring and expressing system performance:
  - Each manufacturer must develop their own criteria.
  - It is very challenging for potential customers to evaluate and compare the performance of different systems in different applications.
  - Customers may make up their own criteria and as a result force re-testing.
  - Result is deployment of ESS will become more costly and time consuming.

✓ The energy storage industry and its customers/users need **uniform** ways of measuring performance.

Motivation and Background

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

- DOE Office of Electricity sponsored an effort led by SNL and PNNL involving the ESS industry, utilities, national labs, academia, and regulatory agencies to address **uniform** performance evaluation.
- Nov. 2012 – first version of the protocol completed (2 applications)
  April 2016 – second version completed (added 6 more applications, revised format for ease of use)
- 2016 version can be downloaded at:
  https://www.sandia.gov/ess-ssl/publications/SAND2016-3078R.pdf
- Late 2020 – third version will feature 4 new applications



Applications Addressed

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

New applications for 2020:

- Wind Firming
- Stacking (Frequency regulation & Peak shaving)
- Frequency regulation with Var
- Peak shaving with Var

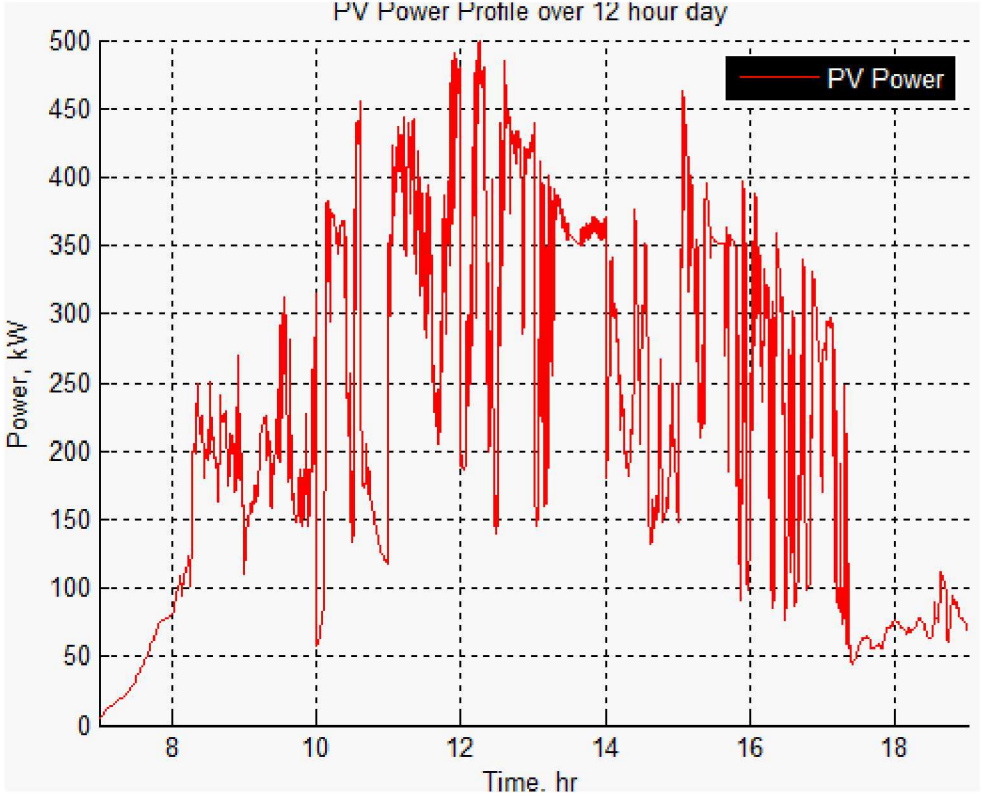
Process for each application:

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

Application: PV Smoothing

- PV Smoothing – the use of an energy storage system (ESS) to mitigate **rapid fluctuations** in variable photovoltaic (PV) power output
- Purpose:
  - To mitigate frequency variation and stability issues that can arise at both feeder and transmission level in **high penetration PV** scenarios
  - To help meet ramp rate requirements
  - Feeder level – To mitigate voltage flicker and voltage excursions outside desired bands
  - Transmission level – PV variability can require additional operating reserve to be set aside and can cause traditional generation to cycle more than otherwise
- Method:
  - ESS is used to absorb or supply power at appropriate times as determined by a control system resulting in a less variable composite power signal at feeder and/or transmission level

Example PV Power Profile on a Partly Cloudy Day



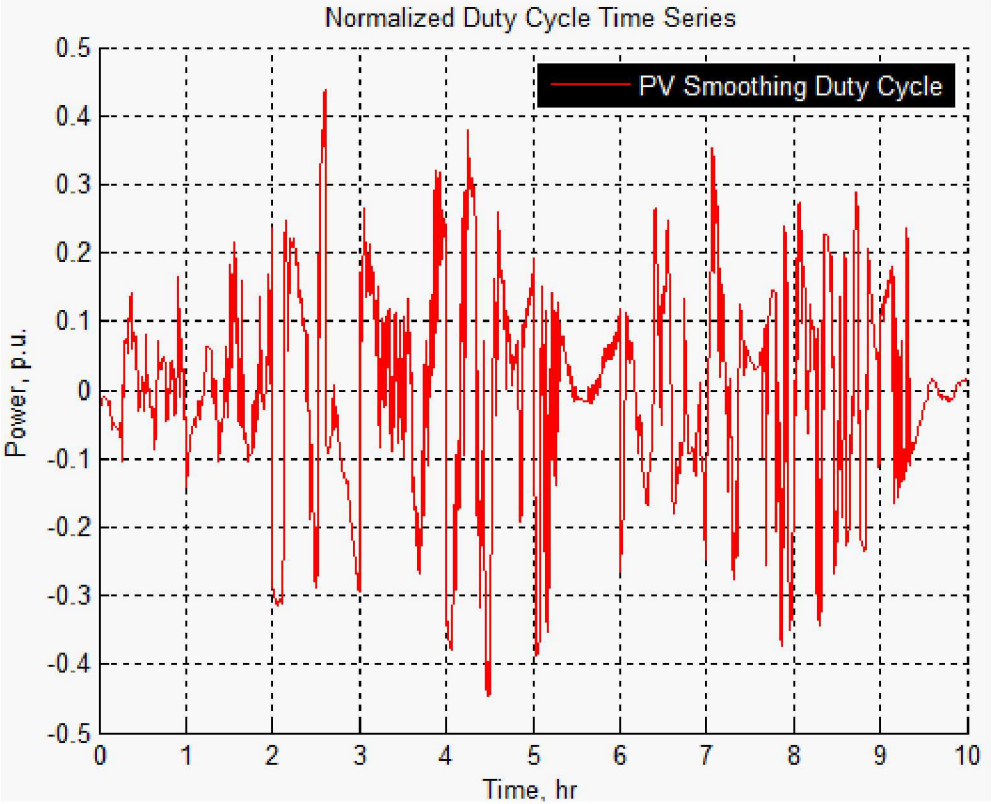
Duty Cycle Construction Philosophy

- What is basic time length of duty cycle?
  - 10 hours should be sufficient
- What key features should duty cycle capture?
  - Idea is to capture 1 hour “slices” of typical PV generation obtained from different days and splice together, rather than look for one day with “everything”
  - “Slices” should capture scenarios such as sunny, partly cloudy, and cloudy days
  - Majority of “slices” should be moderate to very high in PV power variability ➔ aggressive signal is preferred
  - Different areas & seasons can be captured in one signal instead of many signals
- Time resolution of data?
  - 1 second data is best and is available

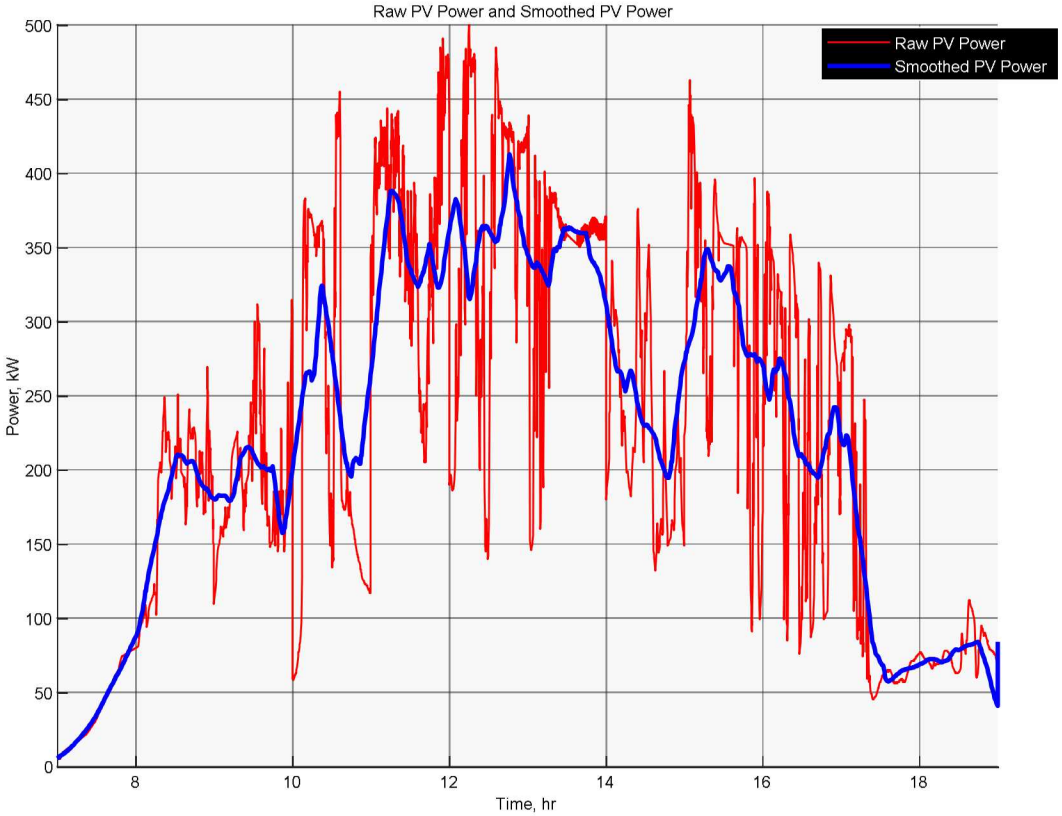
Duty Cycle Construction Procedure

- To effectively smooth our composite “day”, ESS needs to track a “smoothed” day: Use moving average for the “smoothed” goal
- Duty cycle is the signal the ESS must track: Difference between raw PV power and moving average of raw PV power
  - A 30 minute window length was used to compute the moving average of the raw PV power
  - Duty cycle was normalized to the PV smoothing battery’s rated power = +/- 500 kW in this example ➔ Duty cycle signal should be agnostic to ESS power ratings
  - Sign convention:
    - positive duty cycle value ➔ ESS is discharging power
    - negative duty cycle value ➔ ESS is in charging mode

Duty Cycle Signal for PV Smoothing



Resultant Smoothed PV Power



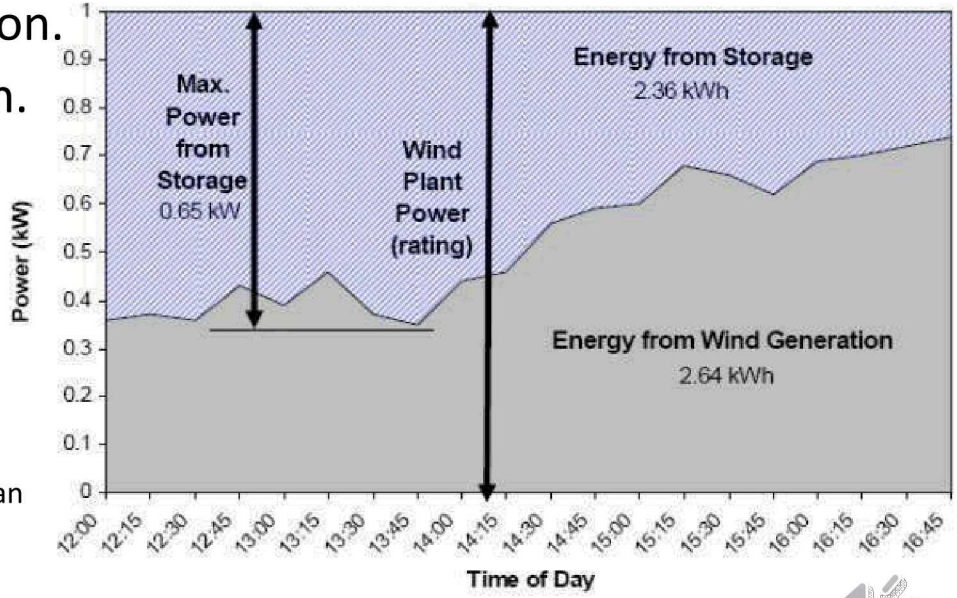
Distinction Between Smoothing and Firming

- **Smoothing** attempts to limit ramp rates over one second to one minute durations.
- **Firming** is more concerned with 15 minute to several hour durations.

Smoothing is a power intensive application.

Firming is an energy intensive application.

Example: Note that ESS power plus wind generation adds up to a fairly constant level over 15 minute time windows.

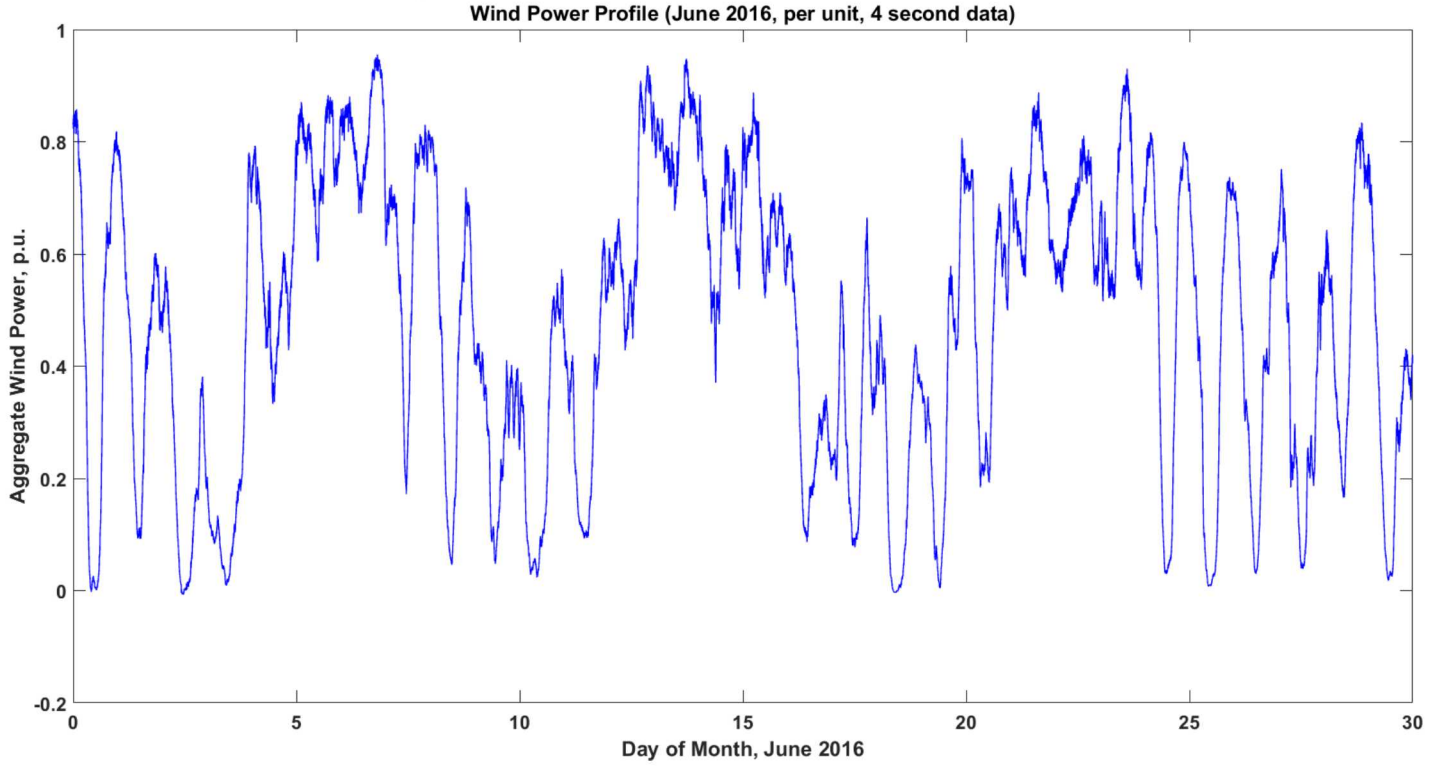


From: Elisabeth Lemaire, Nicolas Martin, and Per Norgard, "European White Book on Grid Connected Storage," European Distributed Energy Resources Laboratories Report No. R-003.0, 2011.

Application: Wind Firming

- Wind Firming – the use of an energy storage system (ESS) to provide energy to supplement wind power generation such that their combination (ESS output + wind power) produces steady power over a desired time period
  - Analogous to the PV firming application
  - Purpose is to provide (or absorb) energy when wind generation falls below (or exceeds) some threshold
  - Performed to provide steady power output over a desired time window, usually a period of multiple hours
  - Threshold is typically based upon the forecasted nominal wind power generation over the desired time window ➔ ESS is compensating for the forecast uncertainty in actual wind generation during that time window

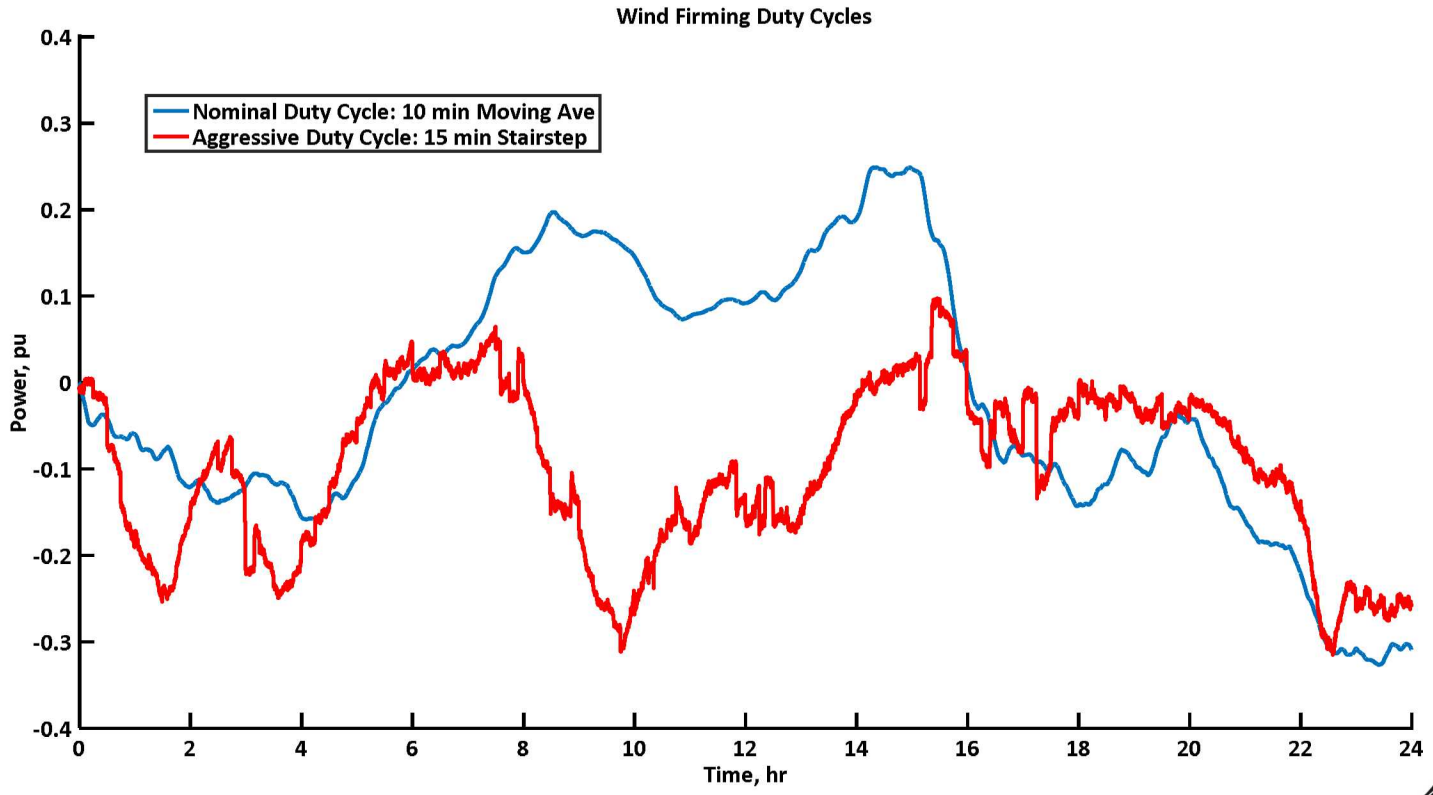
Example Wind Power Data



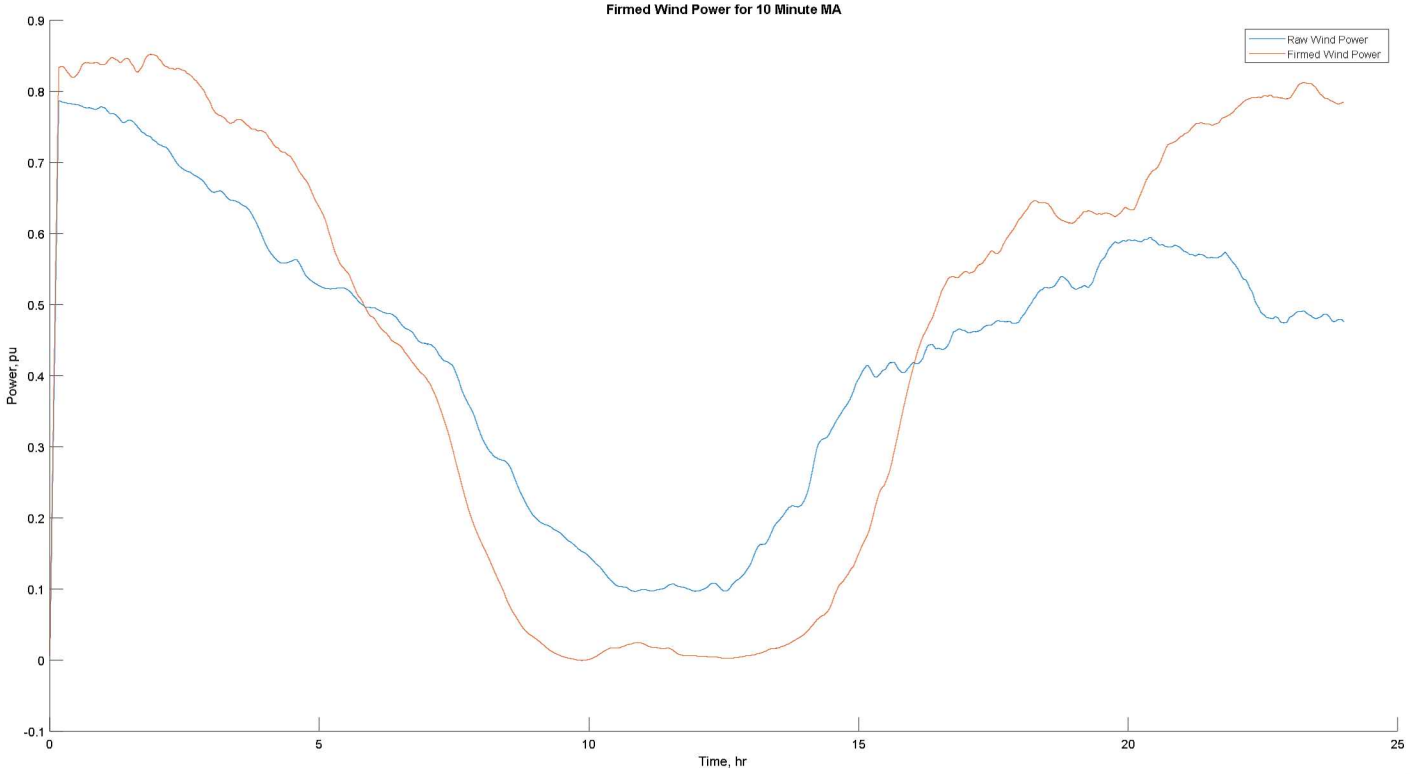
Duty Cycle Construction for Wind Firming

- Duty cycle length is nominally 24 hours ➔ choose some example days
  - Determine measure of “variability” – e.g., ramp rate
  - Pick days with high variability
- ESS should firm over a 10-15 minute time window ➔ use 10-15 minute moving average of wind power signal
- Fixed averages, e.g., stairsteps can be used to get more aggressive duty cycles
- Choose threshold signal from among several options:
  - Moving averages of previous day, e.g., 10-15 minute moving averages
  - Moving averages over longer periods of time, e.g., 1 month, season, 1 year, …
  - Forecasted wind power profiles (if available)
- Subtract current moving average from threshold value ➔ desired firming value for ESS

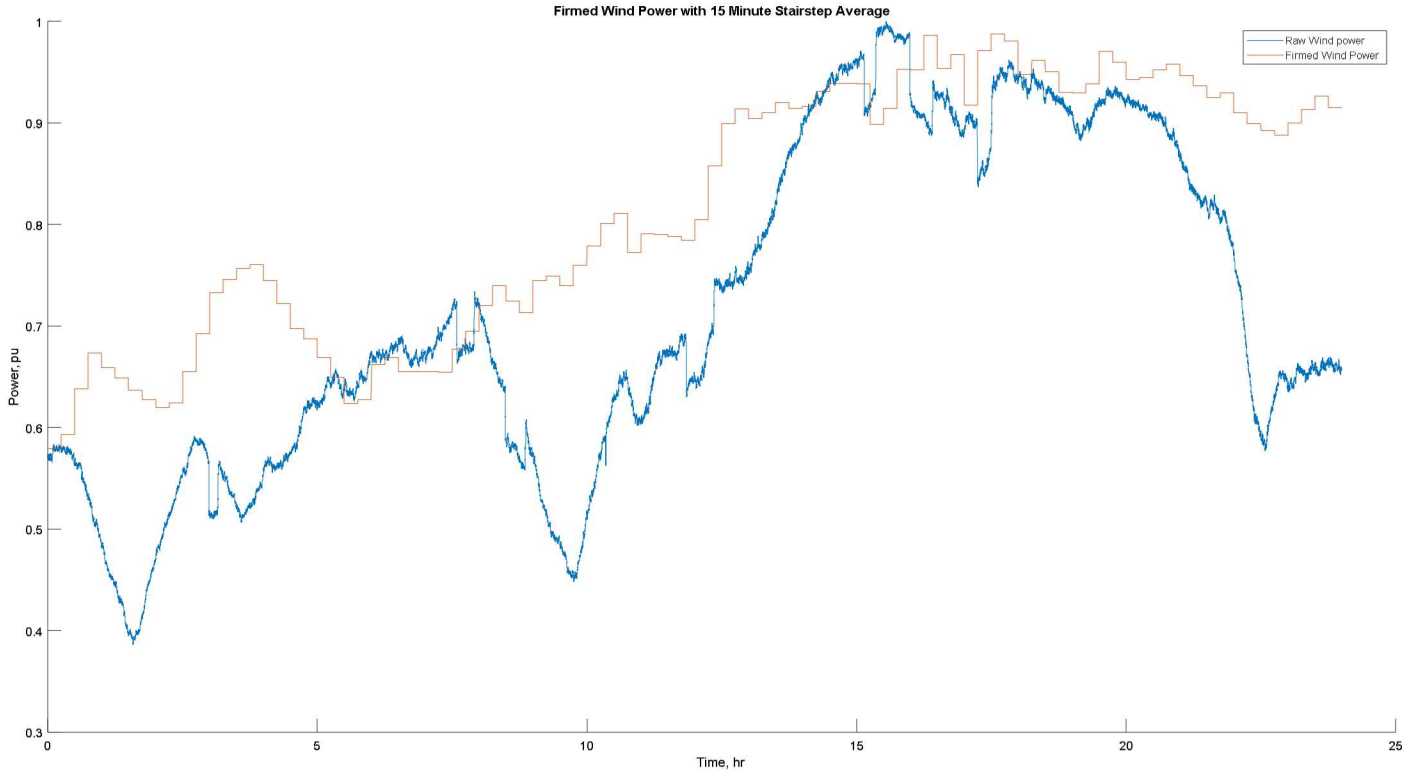
Duty Cycle Signals for Wind Firming



Firmed Wind Power with 10 min MA Duty Cycle



Firmed Wind Power with 15 min Stairstep Duty Cycle



Conclusions

- Smoothing requires high ES power for short durations while firming requires steady power for longer time periods.
- Same set of performance metrics suffices for both applications presented.
- Two different approaches to constructing firming duty cycles have been shown: moving average and stairstep. The stairstep approach results in a more aggressive duty cycle.
- Multiple organizations are using ES Performance Protocol as a basis for new ES standards, e.g., IEEE, IEC, ANSI.

Acknowledgements

The presenter gratefully acknowledges the support of the DOE-Office of Electricity Energy Storage Program managed by Dr. Imre Gyuk.

Thank you!

Questions?

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