NREL
NATIONAL RENEWABLE ENERGY LABORATORY

40
1977 – 2017



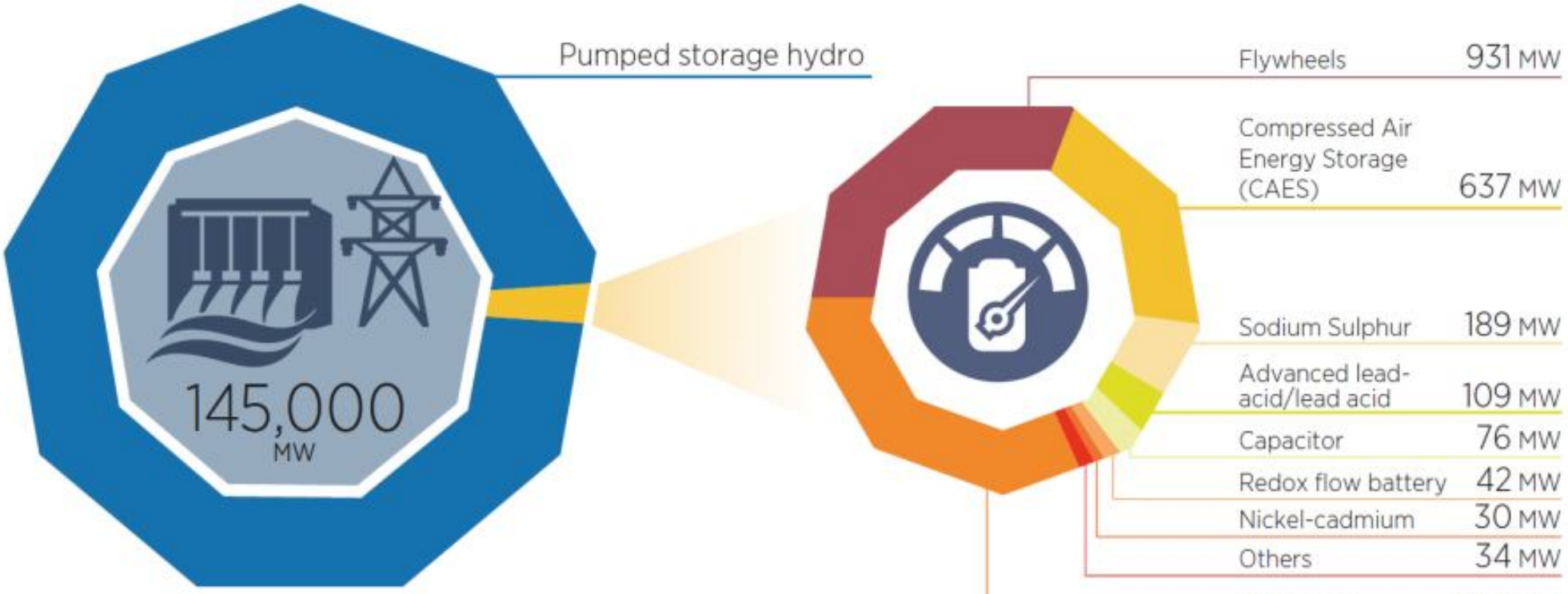


Overview of Energy Storage for Renewables Integration

V. Gevorgian, M. Baggu, NREL

Workshop on "99+ Grid Availability for RE Integration"
January 23, 2018
Chennai, India

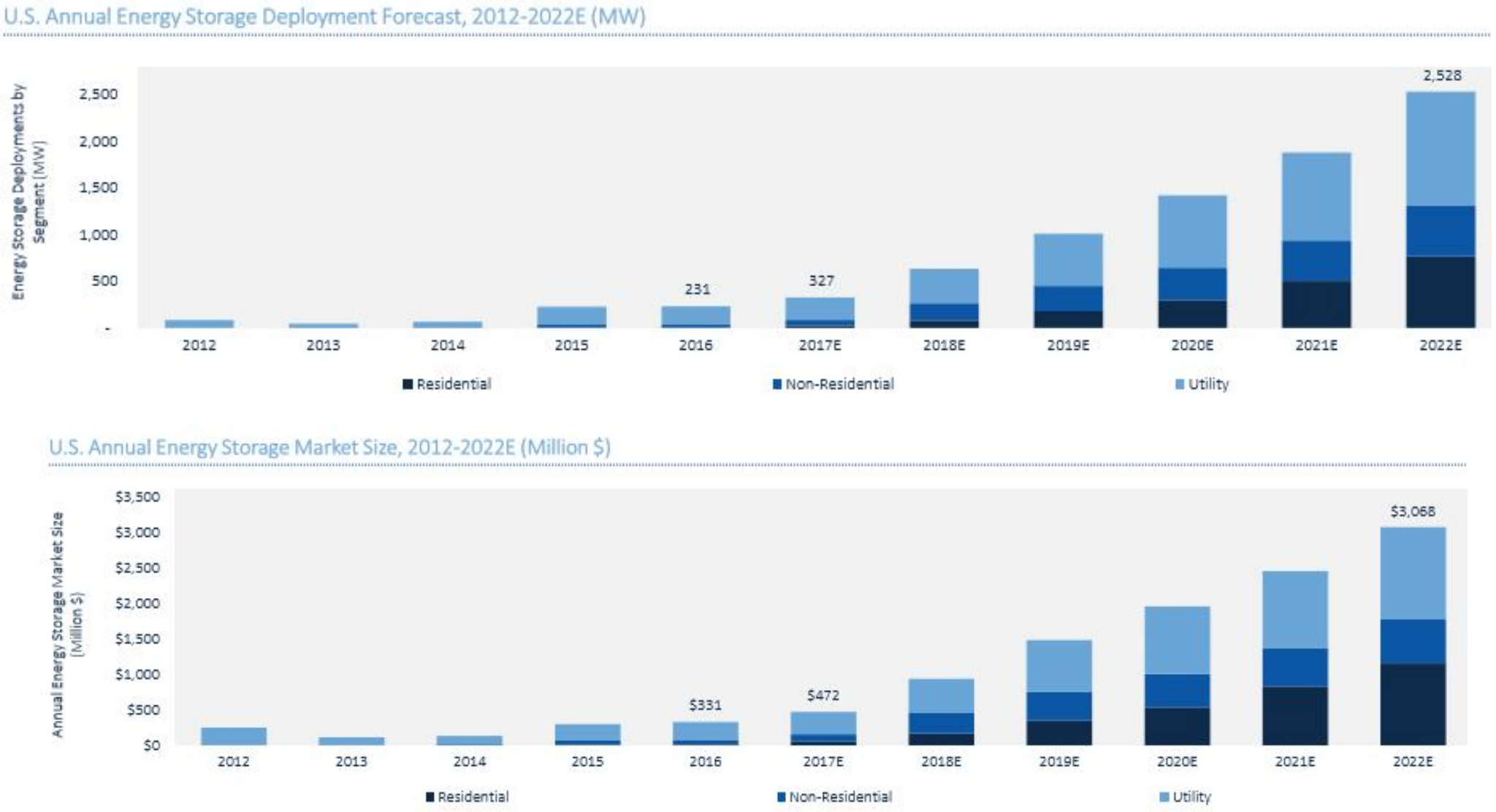
Share of Storage Technologies in Global Market



Note: Pumped storage data are for 2016; other data are for 2014.
Source: IRENA, 2015h; pumped storage data from IHA, 2016

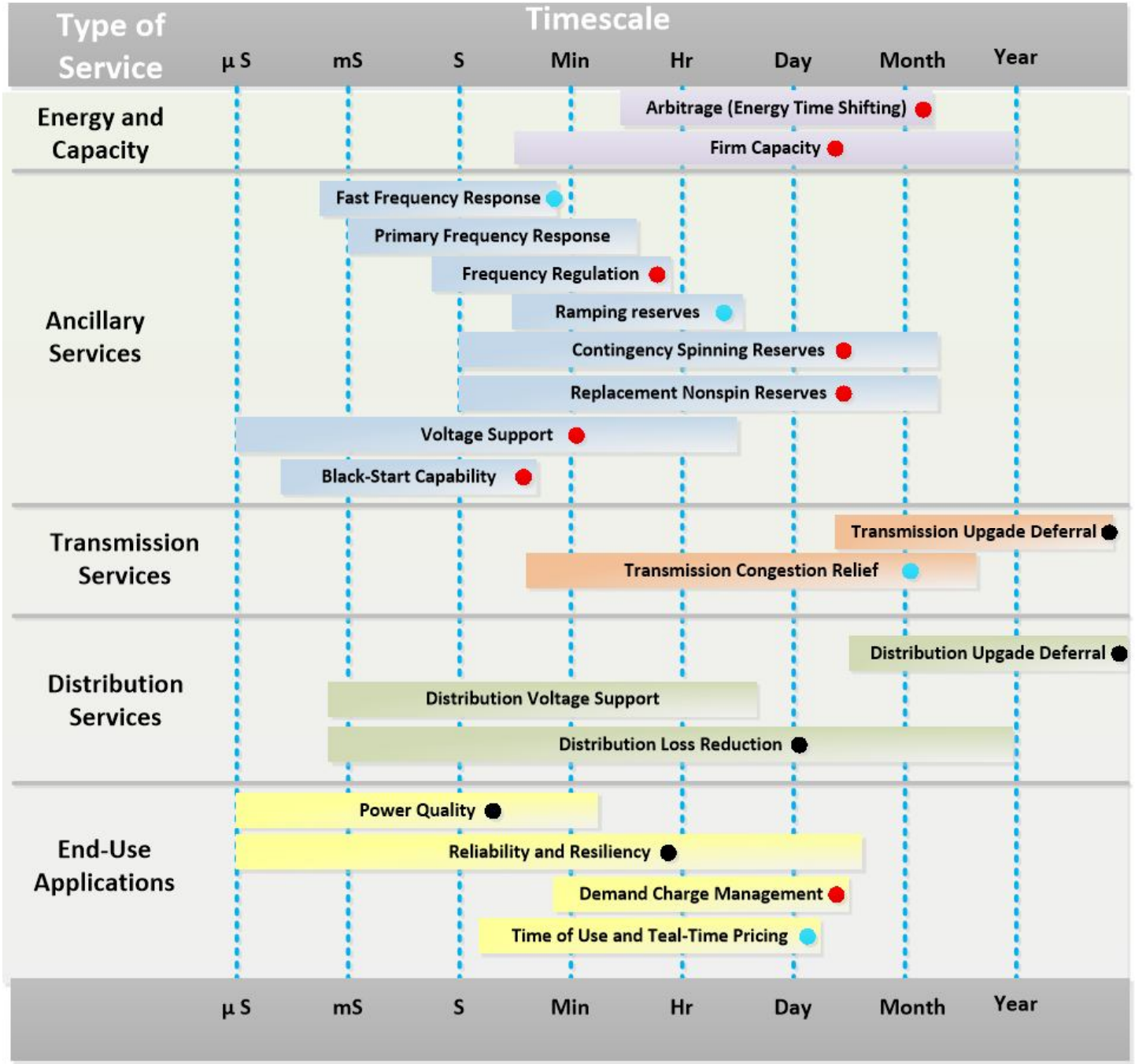
Source: IRENA Rethinking Energy 2017 report

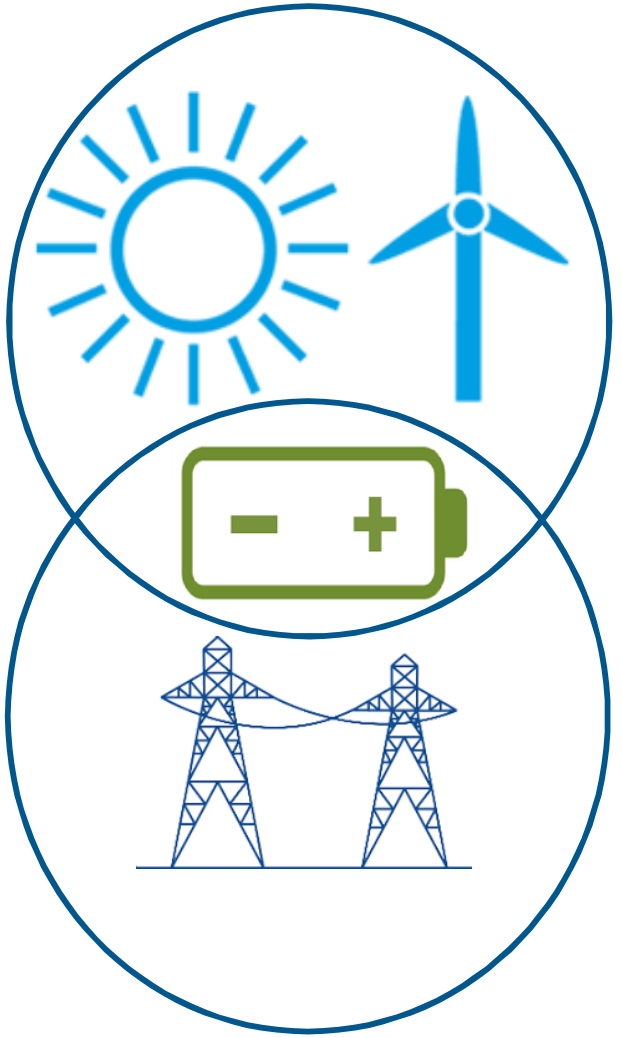
Energy Storage Will Be a $3.1 Billion Market in the U.S. by 2022



- Lithium-ion batteries dominated the energy storage market for the last three years

Value Streams of Battery Energy Storage

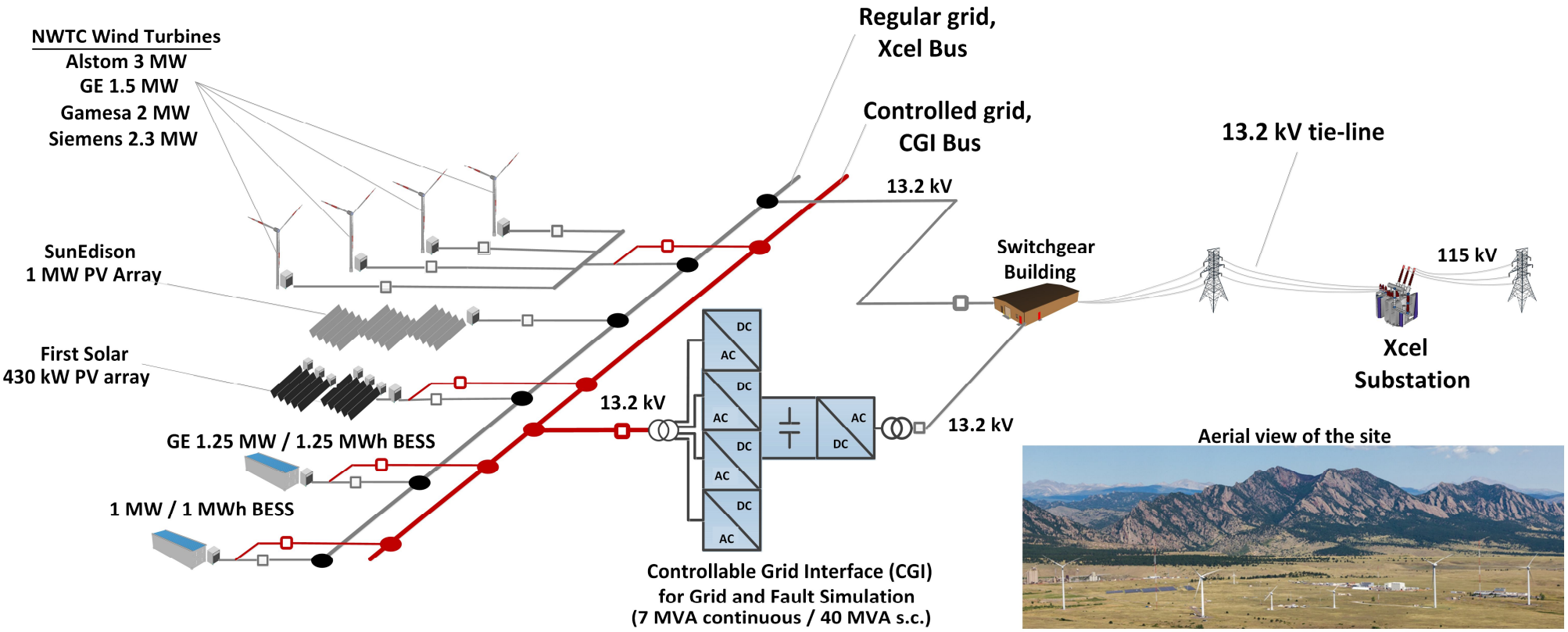




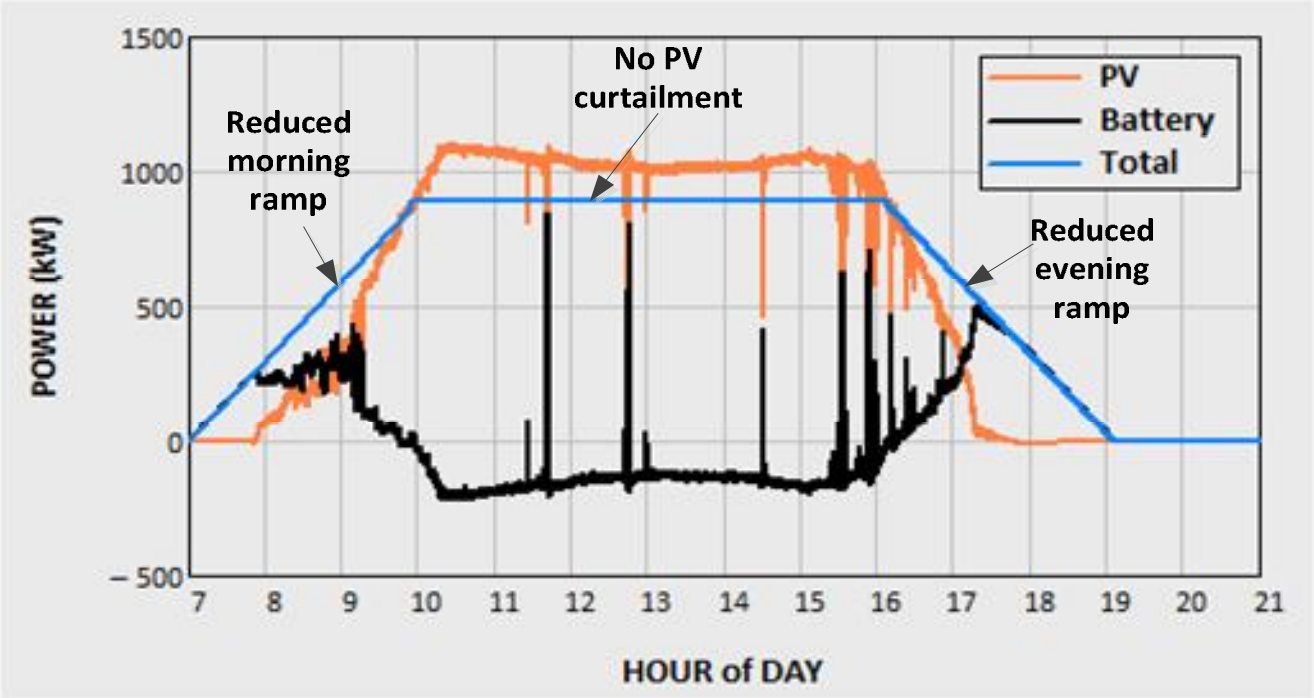
- Services currently valued in some markets
- Proposed or early adoption services
- Currently not valued services

NREL Grid Integration Test Platform

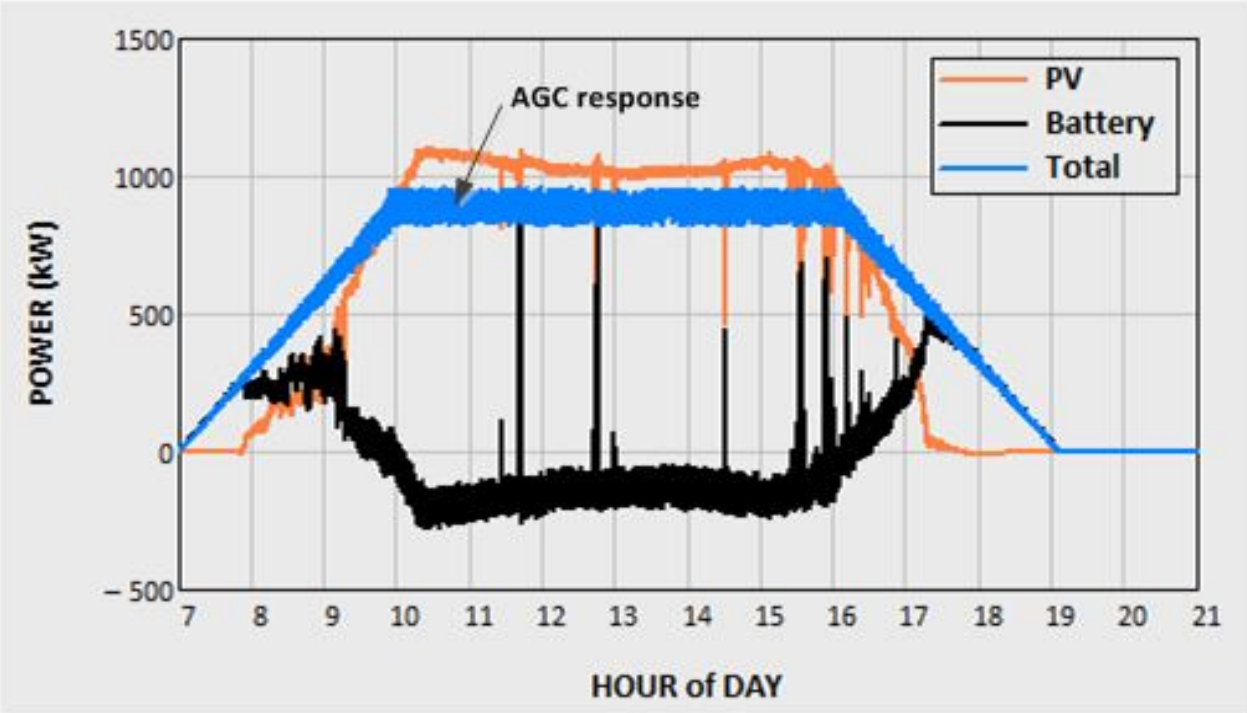
- **12 MW installed renewable capacity – wind and solar**
- **Various energy storage technologies**
- **Control system**
- **Simulated grid – 50Hz and 60 Hz operation**
- **Emulation of strong and weak grids**
- **Power-hardware-in-the-loop (PHIL)**

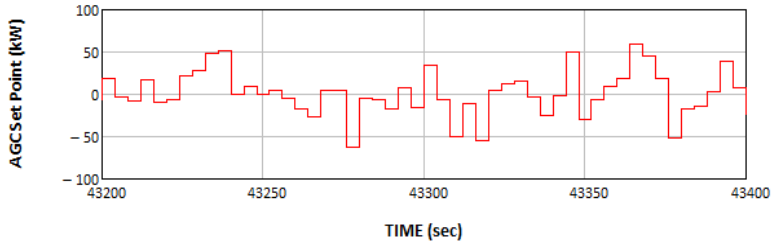


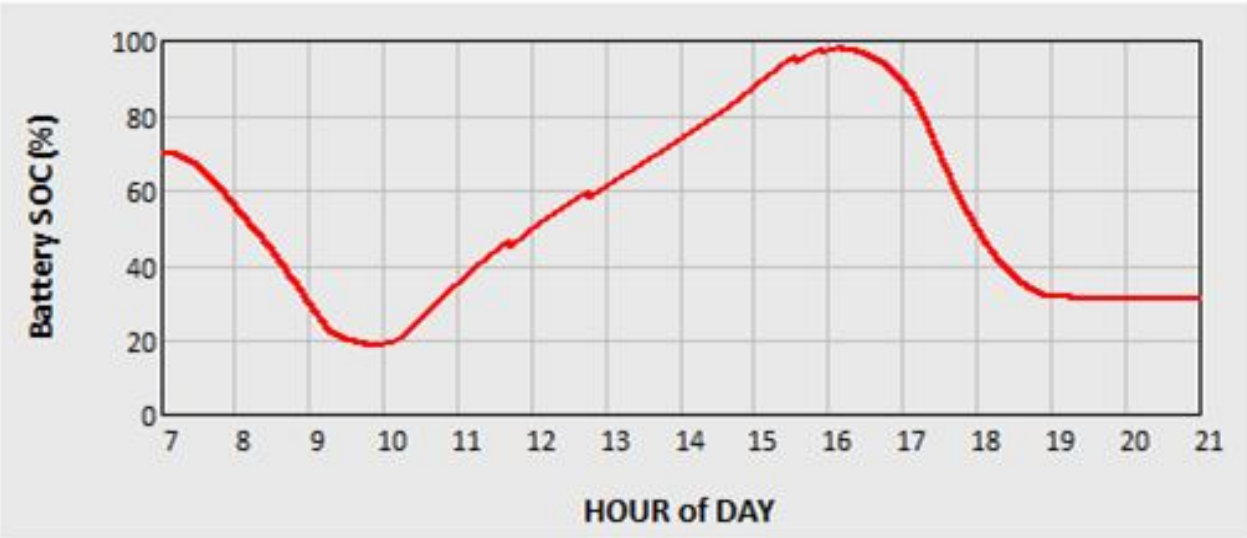
Curtailment Reduction and Ramp Control Use Case



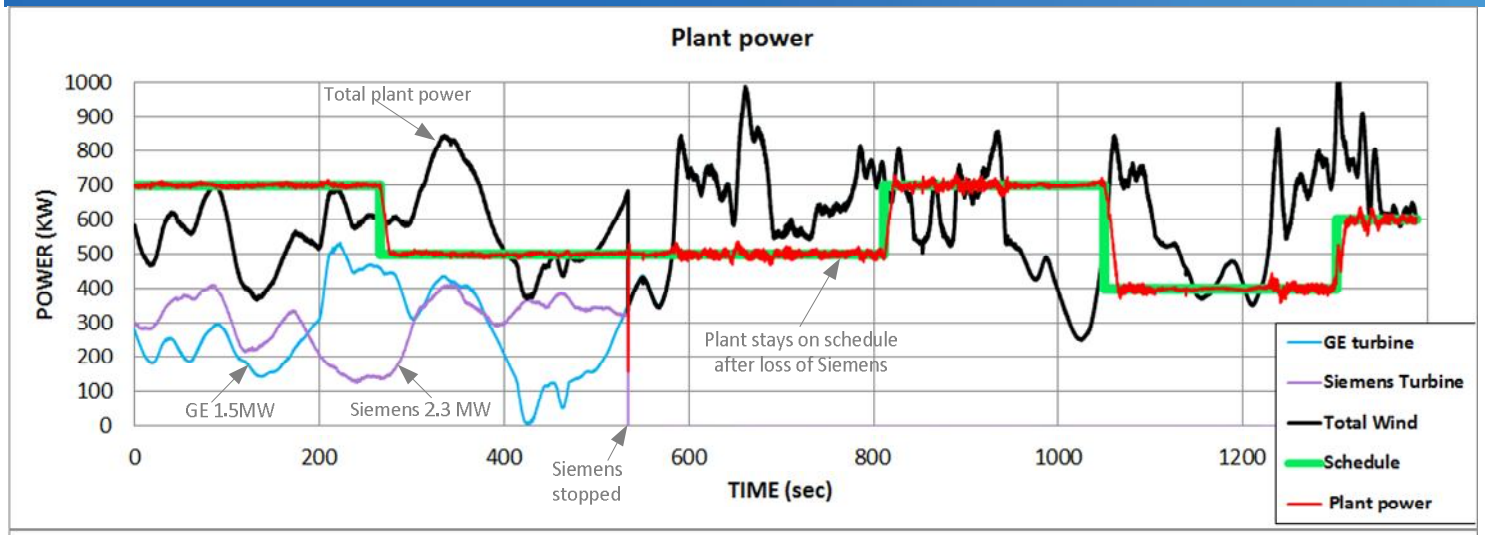
Curtailment Reduction and Ramp Control +AGC

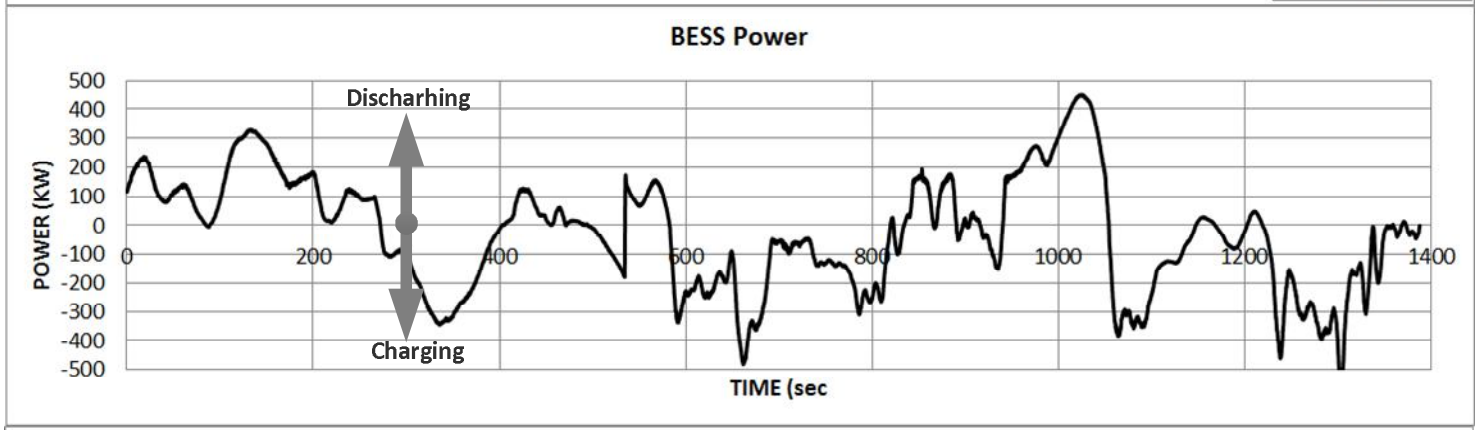


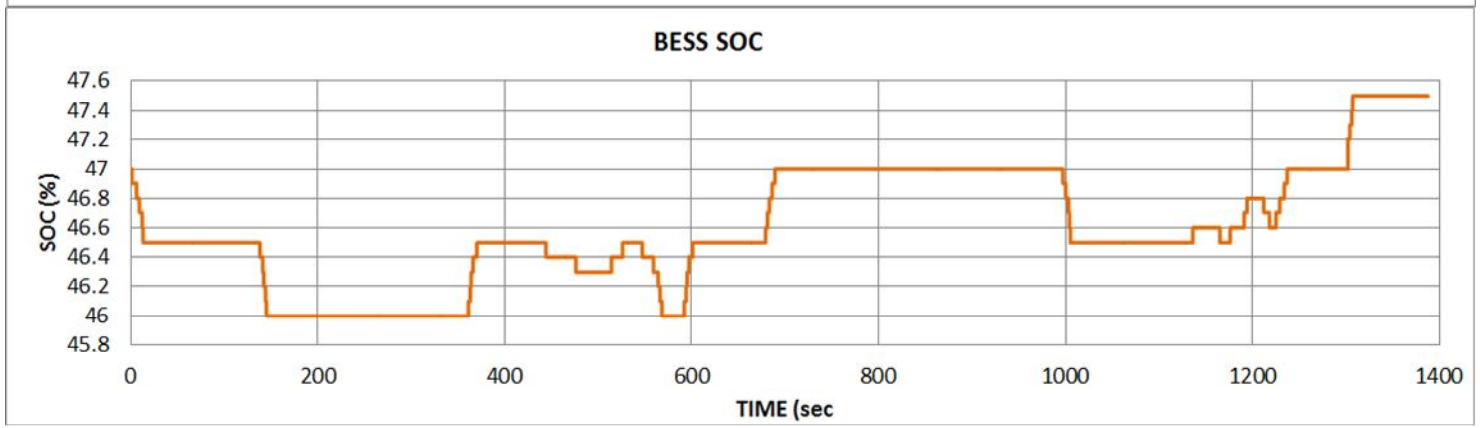




NWTC Dispatchable Hybrid Wind-BESS Plant Demonstration







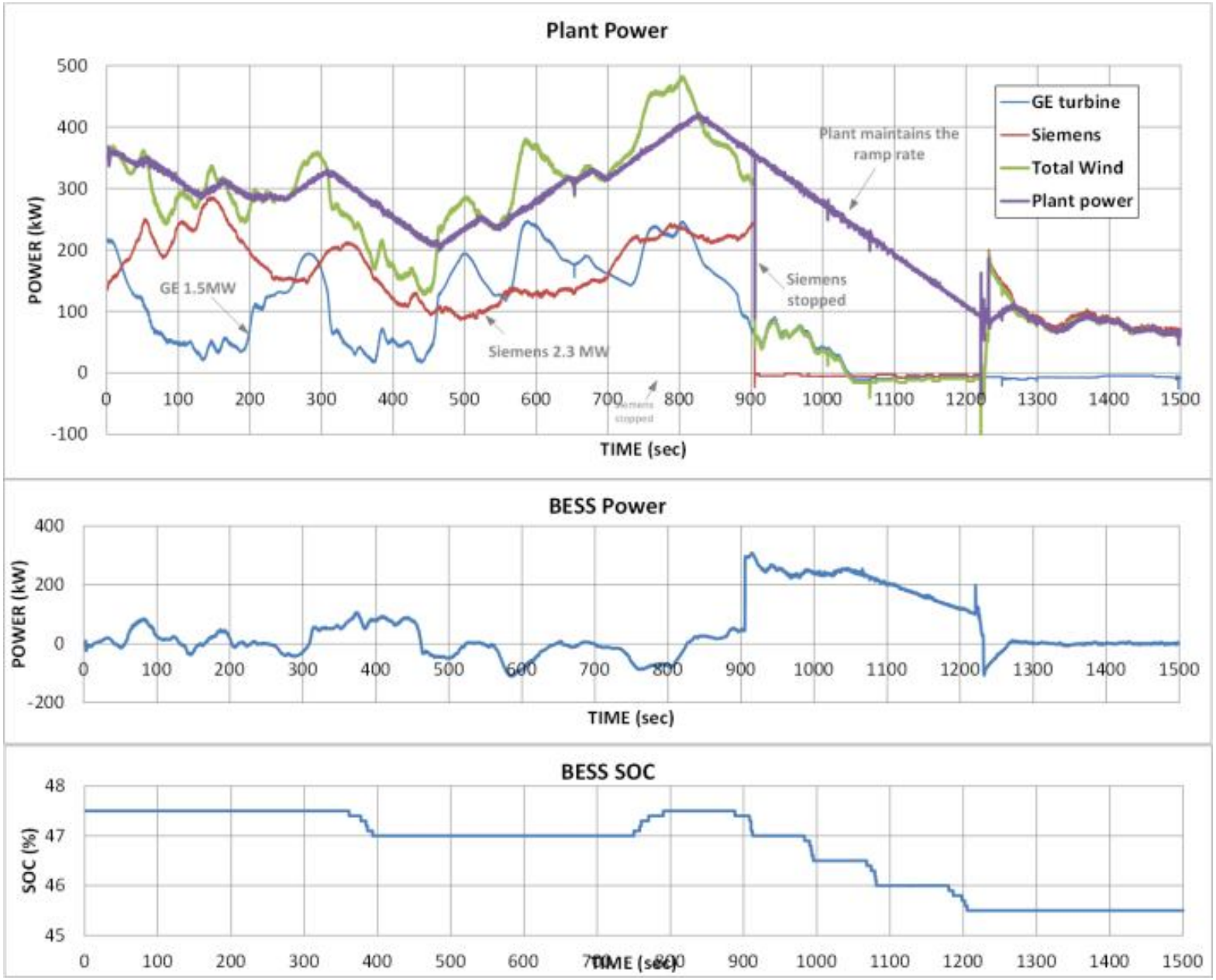
Virtual plant description

- Hybrid virtual plant consists of :
  - GE 1.5 MW turbine
  - Siemens 2.3 MW turbine
  - 1MW/1MWh BESS
- The plant was operated on a virtual 1-min scheduled dispatch signal
- Low-to-medium wind speed conditions
- BESS was commanded to keep the total plant output at scheduled level
- A ramp limit was introduced for transition from one schedule level to another (difference between **green** and **red** plots)

Observations

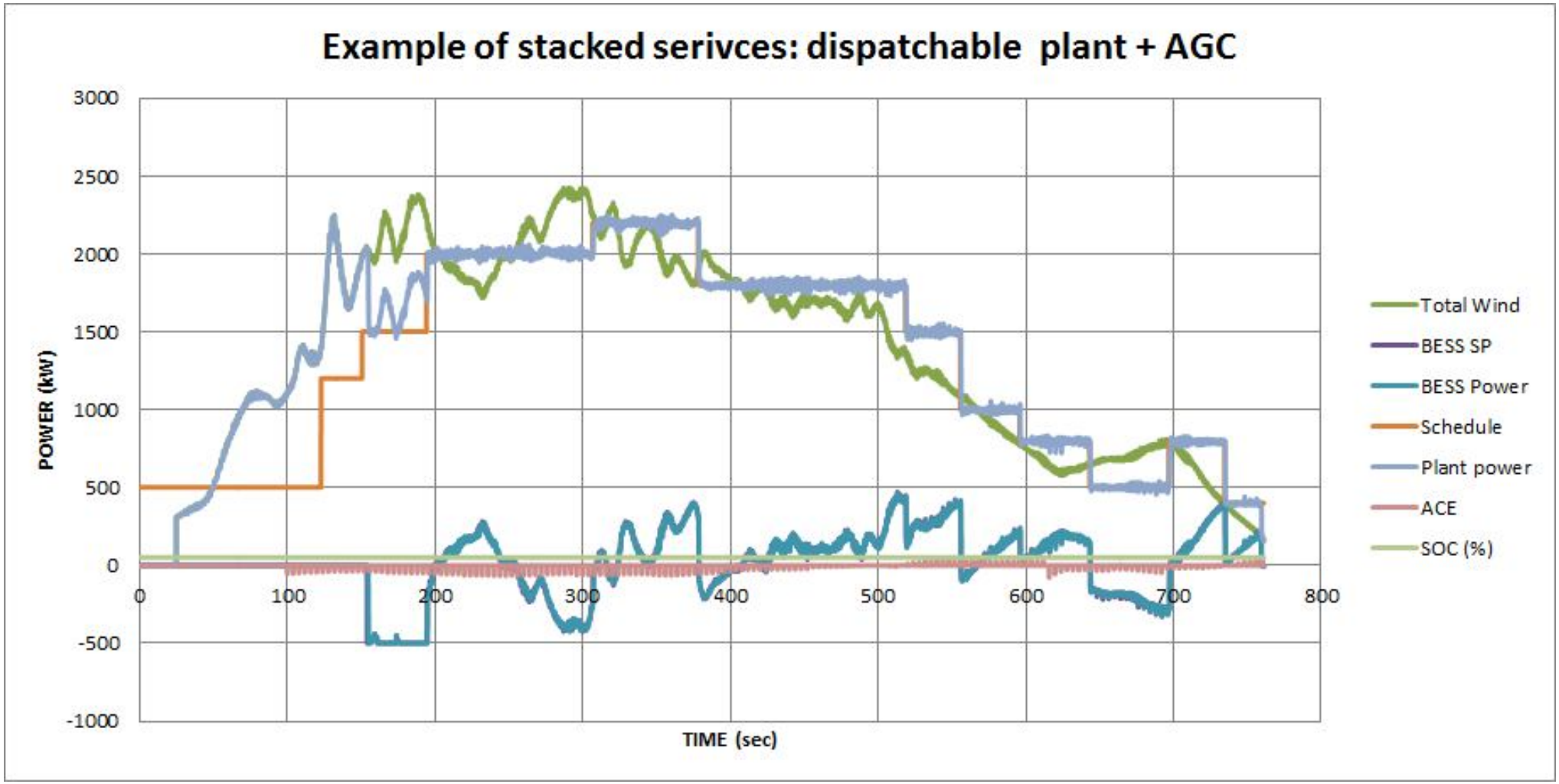
- BESS performed very well helping to stay on schedule when both turbines were producing due to lower aggregate variability
- Siemens turbine was stopped at t=534 sec causing immediate decline in total plant power
- BESS responded as fast as it could to compensate for a loss and maintain scheduled production level (zoom-in of this this event is shown on next slide)
- The accuracy of maintaining the scheduled level with one turbine is lower due to increased variability
- There was very low imp[act on BESS state of charge (SOC) during this test (beginning SOC=47%, end SOC=47.5%)

Ramp Limit Demonstration

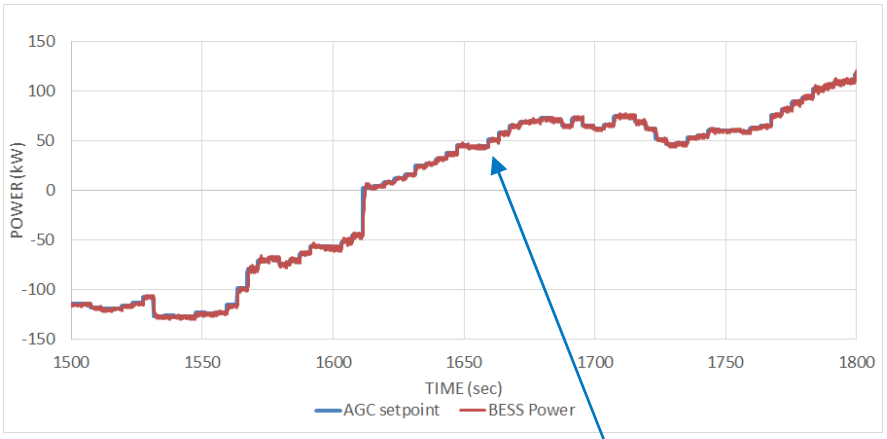


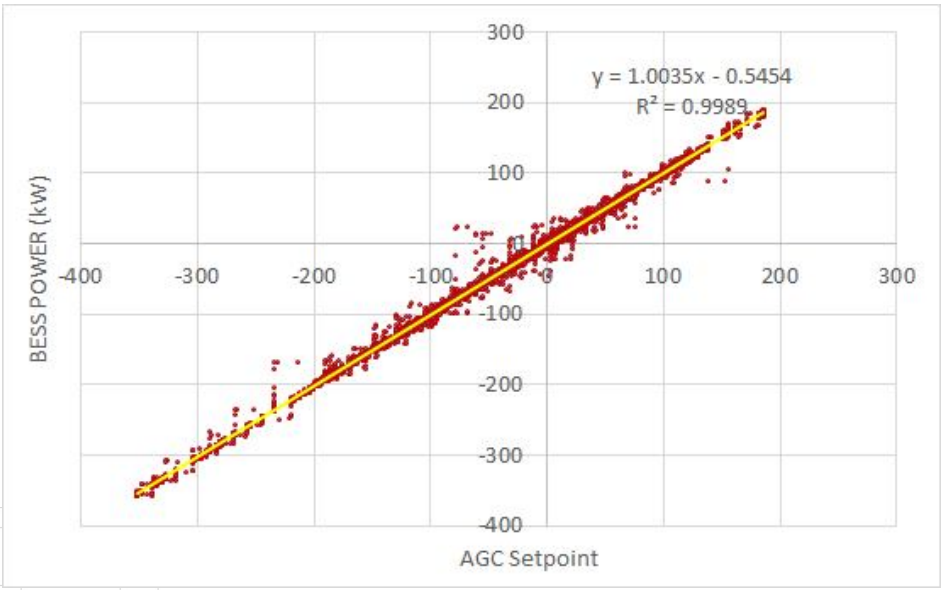
- The plant was set to operate at ±50 kW/min (1.3% of installed capacity per minute) ramp rate
- Siemens turbine stopped at t≈900 sec

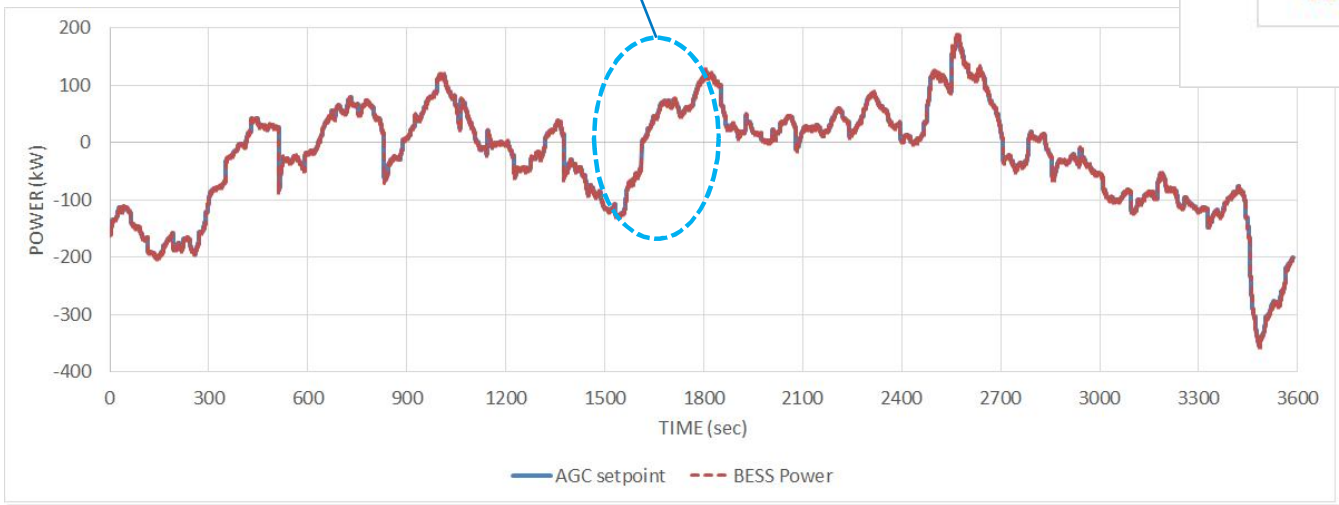
BESS-Alstom Test

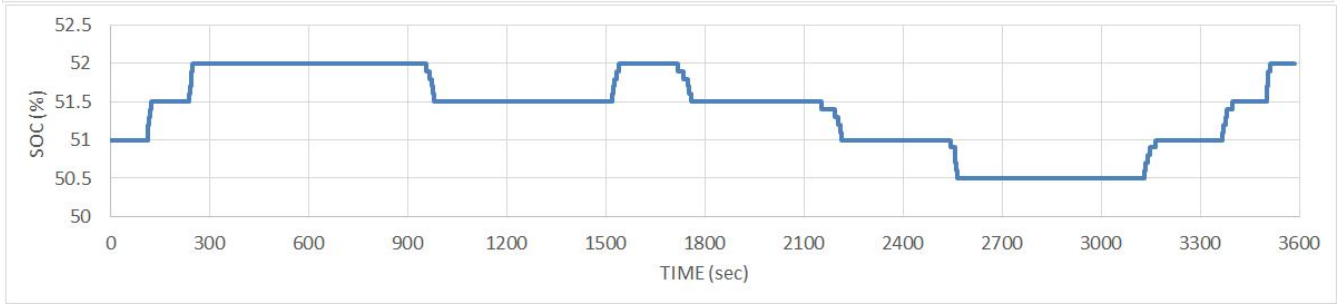


BESS Participating in AGC



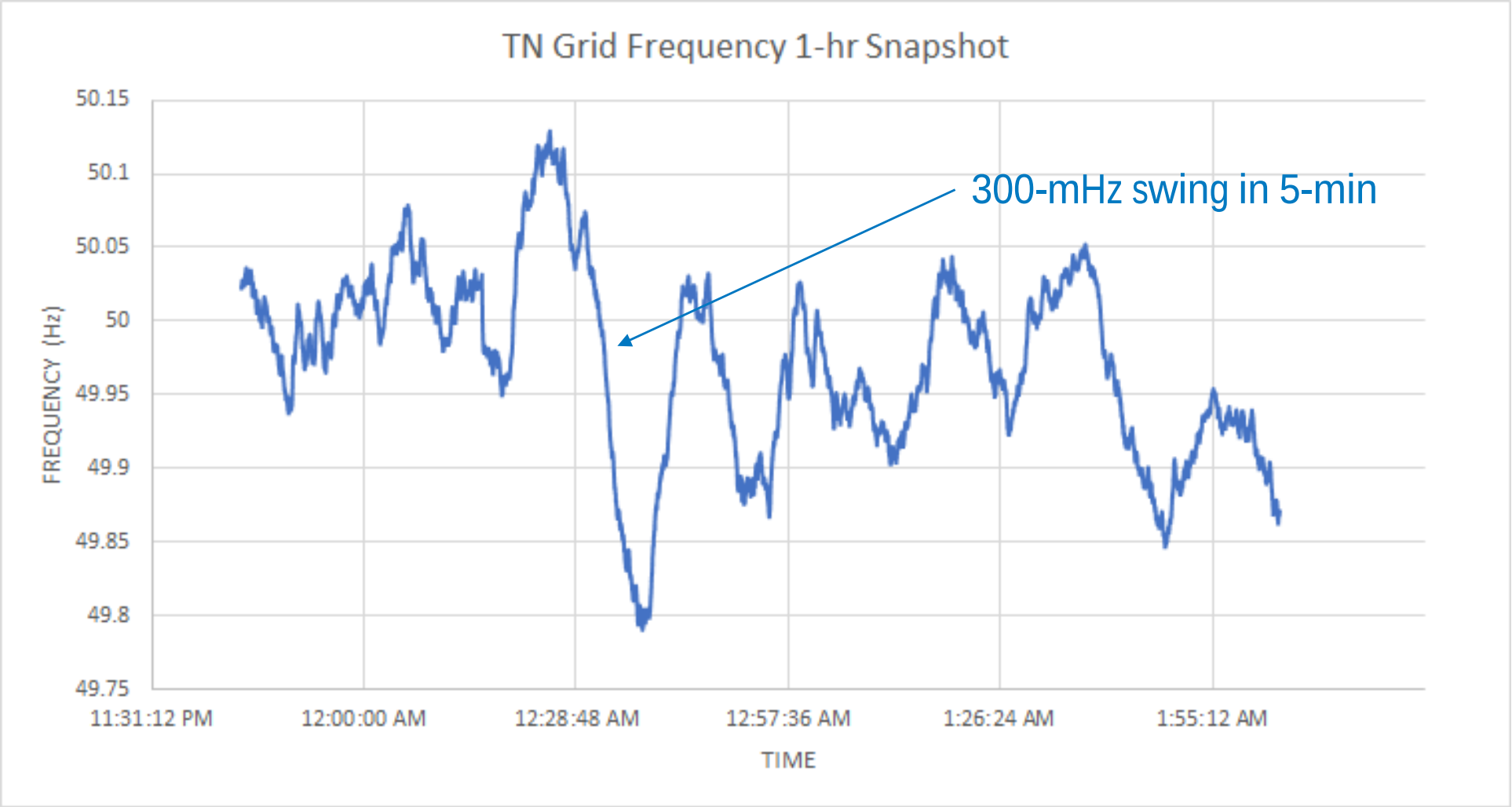




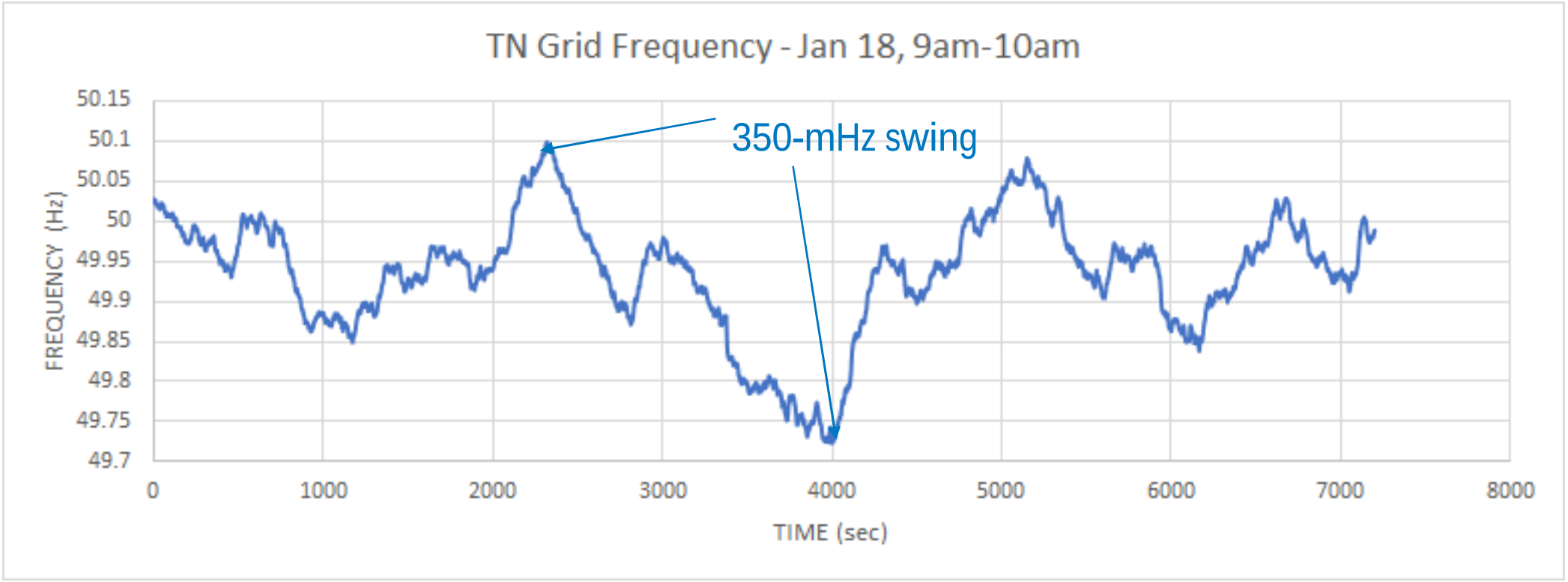


- PSCO historic ACE time series (updated every 4 sec)
- ACE is scaled down to match BESS rating

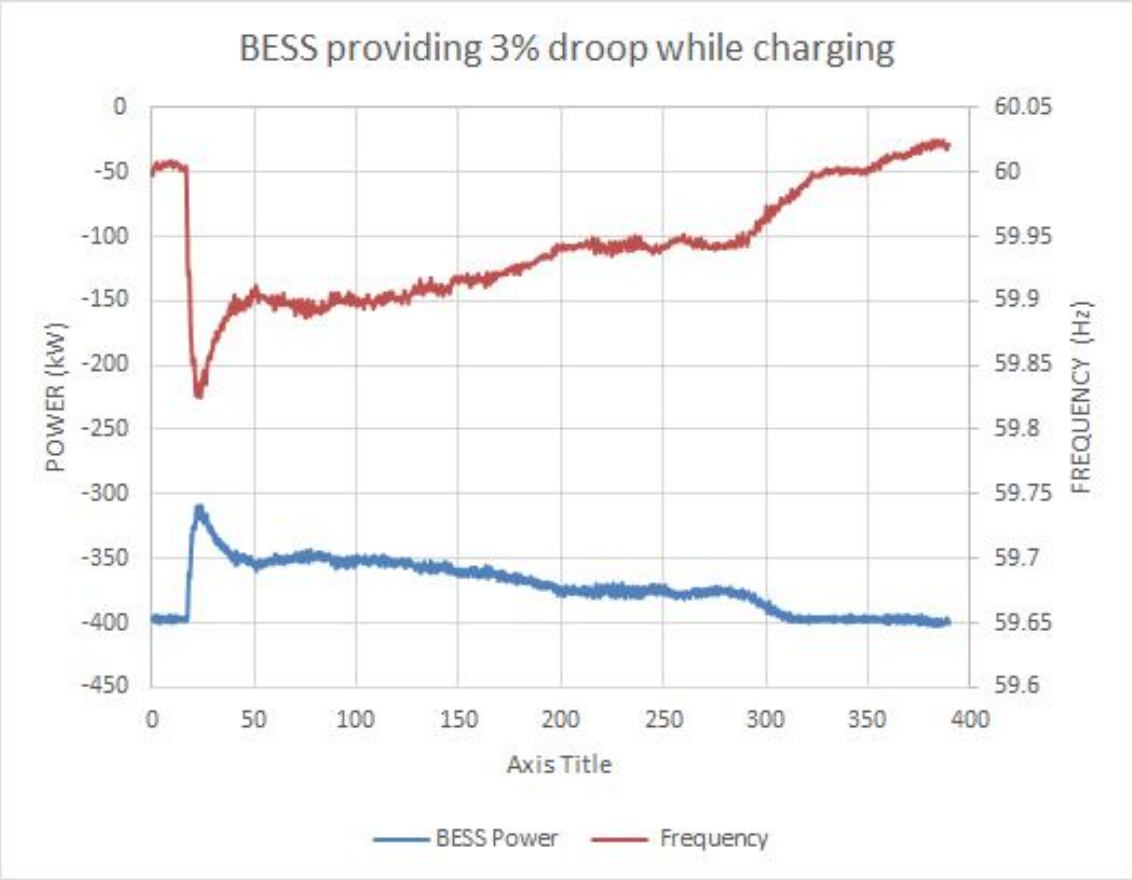
TN Frequency Jan 17, 2018

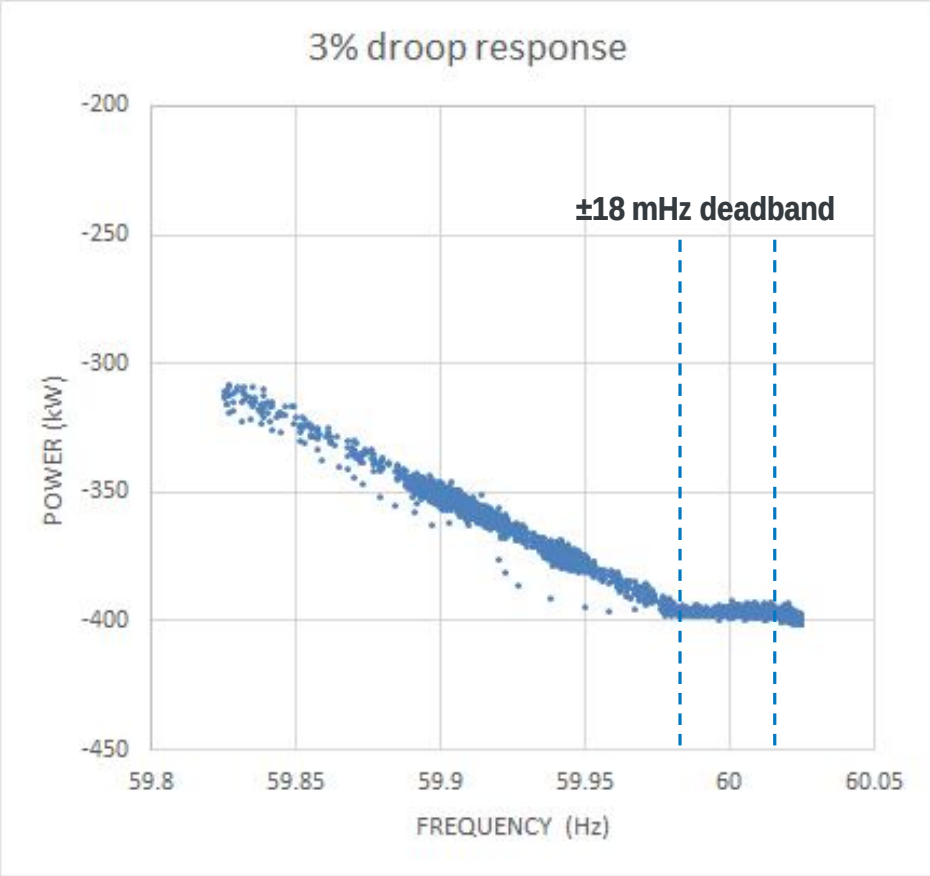


TN Frequency Jan 18, 2018

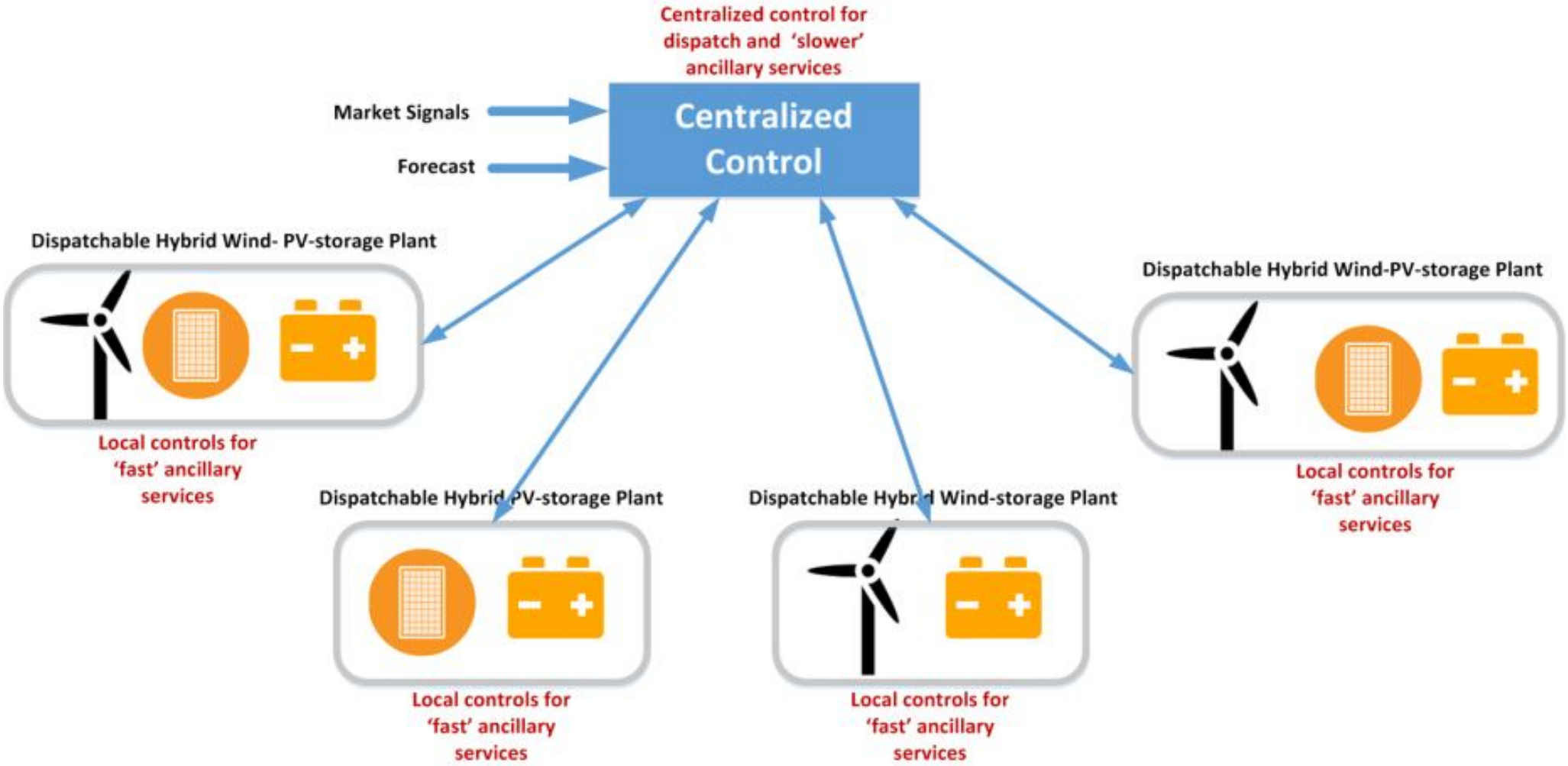


BESS Providing Frequency Droop





Dispatchable Hybrid Wind and Solar Plants Coupled with ESS



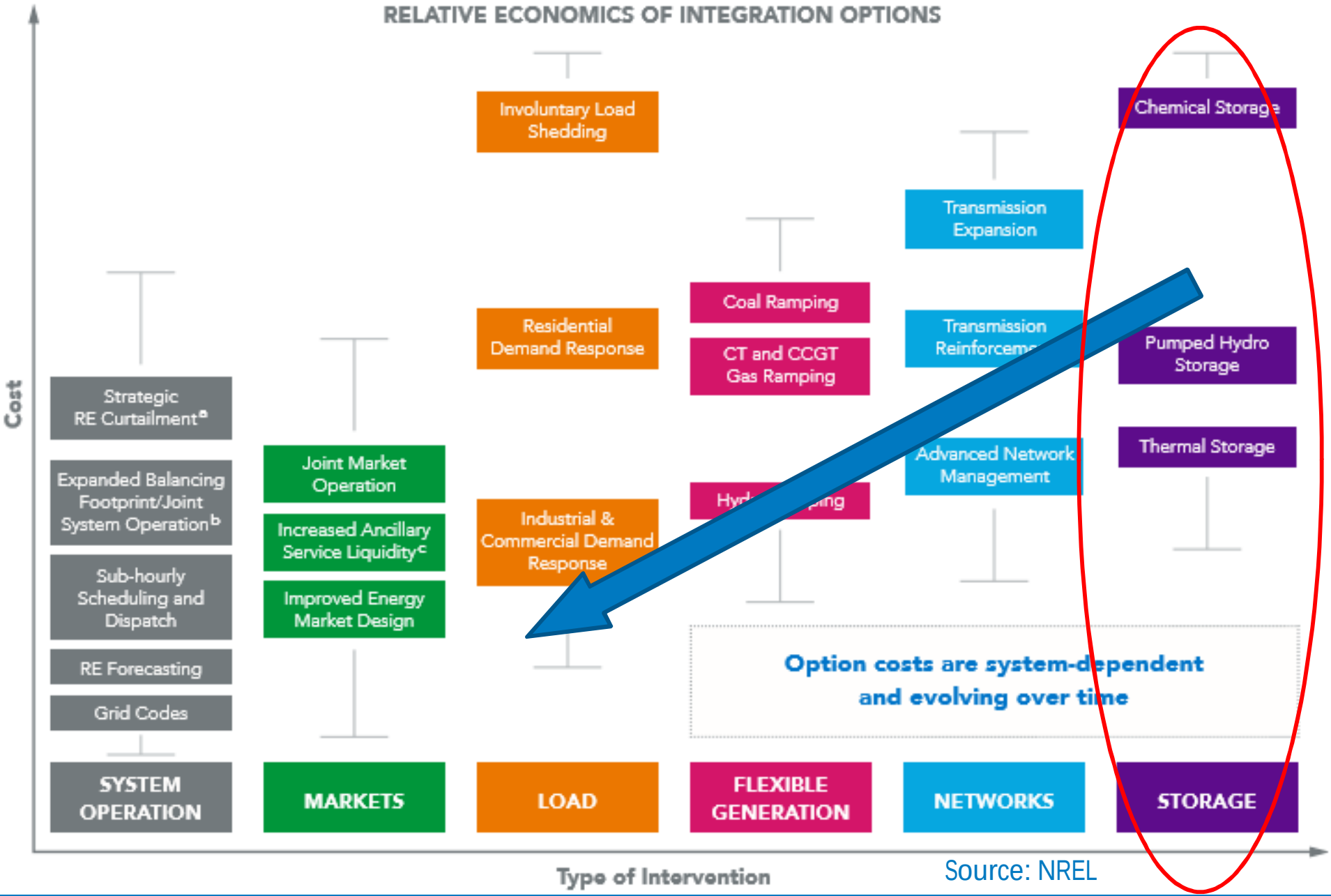
- Similar performance as conventional plants
- Wide area aggregation
- Hybrid forecasting

- All essential reliability services
- Optimized storage dispatch
- Storage for plant performance optimization

Services by Wind-PV-BESS Hybrid Plants

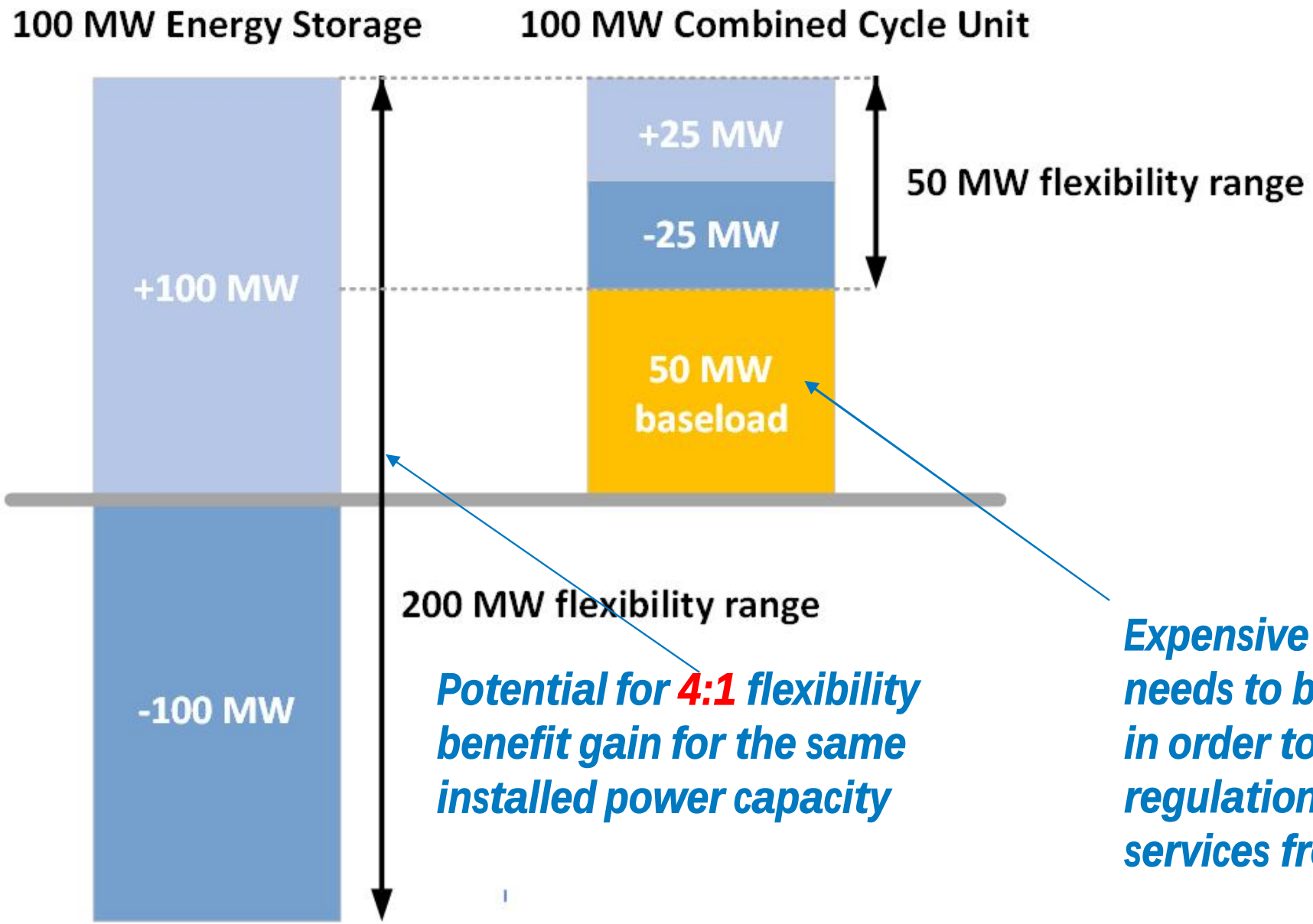
- Dispatchable renewable plant operation
  - Long-term and short-term production forecasts
  - Capability to bid into day-ahead and real-time energy markets like conventional generation
- Ramp limiting, variability smoothing, cloud-impact mitigation
- Provision of spinning reserve
- AGC functionality
- Primary frequency response (programmable droop control)
- Fast frequency response (FFR)
- Inertial response:
  - programmable synthetic inertia for a wide range of H constants emulated by BESS ✓
  - Selective inertial response strategies by wind turbines
- Reactive power/voltage control
- Advanced controls: power system oscillations damping
- Stacked services
- Plant electric loss reduction, AEP increase
- Selective plant configuration for BESS: ability to serve a whole wind power plant, or selected rows/turbines
- Battery SOC management (optimized using resource and energy price forecasts)
- Optimization model-predictive control strategies

Changing Flexibility Resources Landscape



Source: NREL

Energy Storage vs. Combined Cycle for Flexibility Services



Source: V. Gevorgian, NREL

Thank you!

www.nrel.gov