Using Renewables to Operate a Low-Carbon Grid

Demonstration of Advanced Reliability Services from Utility-Scale Solar PV & Wind Plants

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US Energy Association
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California ISO facts

As a federally regulated nonprofit organization, the ISO manages the high-voltage electric grid of California and a portion of Nevada

50,270 MW record peak demand (July 24, 2006)

26,000 circuit-miles of transmission lines

224.8 million megawatt-hours of electricity delivered (2020)

75,747 MW power plant capacity *Source: California Energy Commission*

1,119 power plants
Source: California Energy Commission

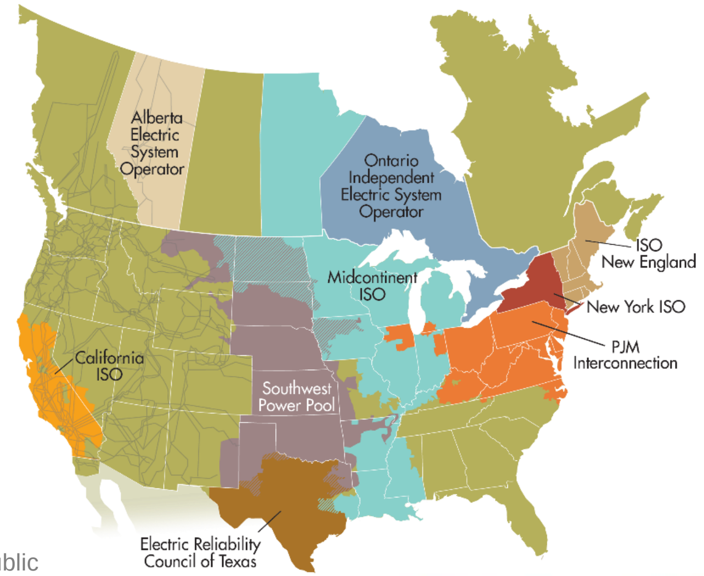
32 million people served

One of **9** ISO/RTOs in North America

$10.8 billion annual market (2018)

78¢ per MWh grid management charge (June 1, 2020)

33,617 market transactions per day (2020)



California is aggressively pursuing a low carbon future

- Aggressive renewable energy goals

33% by 2020 → 60% by 2030 → 100% zero-carbon by 2045

- Deep greenhouse gas (GHG) reduction goals

2020 Target	2030 Target	2050 Target
Reduce GHG emissions to 1990 levels	40% below 1990 levels	80% below 1990 levels

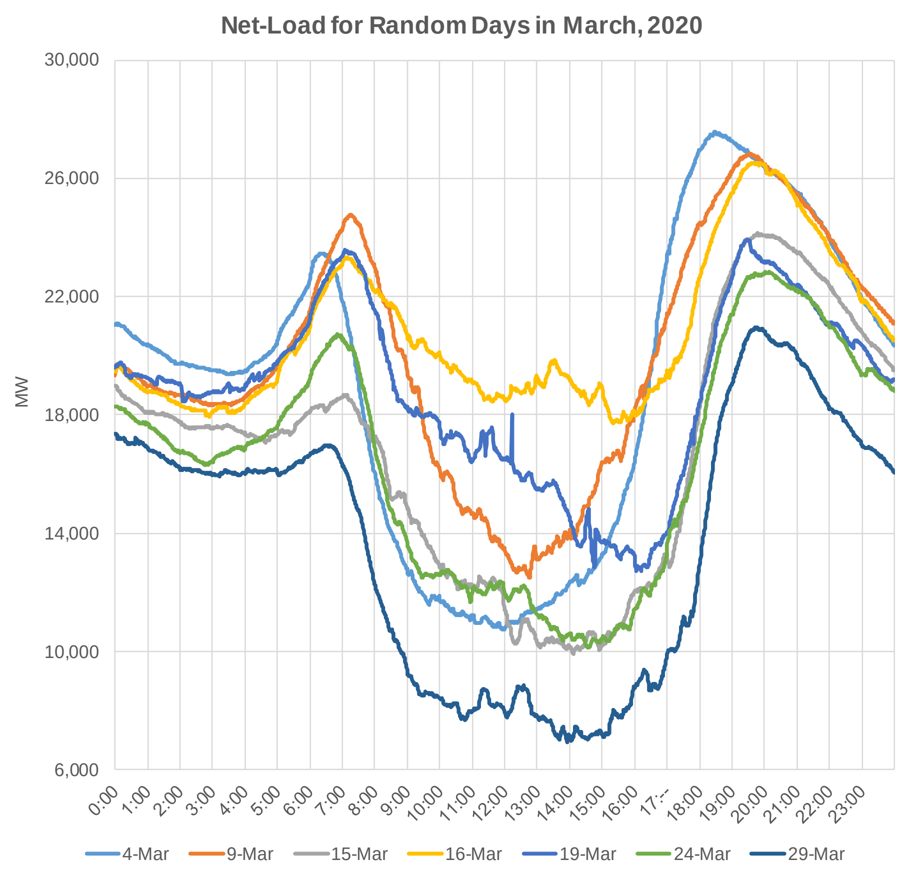
- Robust electric vehicle's goal: 5-7 million by 2030
- 12,000 MW of rooftop solar PV by 2020
- 2,000 MW of battery storage by 2021

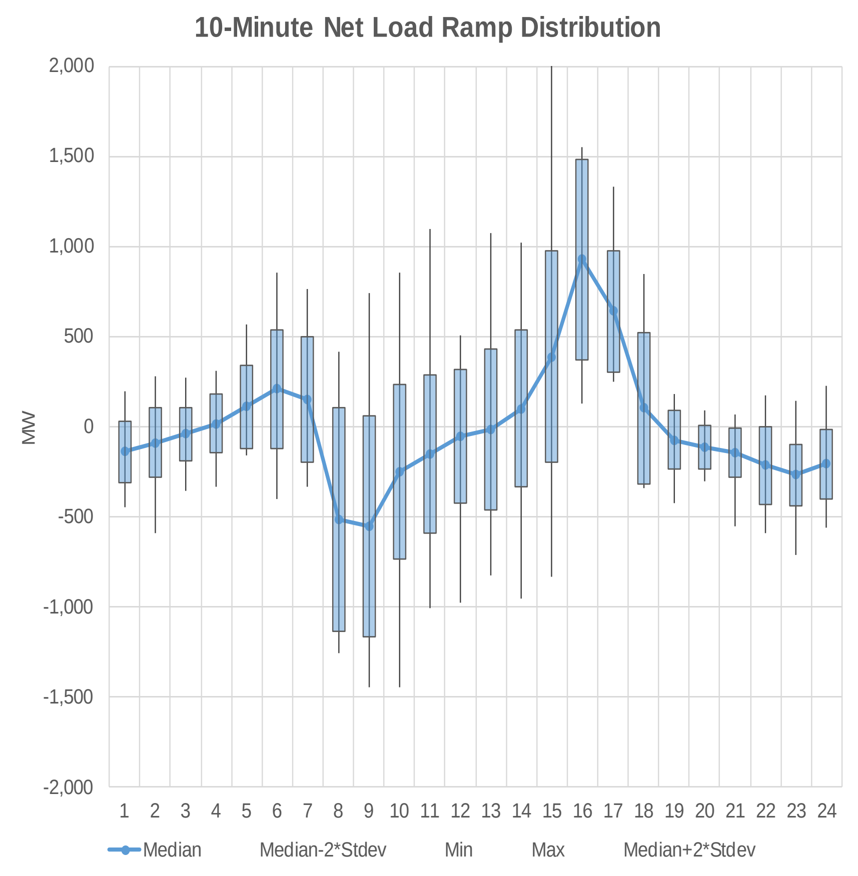
Decarbonization is creating opportunities to develop a high renewables and high DER energy service industry

CAISO’s current real time operational challenges

- Intra-hour ramps can be greater than ± 7,000 MW in some hours
- Maximum 3-hour ramps greater than 17,000 MW during sunset
- 10-minute variability between ±1,000 MW and ± 1,500 MW
  - Dispatch decisions for the binding 5-minute interval could be off by ± 1,500 MW
- Depleting regulation procured in some hours
- Oversupply conditions continues to increase
- Experiencing control performance challenges during sunrise and sunset and the middle of the day on weekends
- During spring, cannot commit enough gas units on governor control to meet primary frequency response obligation --- especially under hydro spill conditions

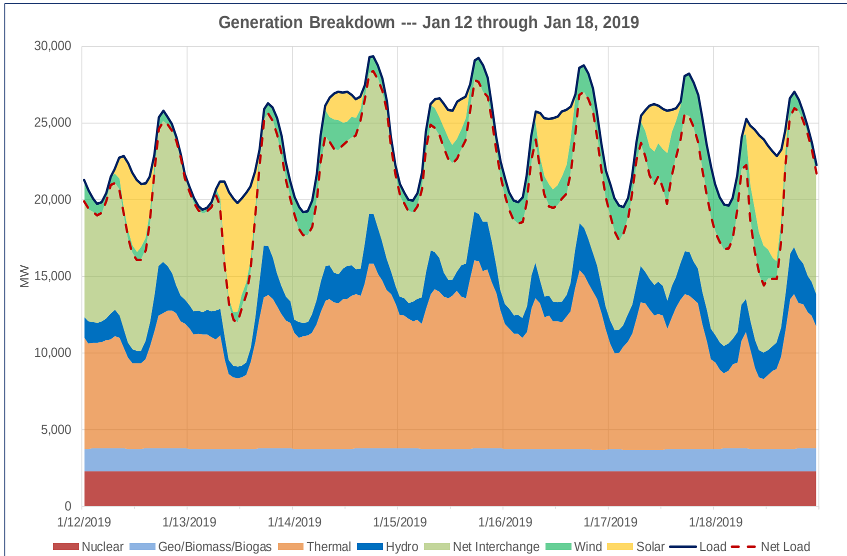
Example of net-load variability for seven random days in March 2020 and 10-minute variability is increasing

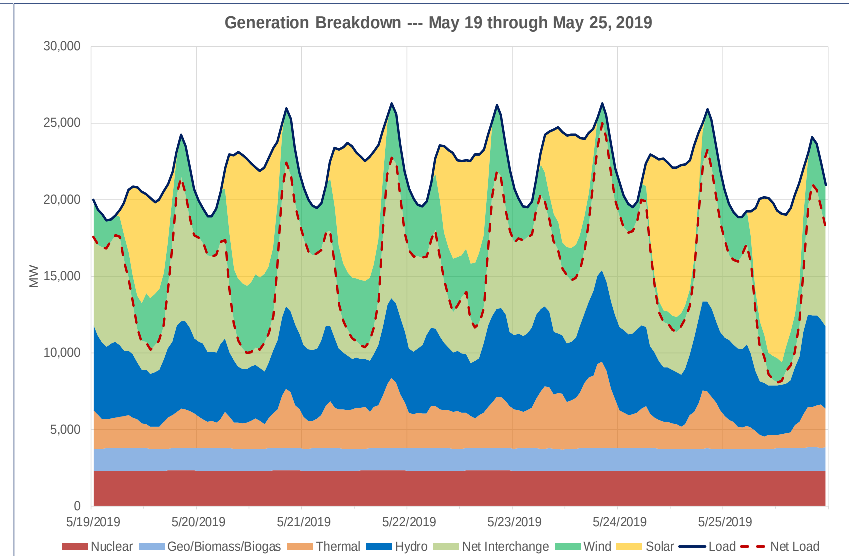




The 10-minute variability is about ±1,000 to ± 1,500 MW before regulation.
The blue shaded areas represents 95% of the time

Challenges under different operating conditions show the need for VERS including storage to provide grid services





Cloudy/Rainy Days

- Maximum net import was 9,820 MW
- Max hourly solar production was 1,970 MW
- Maximum simultaneous wind/solar was about 3,800 MW and occurred during HE11
- Maximum thermal generation was about 12,000 MW
- Need long-tern storage to address extended periods with minimal wind/solar production

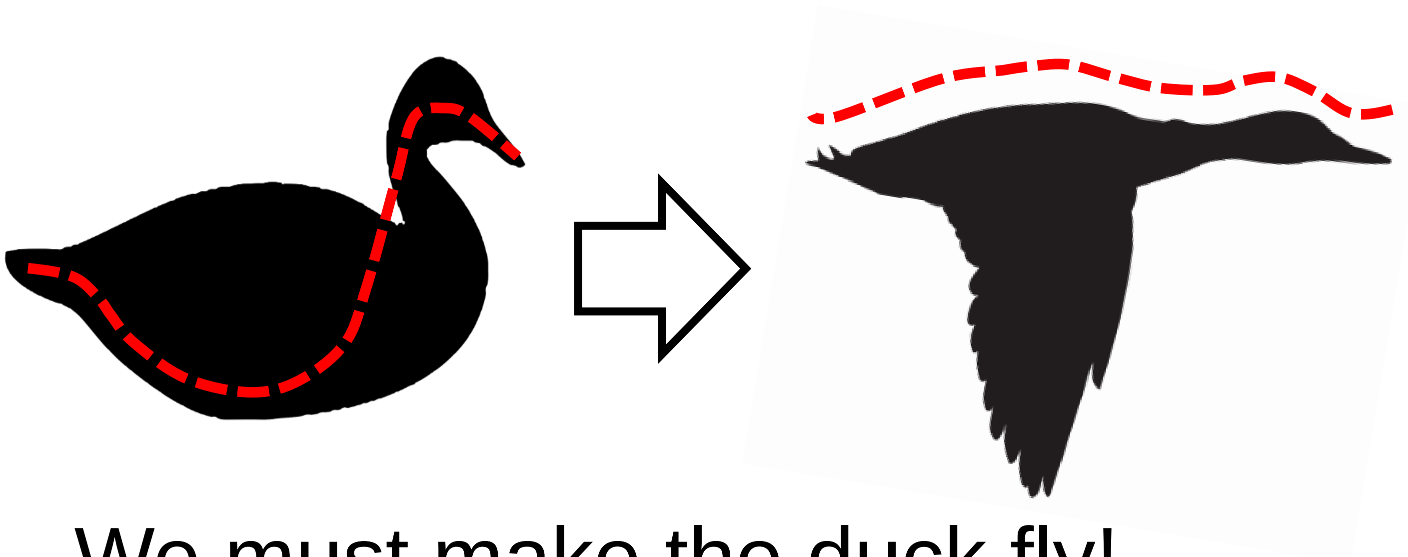
During Hydro Spill Conditions

- Rely on gas fleet for most ancillary services
- Typically operate gas fleet at low operating levels to minimize over supply
- Committed gas fleet cannot provide adequate primary frequency response obligation
- Need renewable resources to provide essential grid services
- Need storage devices to provide ancillary services, intra-hour and multiple hour ramping needs

What is the “Duck” telling us?

- Integrating renewables is making significant impact on how we meet mid-day demand
- Management of increased oversupply requires economic bids from all resources, including renewables
- Increasing evening ramp requires flexible capacity to balance supply and demand
- Need additional solutions such as storage, time of use (TOU) rates, regional collaboration, and using available flexibility from all resources could help manage increasing oversupply and ramping needs
- Need to maintain sufficient capacity during periods of low renewable production due to multiple days of cloud cover and low wind speed
- The volume and speed at which solar resources ramp up is faster than demand is increasing and needs to be managed
- Renewable resources need to follow dispatch instructions similar to other resources

How are we going to ensure our energy future is resilient, sustainable and efficient?



We must make the duck fly!

A healthy grid must counter-act the ill-affects of the sitting “duck curve”

What is Ancillary Service?

- Services that are necessary to support the transmission of energy to loads while maintaining reliable operation of the transmission system in accordance with good utility practice (From FERC order 888-A)

- Services include:
  - Frequency Response
  - Regulation Service
  - Spinning Reserve
  - Non-Spinning Reserve
  - Black Start Capability
  - Reactive Supply and Voltage Control
  - Energy Imbalance Services
  - Flexible Ramping Product

Most U.S. power systems do not operate markets for these products but do maintain adequate resources through internal requirements and other procurement mechanisms

CAISO's Market Process

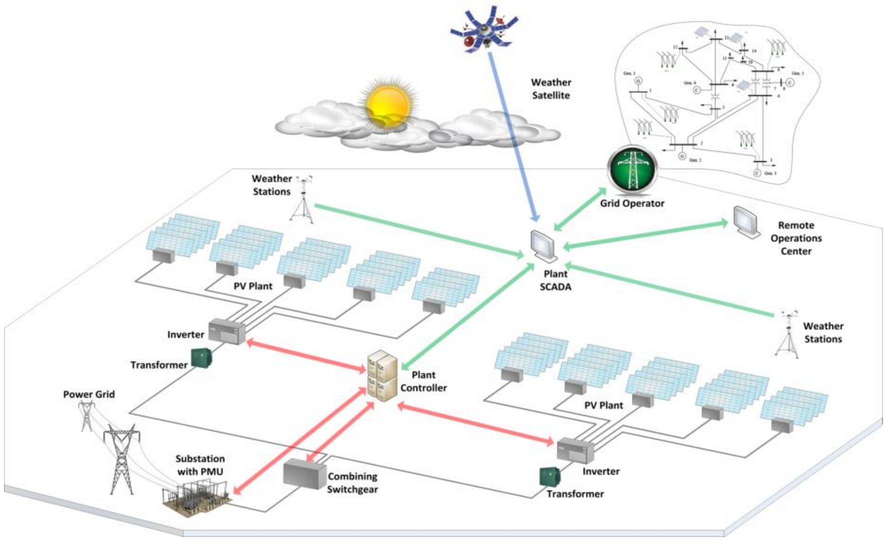
- Ancillary service bids may be accompanied by an energy bid in the Day-Ahead Market (DAM) and must be accompanied by an energy bid in the Real-Time Market (RTM)
- CAISO sets the required amount of contingency reserve based on WECC/NERC standards for reserves; regulation procurement is based on forecast conditions
- Ancillary service bids are co-optimized with energy bids to obtain the least cost solution (prices reflect marginal cost, which includes availability cost & lost opportunity cost)
- Spinning Reserves and Non-Spinning Reserves are procured in the DAM to meet 100% of the reserve requirement
- If needed, additional Reserves are purchased through the RTM
- CAISO selects resources to provide ancillary service capacity based on their capacity bid prices and deliverability

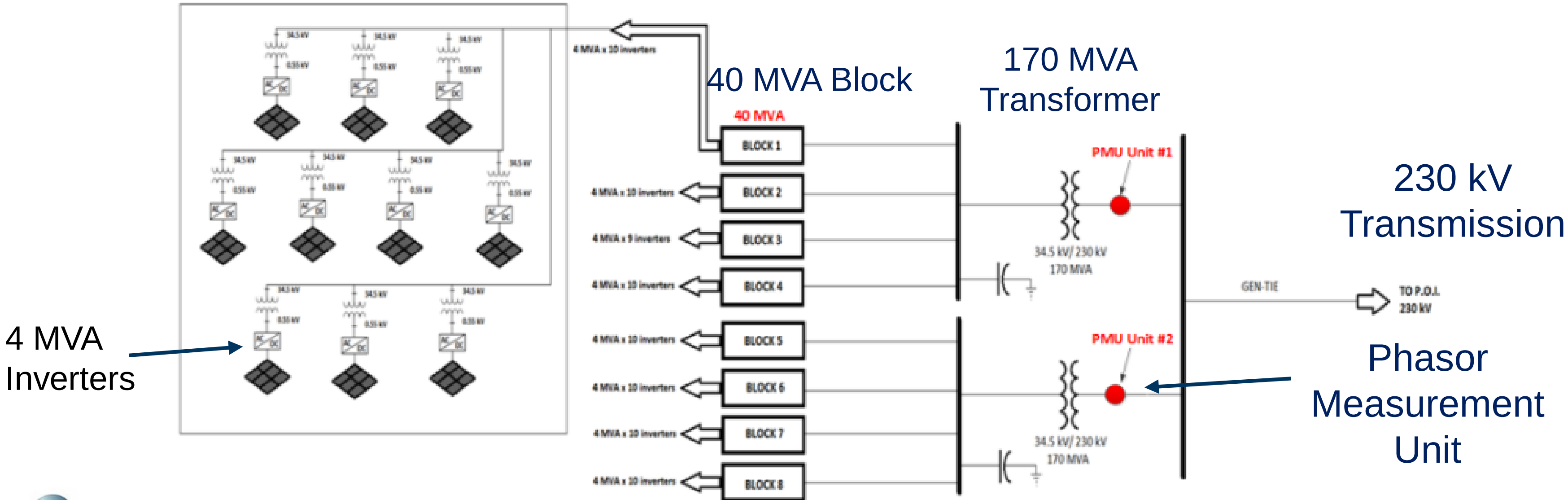
Can variable energy resources provide essential reliability services to reliably operate the grid?

- NERC identified three essential reliability services to reliably integrate higher levels of renewable resources
  - Frequency Control
  - Voltage Control
  - Ramping Capability or Flexible Capacity

320 MW solar PV power plant description

- First Solar PV modules
- 4 MVA PV inverters
- 8 x 40 MVA blocks
- 34.5 kV collector system
- Two 170 MVA step-up transformers
- 230 kV transmission tie lines
- PMUs collecting data on 230 kV side



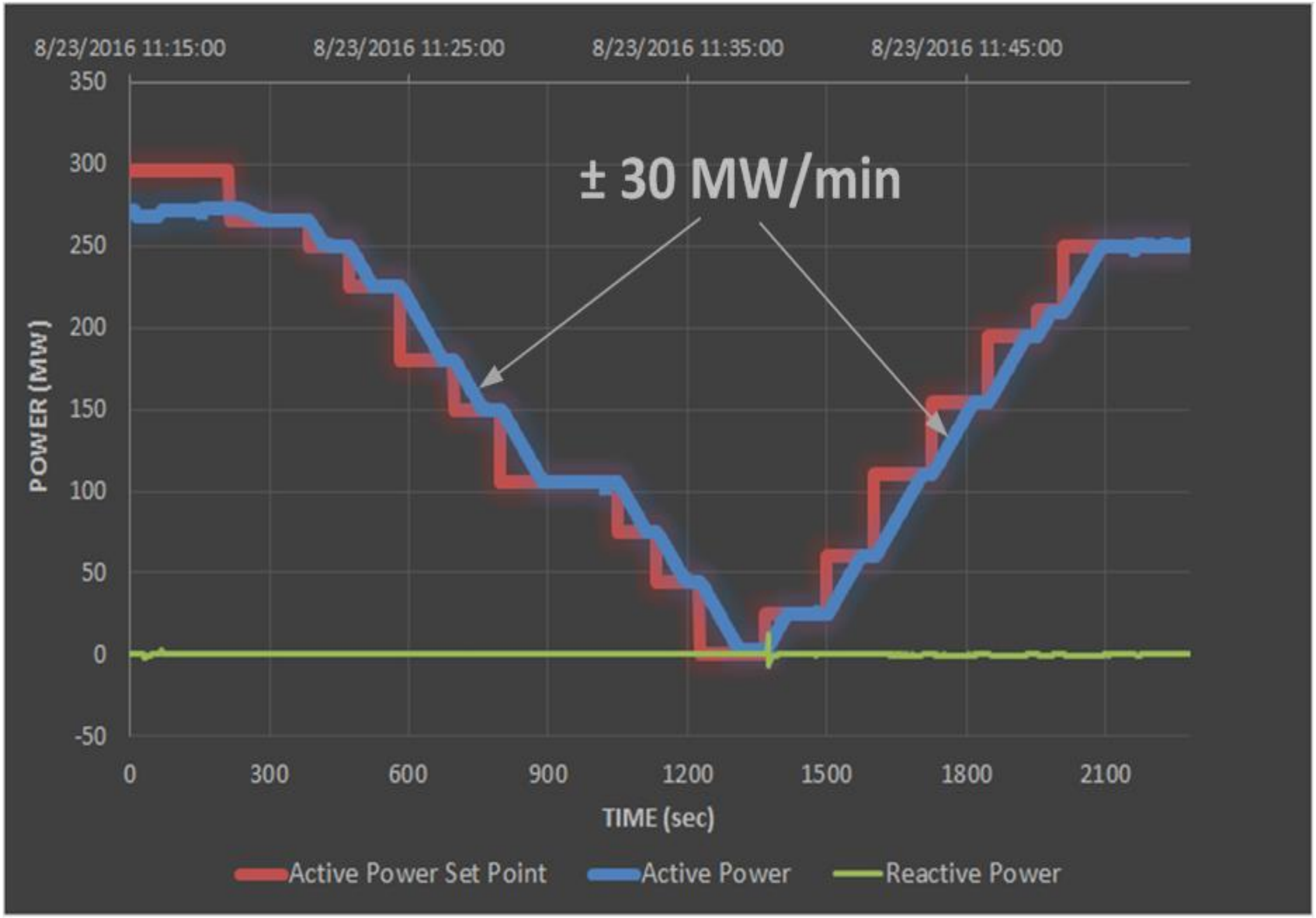


Summary of tests conducted

CAISO-NREL-First Solar custom-developed test scenarios

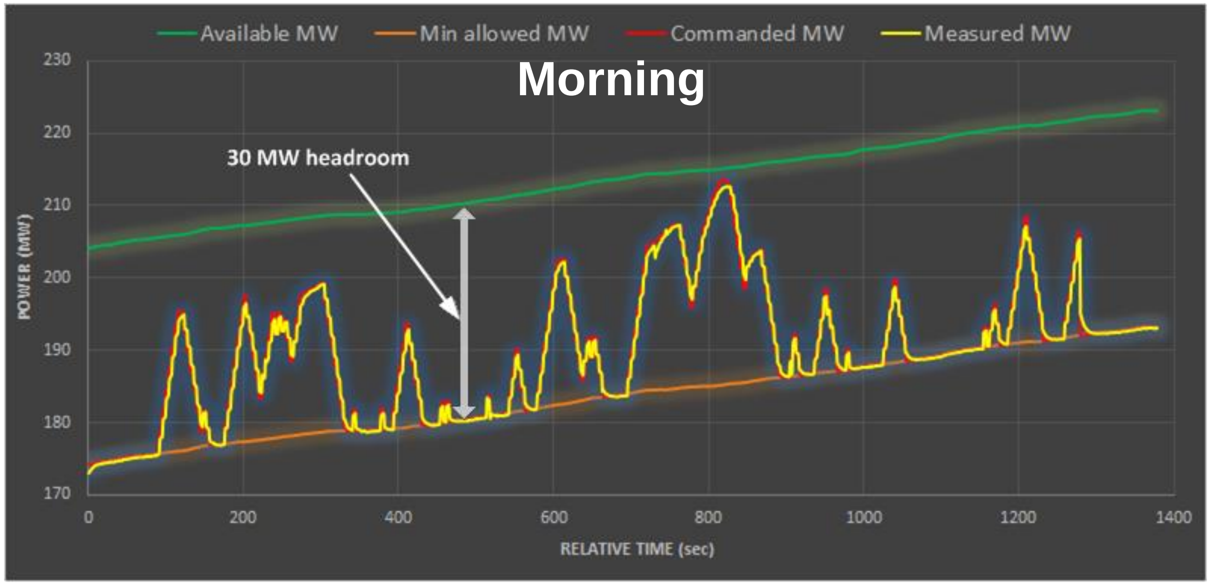
- *Regulation up/down*, or AGC tests during sunrise, middle of the day, and sunset
- *Frequency response* tests with 3% and 5% droop settings for over-frequency and under- frequency conditions
- *Curtailment and active power control (APC)* tests to verify plant performance to decrease or increase its output while maintaining specific ramp rates
- *Voltage and reactive power* control tests
- *Voltage control* at near zero active power levels (nighttime control).
- Automatic manual control of inverters (individual, whole plant)
- Automatic voltage regulation at high and low power generation
- Active power curtailment control, generation failure and restoration control, frequency control validation

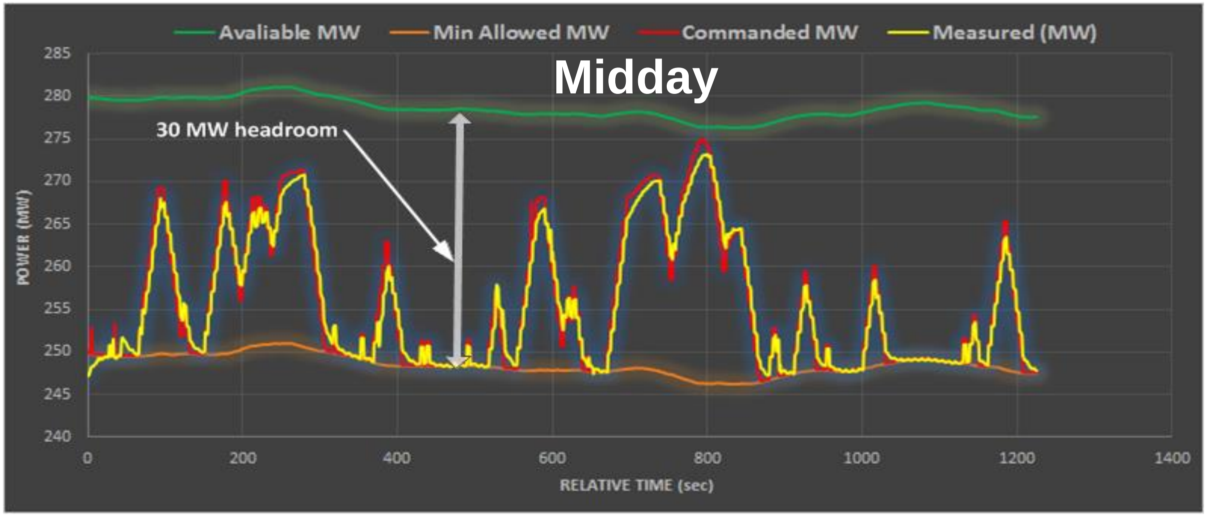
Active power curtailment and recovery at constant ramp rate



AGC Participation Tests

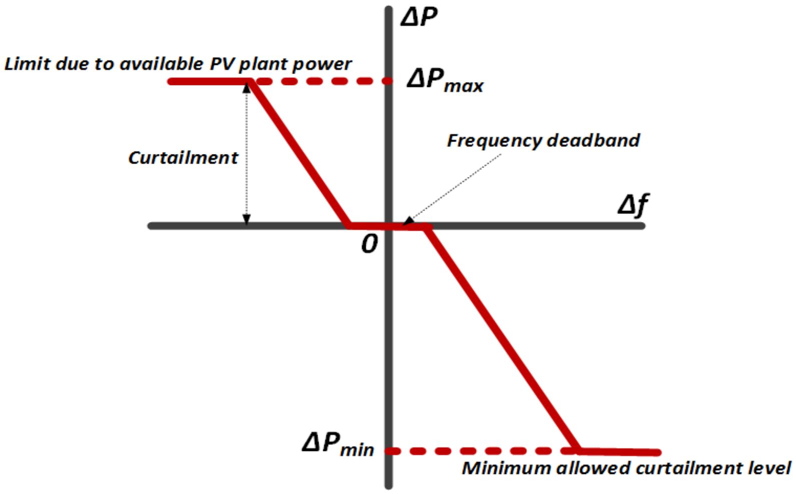
- 4-sec AGC signal provided to PPC
- 30 MW headroom
- Tests were conducted for three resource intensity conditions (30 minutes at each condition):
– Sunrise
– Middle of the day
– Sunset
- 1-sec data collected by plant PPC





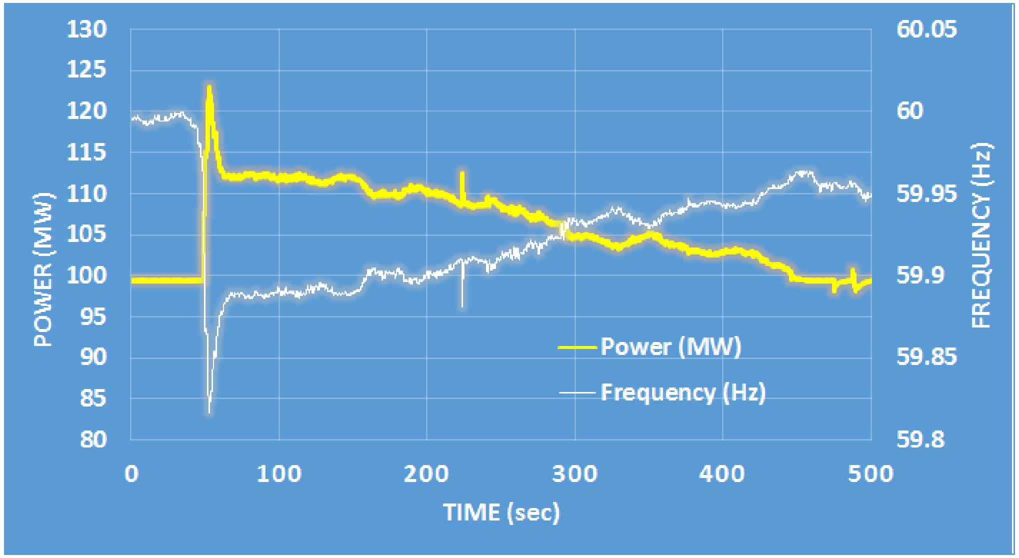
California ISO

Frequency droop tests



$$\text{Droop} = \frac{\Delta f/60Hz}{\Delta P/P_{rated}}$$

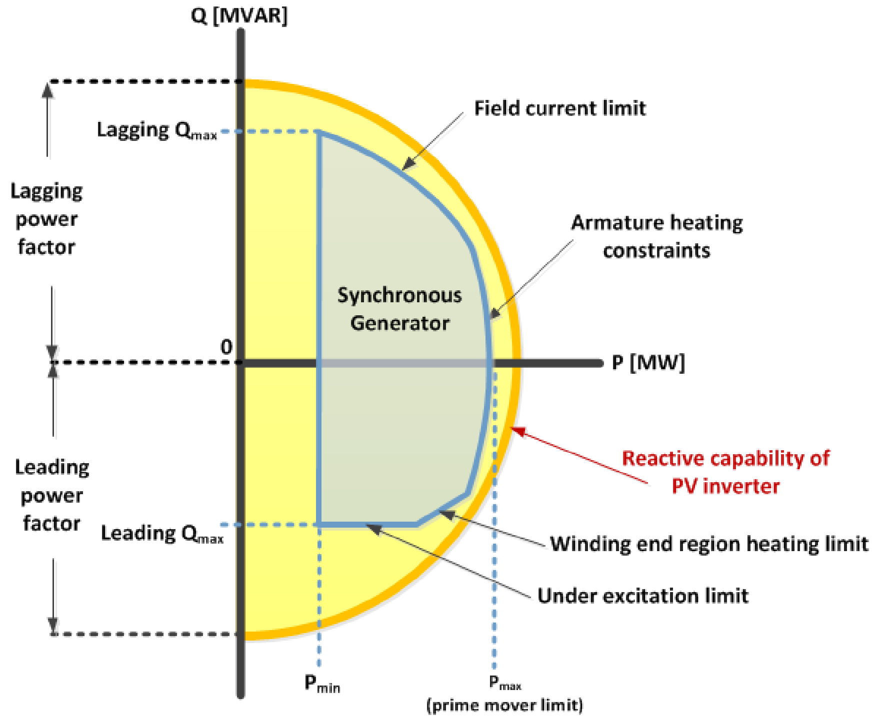
Example of 3% droop test (under-frequency)



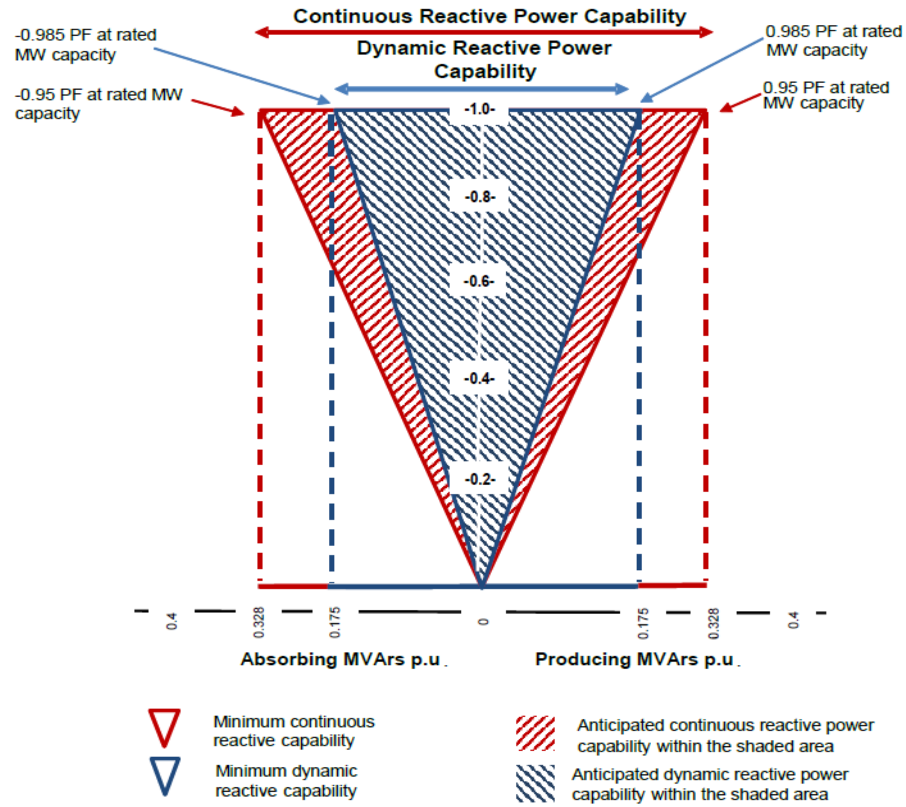
- 3% and 5% under and over-frequency tests
- 20% headroom
- ±36 mHz dead band
- Actual frequency event time series measured in the U.S. Western Interconnection

CAISO's reactive power and voltage control tests before FERC Order requiring dynamic reactive

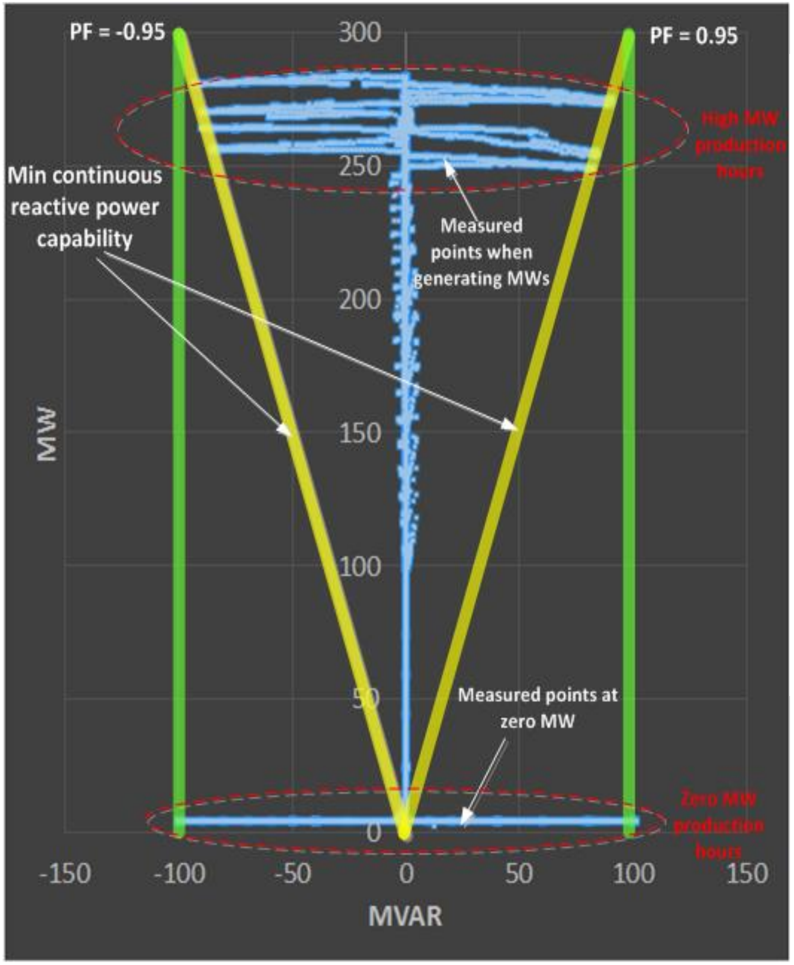
Comparison of reactive power capability for a synchronous generator and PV Inverter

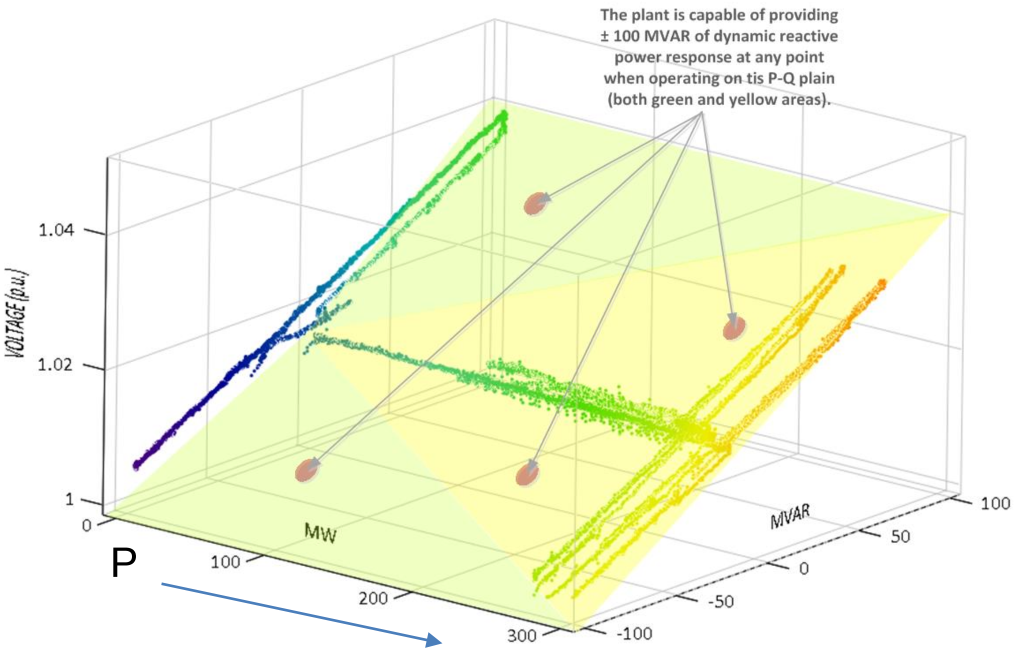


Proposed CAISO Reactive Capability for Asynchronous Resources



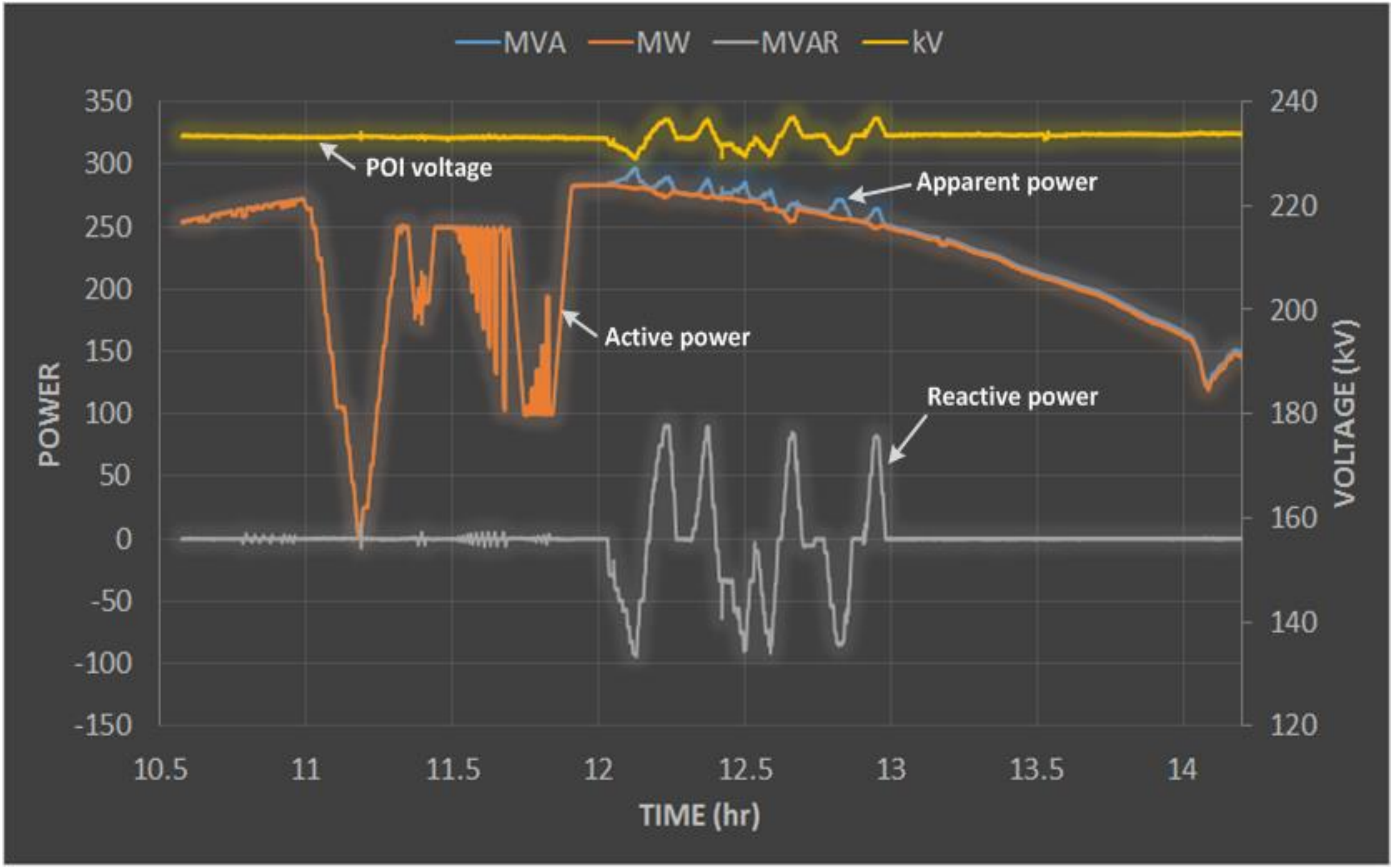
Measured reactive power capability and voltages





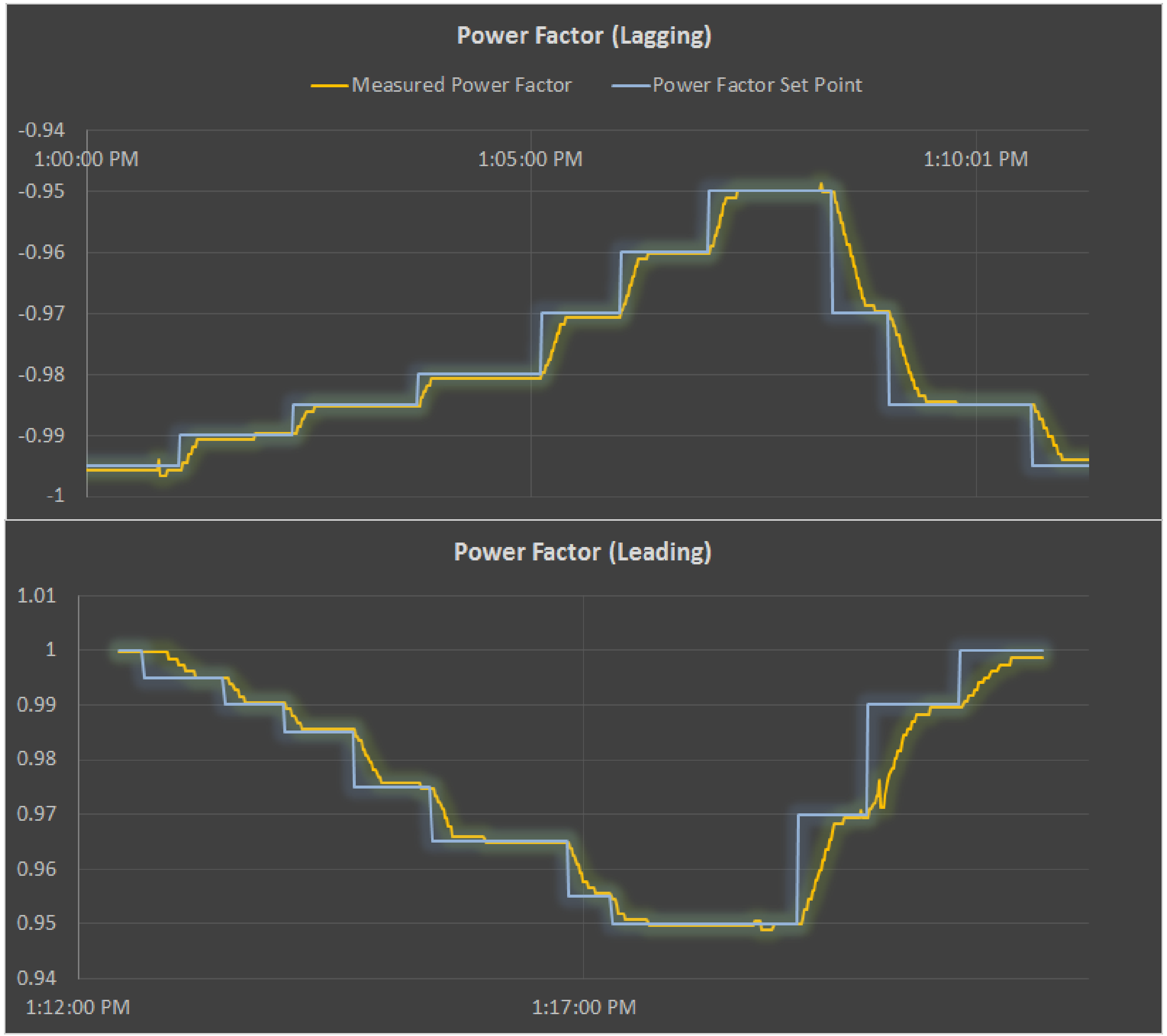
- Reactive power tests at high and low power production levels
- The plant met the proposed CAISO reactive power requirements

300 MW PV plant voltage test



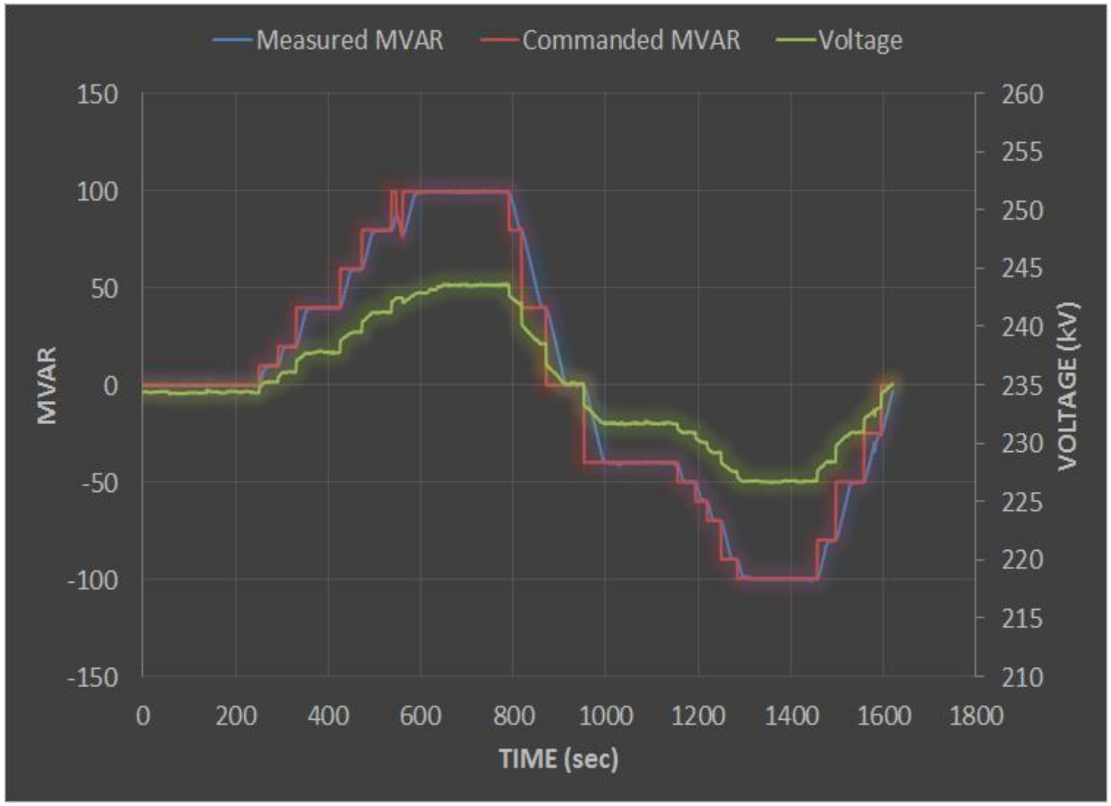
Lagging and leading power factor control tests

- ±100 MVAR/min ramp rates applied
- PF limit = ±0.95
- Tests conducted at nearly full power output



Reactive power control test at low generation output

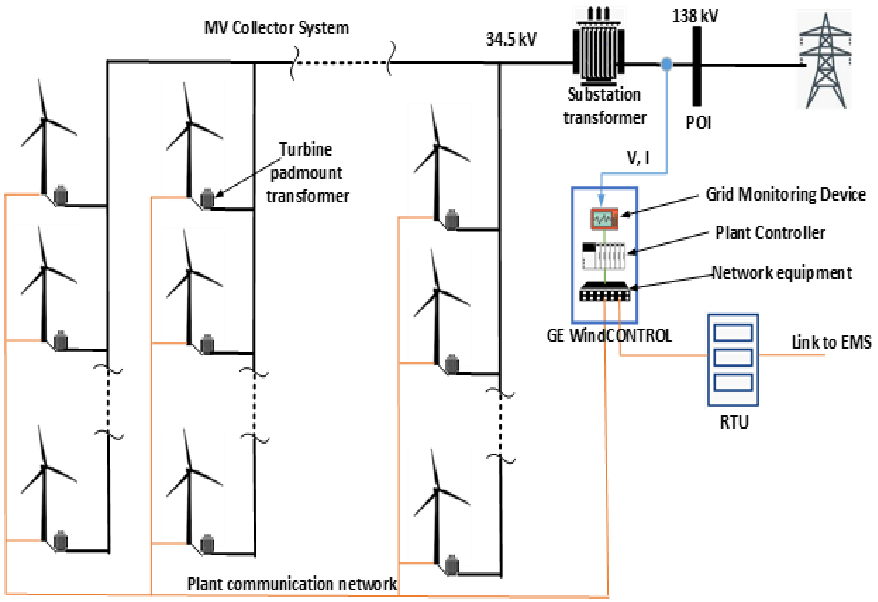
- Plant was curtailed down to 5 MW output level
- Ability of the plant to produce or absorb VARs (±100 MVAR) was demonstrated
- True night VAR support will be demonstrated in future



Conclusions of solar PV tests

- Solar PV resources with smart inverter technology have unique operating characteristics that can enhance system reliability by providing:
  - Essential reliability services during abnormal operating conditions
  - Voltage support when the plant's output is near zero
  - Fast frequency response (inertia response time frame)
  - Frequency response for low as well as high frequency events
- Accurate estimation of available peak power is important for the precision of AGC control:
  - It makes sense to include specifications for such available peak power estimations into future interconnection requirements and resource performance verification procedures.
  - Perhaps, standardization for reserve estimation methods

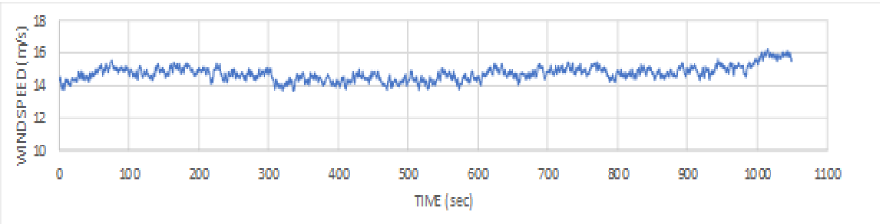
131.1 MW wind plant test was conducted by the California ISO, Avangrid Renewables, NERL and General Electric

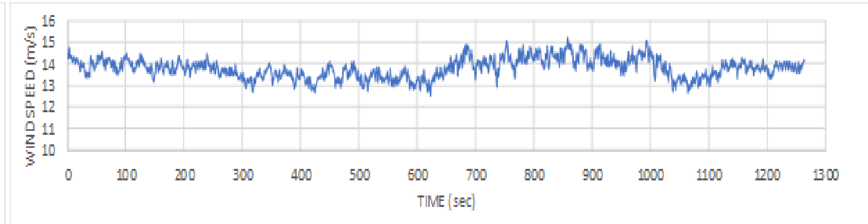


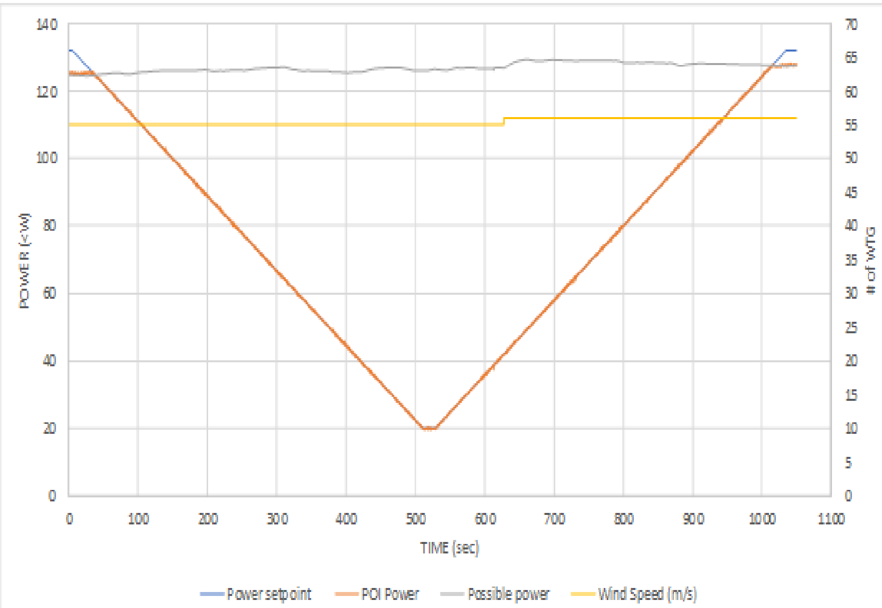
The wind plant is connected via a combination of underground and overhead distribution lines to a 150 MVA (34.5/138 kV) transformer

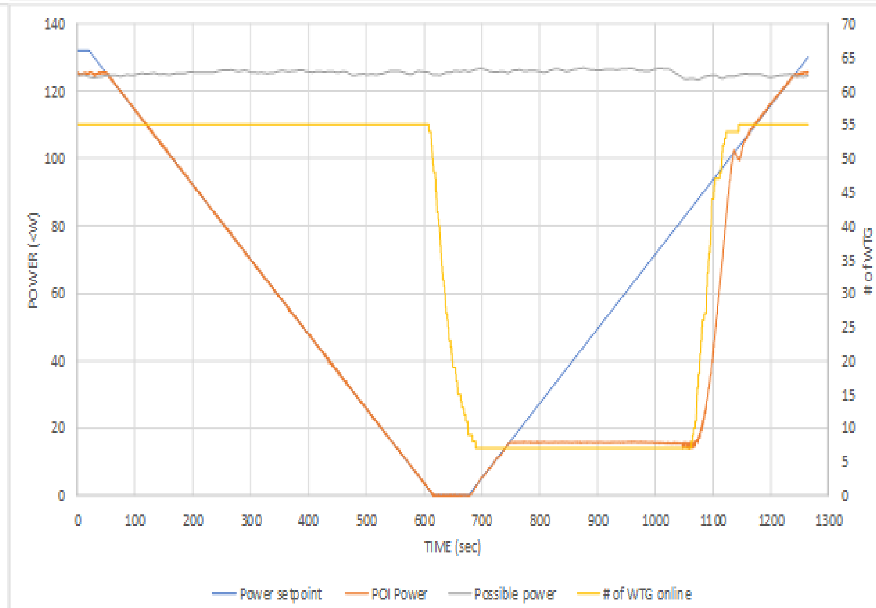
Each inverter performs its own energy production based on local wind speed, however the PPC coordinates the output to provide typical large power-plant services

Wind curtailment tests with different modes of recovery





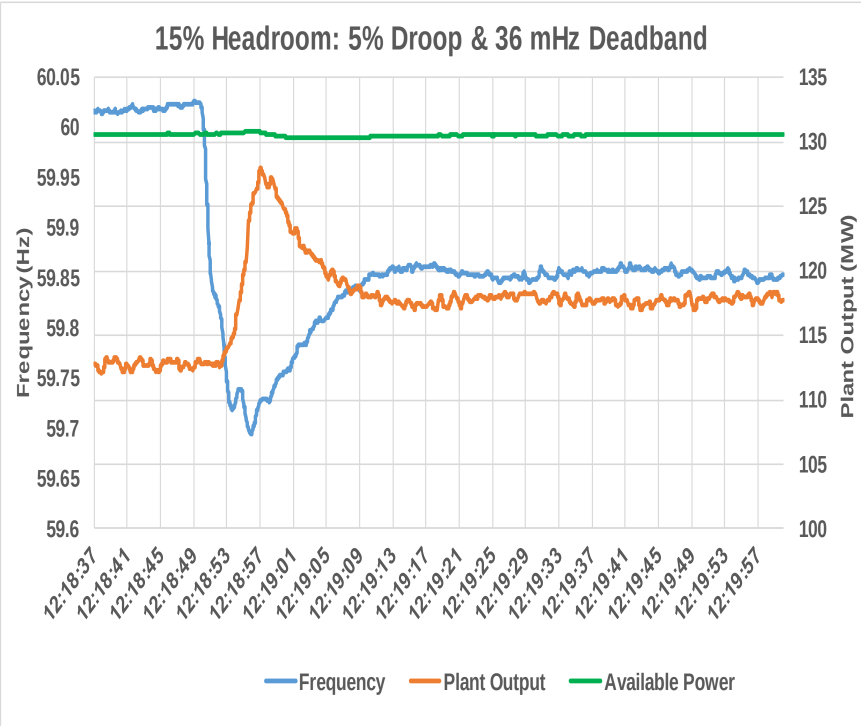


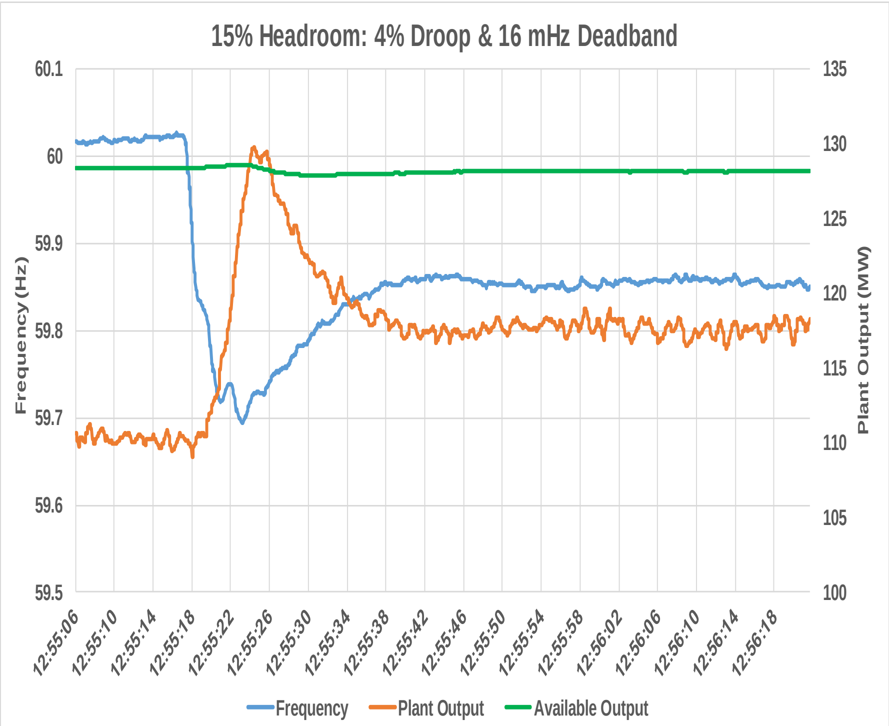


During this test, the PPC was instructed to ramp up and down at the same ramp rate

The PPC was operating with an end goal to achieve the peak power production only at the end of the production restoration interval

Wind plant response at 5% droop and 36 mHz dead band vs. 4% droop and 16 mHz deadband

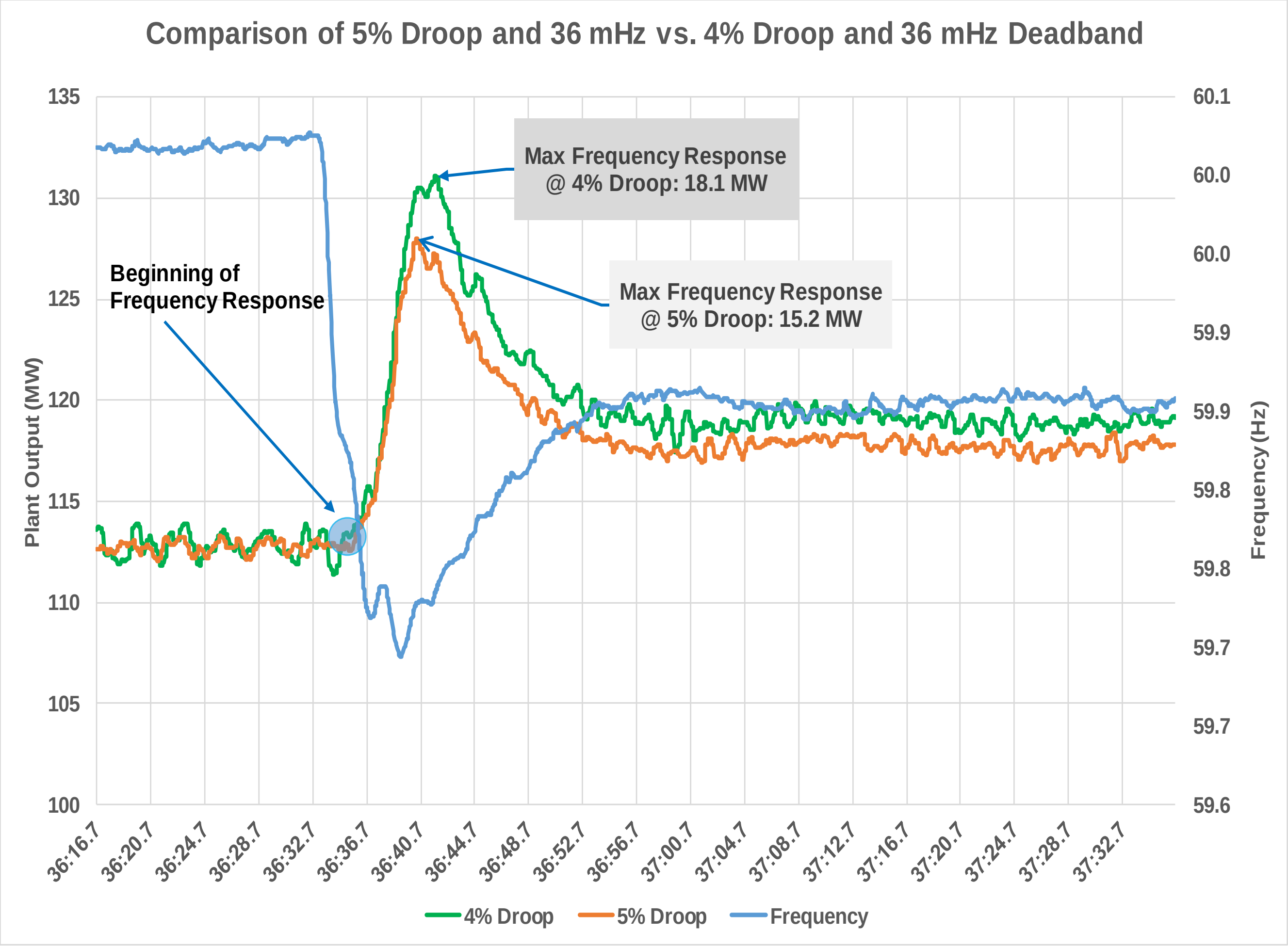




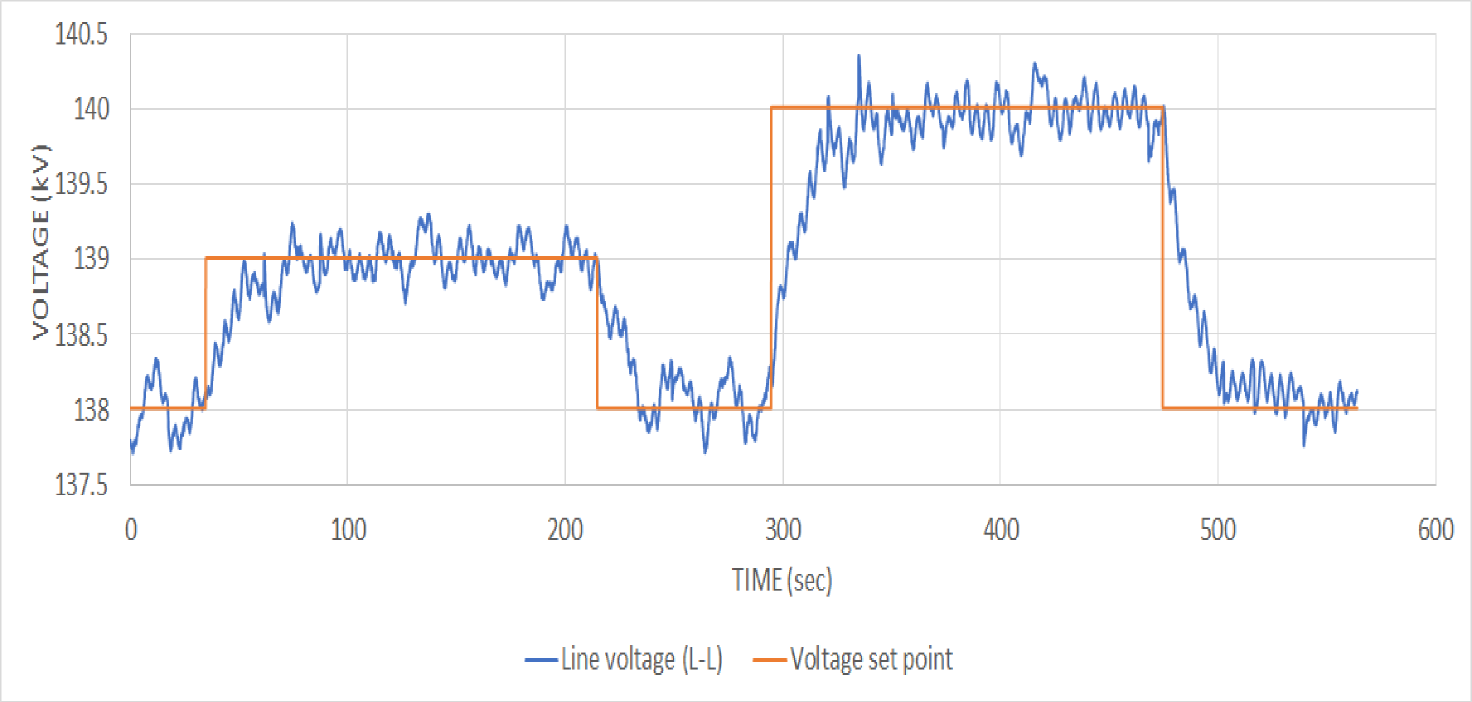
Maximum frequency response within the first 20 seconds was 15.36 MW

Maximum frequency response within the first 20 seconds was 19.32 MW

Comparison of wind plant frequency response at 5% droop and 36 mHz vs. 4% droop and 36 mHz

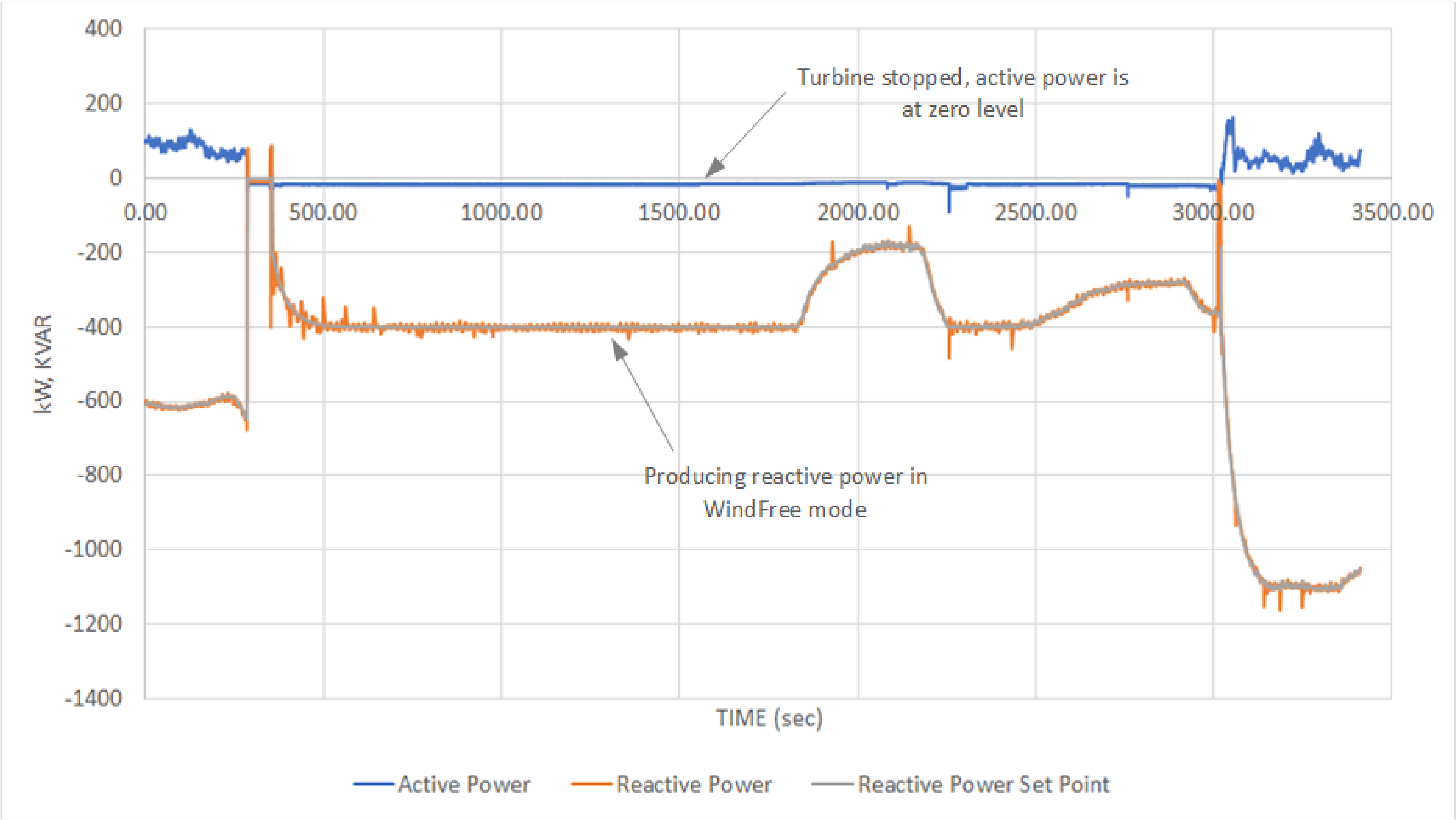


Wind plant capability to control voltage set points at the 138 kV tie line



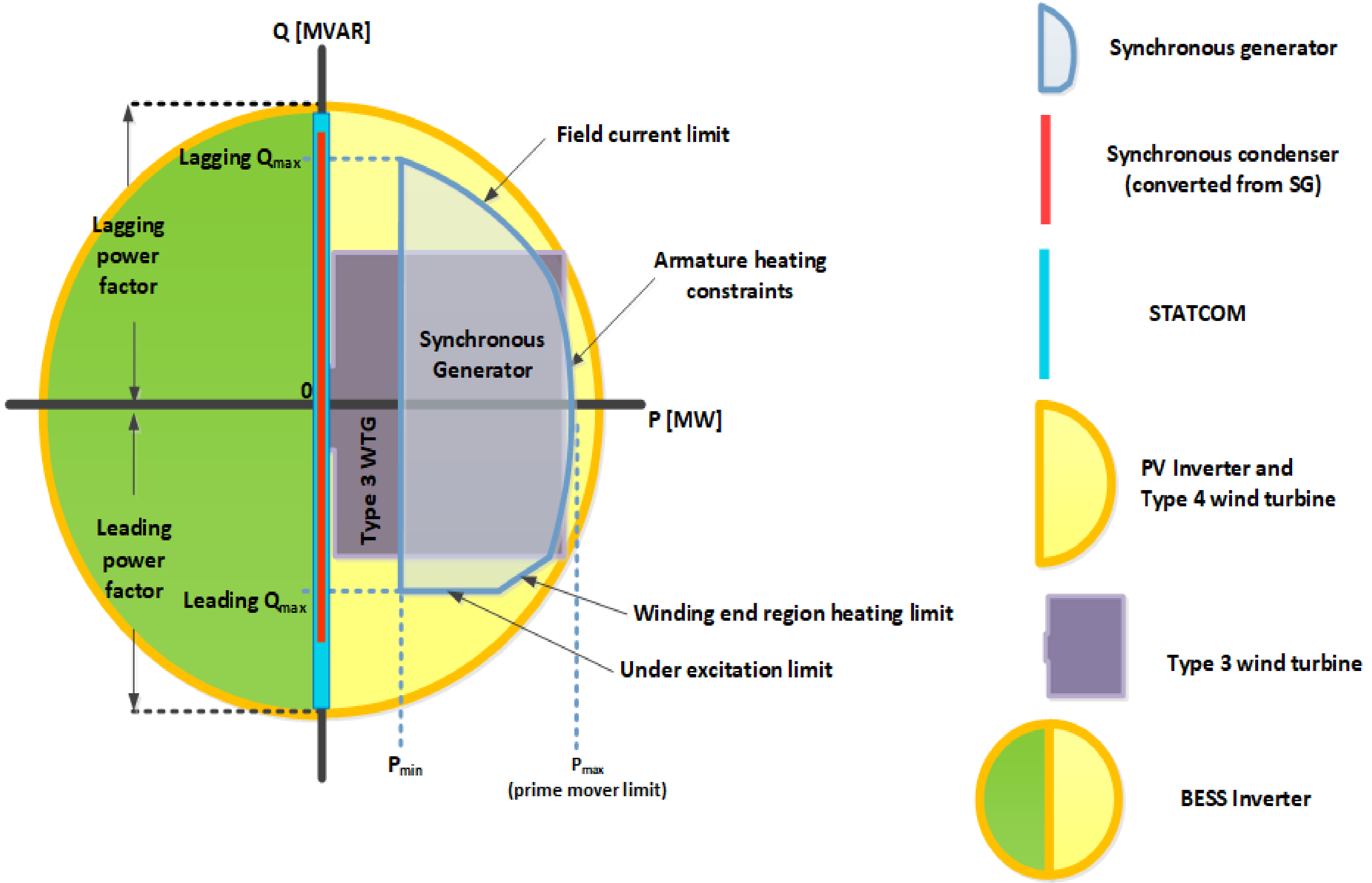
The active power production of the plant was around 70 MW during this test

Wind plant capability to control a voltage set-point with the turbine's active power production set at zero



Wind power plants can provide effective grid reinforcements through continuous voltage regulation – a benefit not possible with conventional thermal or hydro generation

Comparison of voltage control capabilities of various resource types



Source: NREL

General conclusion of the wind test

- Smart inverter technology combined with advanced plant controls allow inverter based resources to provide essential grid services
- Variable energy resources (VERs) with the right operating characteristics are necessary to decarbonize the grid
- Accurate estimation of available peak power is important for the precision of automatic generation control (AGC) control
- All hardware components enabling wind power plants to provide a full suite of grid-friendly controls already exist in many utility-scale wind plants
- Many utility-scale wind power plants are already capable of receiving curtailment signals from grid operators; each plant is different, but it is expected that the transition to AGC operation mode will be relatively simple with modifications made only to a PPC and interface software
- Fast response by wind inverters coupled with plant level controls make it possible to develop other advanced controls, such as STATCOM functionality, power oscillation damping controls, sub-synchronous controls oscillations damping and mitigation, active filter operation mode by wind inverters, and other features

Questions

- *Using Renewables To Operate A Low-Carbon Grid: Demonstration of Advanced Reliability Services from a Utility-Scale Solar PV Plant*

http://www.caiso.com/Documents/UsingRenewablesToOperateLow-CarbonGrid.pdf

- *Avangrid Renewables Tule Wind Farm: Demonstration of Capability to Provide Essential Grid Services*

http://www.caiso.com/Documents/WindPowerPlantTestResults.pdf