



Grid Reliability Services by Variable Renewable Generation

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Workshop on “99+ Grid Availability for RE Integration”
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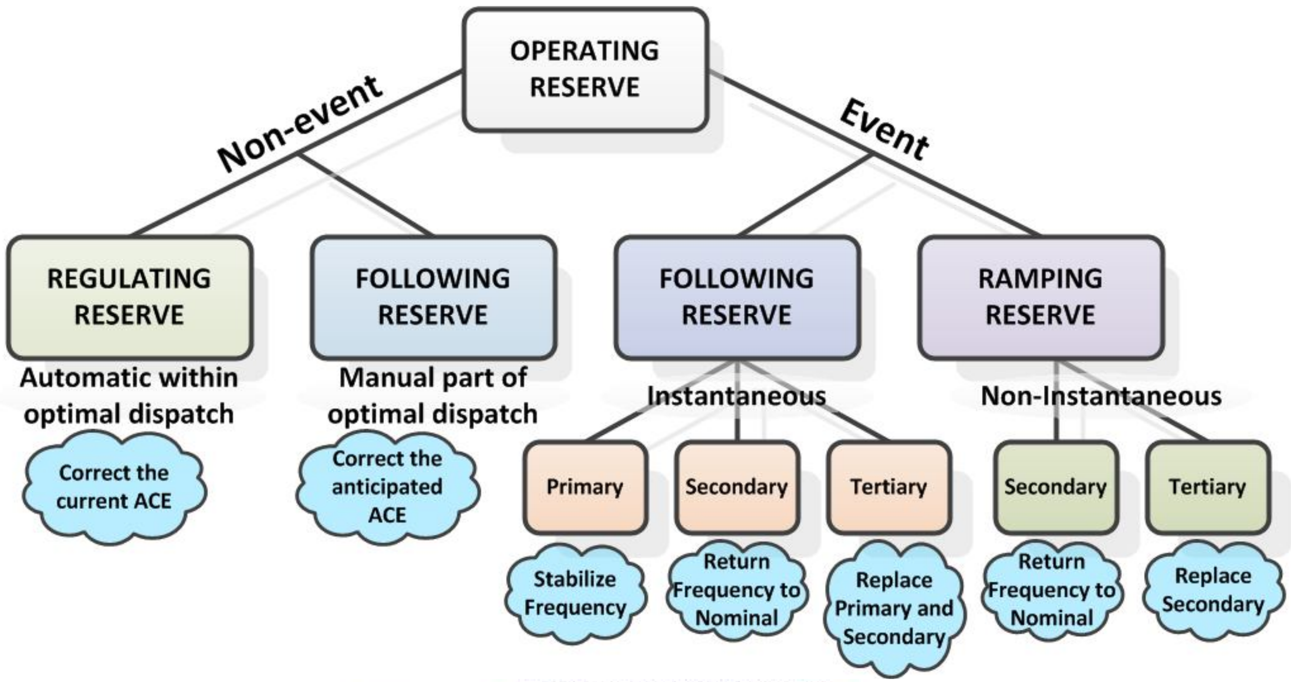
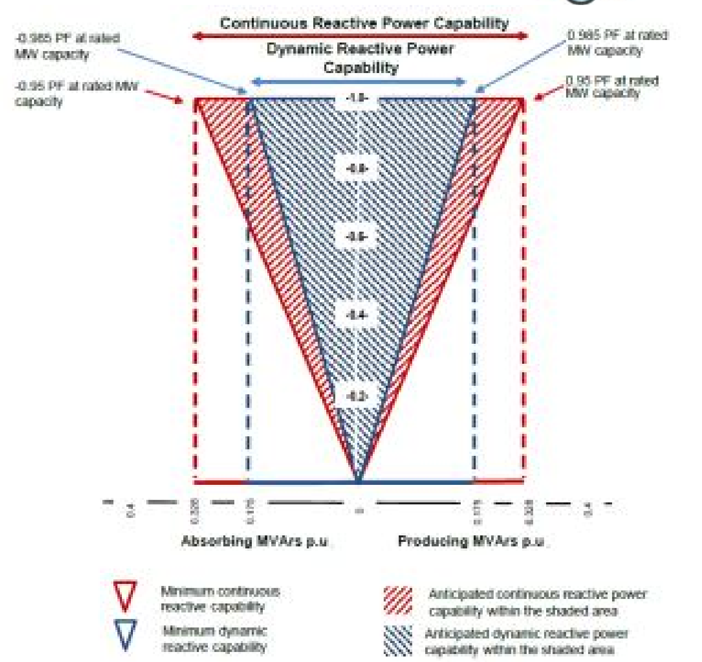
How are US System operators integrating and balancing renewables?

- Energy market designed around reliability and affordability
- Both day-ahead and real-time energy and ancillary services markets
- New gas units designed with high levels of flexibility
  - "Must offer" market obligation – generator to bid portion of their most flexible capacity, so it is always available
  - Flexible ramping products
- Improved forecasting
- Energy imbalance markets
- Distribution system planning and innovation
- Interconnection standards and cost allocation for distributed generation and storage
- Subhourly dispatch co-optimized with reliability (N-1)
- Adoption of new technologies (energy storage)
- Renewables helping to integrate more renewables (advanced grid-friendly controls by wind and solar)

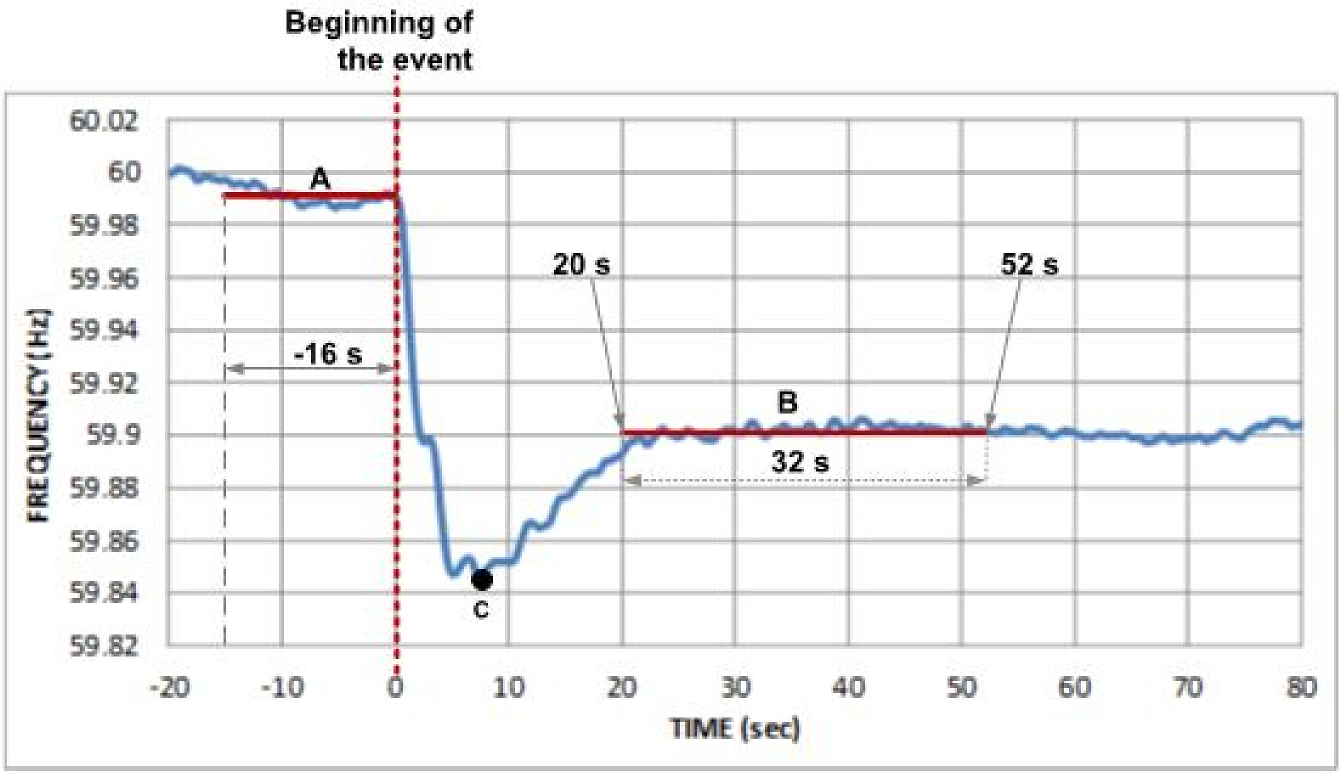
NERC Essential Reliability Services

- Services based Active Power Control
  - o Inertial response
  - o Primary frequency response
  - o Secondary frequency response (AGC)
  - o Ramp control
  - o Economic dispatch following
- Services based on Reactive Power Control
  - o Voltage, power factor and VAR control (night-time VAR control)
- Performance during and after disturbances
  - o LVRT/ZVRT/HVRT
  - o Short circuit current contribution
  - o Frequency disturbance ride-through





Standard BAL-003-01 Frequency Response Metrics Explained

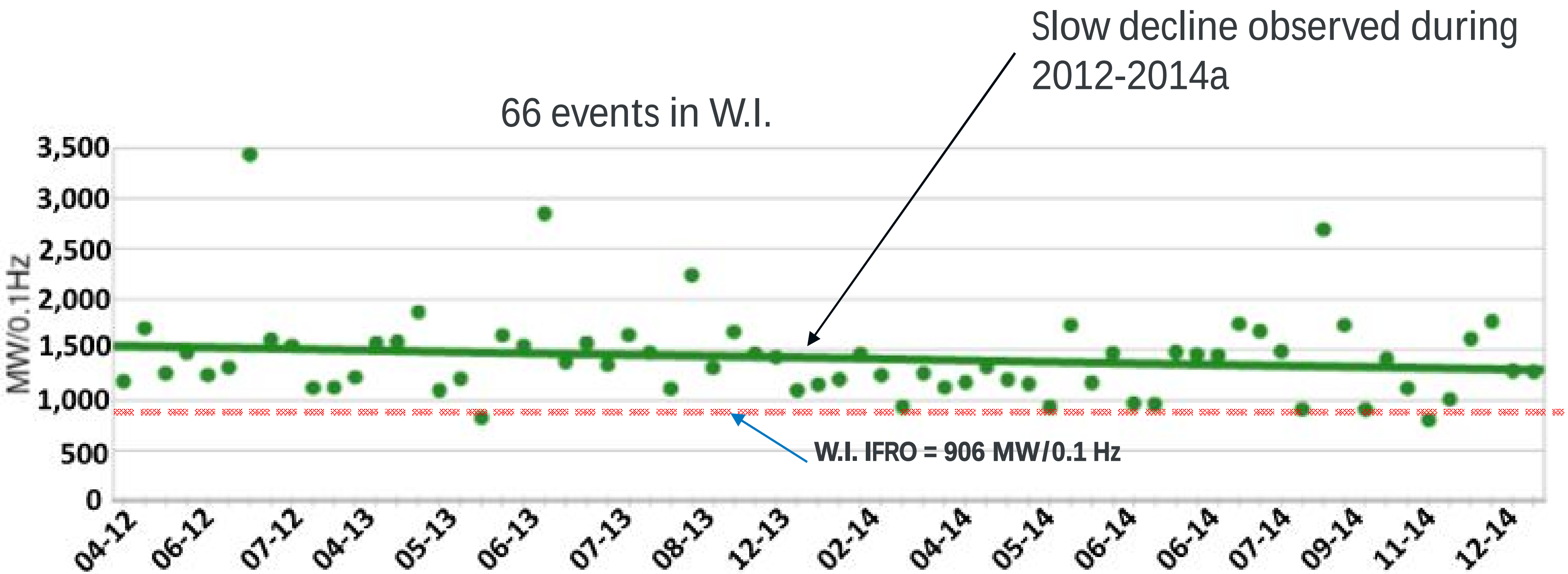


- Initial rate if decline of frequency (ROCOF)
- Value of frequency nadir (point C)
- A-to-C transition time
- Value of settling frequency (point B)
- C-to-B transition time
- C/B ratio

Interconnection Frequency Response Obligation (IFRO)

- **Calculated using statistical observations from many similar events**
- **Depends on**
  - Initial frequency
  - First step of UFLS
  - Contingency criteria
  - Governor withdrawal adjustment
  - C/B ratio
  - Demand response credit
- **WI FRO = -906 MW/0.1 Hz**
- **BAL-003-1 standard also sets FRO for all BA within interconnections**

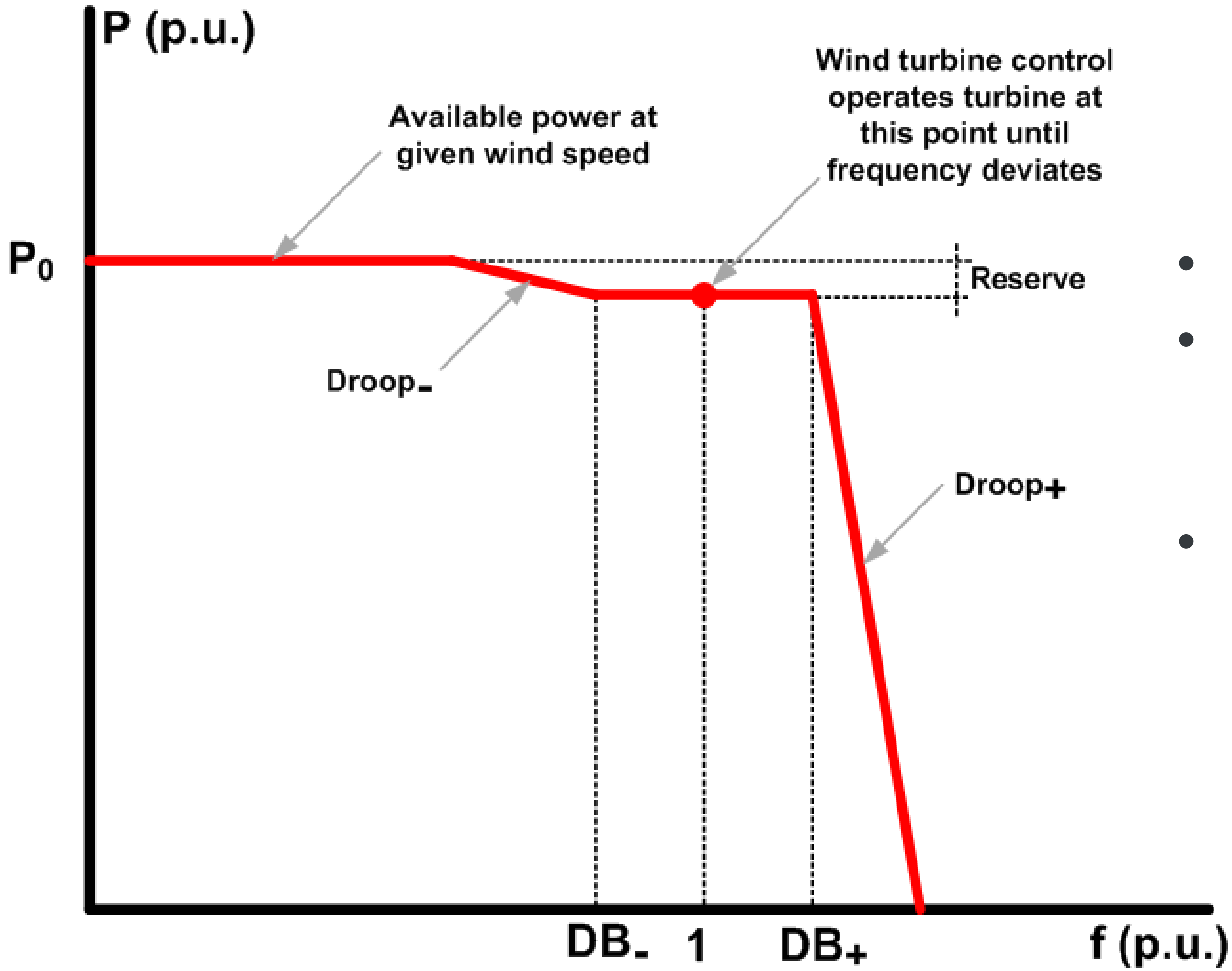
Historic Western Interconnection Frequency Response



Source: NERC M-4 Interconnection Frequency Response database (www.nerc.com)

- Slow decreasing trend in W.I. frequency response
- Can be caused by several factors, not necessarily by increasing penetration of wind and solar PV generation
- Cause of some concern, but the W.I. frequency response in not in crisis by no means

Frequency Droop Control By Wind Power Generation

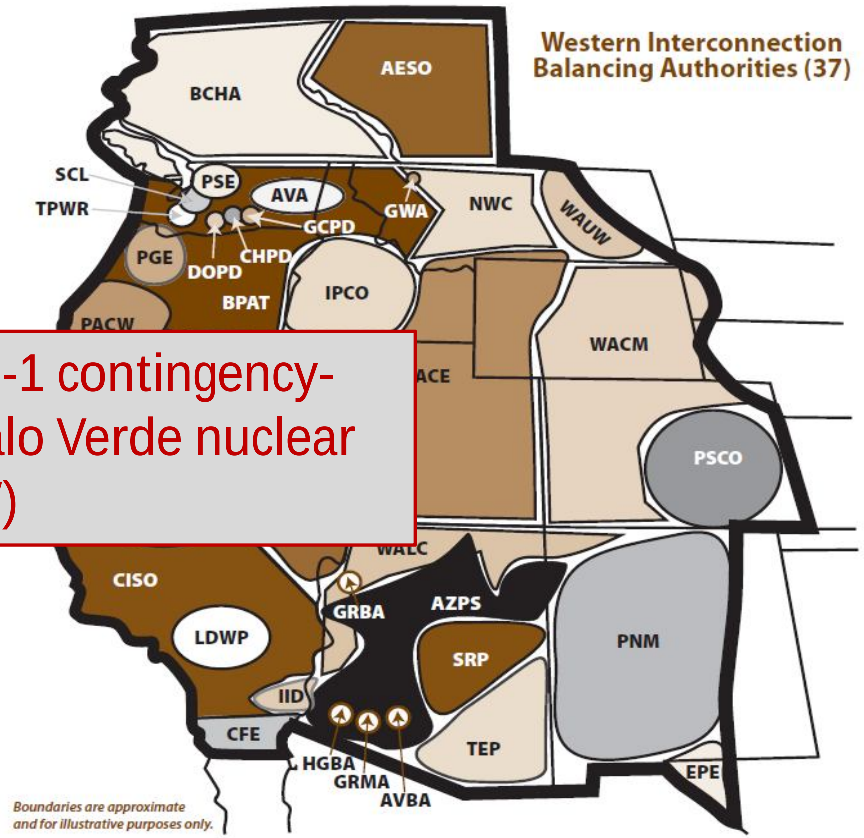


- Plant level control
- Continuous curtailed operation is needed to maintain headroom for up regulation
- Easy for wind to provide non-symmetric droop characteristic

80% Wind Penetration Study

WWSIS-1 In-Area Scenarios

Area	Wind Rating (MW), 10% Case	Wind Rating (MW), 20% Case	Wind Rating (MW), 30% Case
Arizona	3,600	7,350	11,220
Colorado–East	2,040	3,780	5,640
Colorado–West	300	600	900
New Mexico	1,080	1,920	2,790
Nevada	2,340	4,680	7,050
Wyoming	930	1,620	2,340
COB*	90	90	180
Idaho–East	660	660	780
Idaho–SW	750	750	1,500
Montana	780	780	1,050
N. California	5,610	5,610	11,790
Northwest	6,540	6,540	12,930
S. California	7,110	7,110	14,490
Utah	1,410	1,410	2,730
Total	33,240	42,900	75,390



Largest W.I. N-1 contingency-loss of two Palo Verde nuclear units (2.6 GW)

Wind Nameplate Capacities

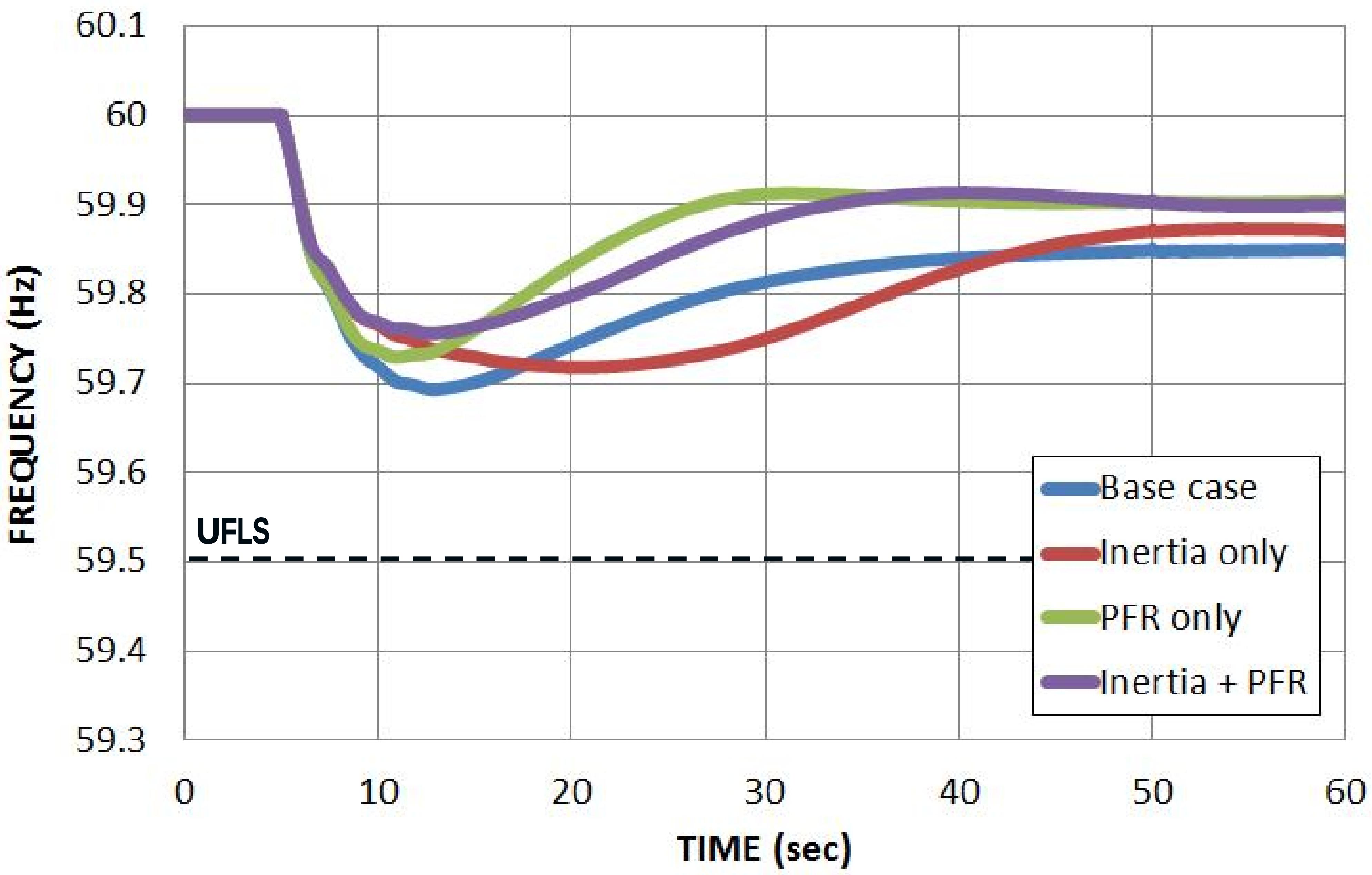
Penetration	Total Wind Nameplate Capacity (GW)	Wind Generation Level (GW)
15% base case	23	17.92
20%	41.65	22.5
30%	60.34	33.76
40%	80.45	45.19
50%	101.67	56.89
80%	180.49	85.51

TEPCC 2022 light spring load base case

Simulations Performed

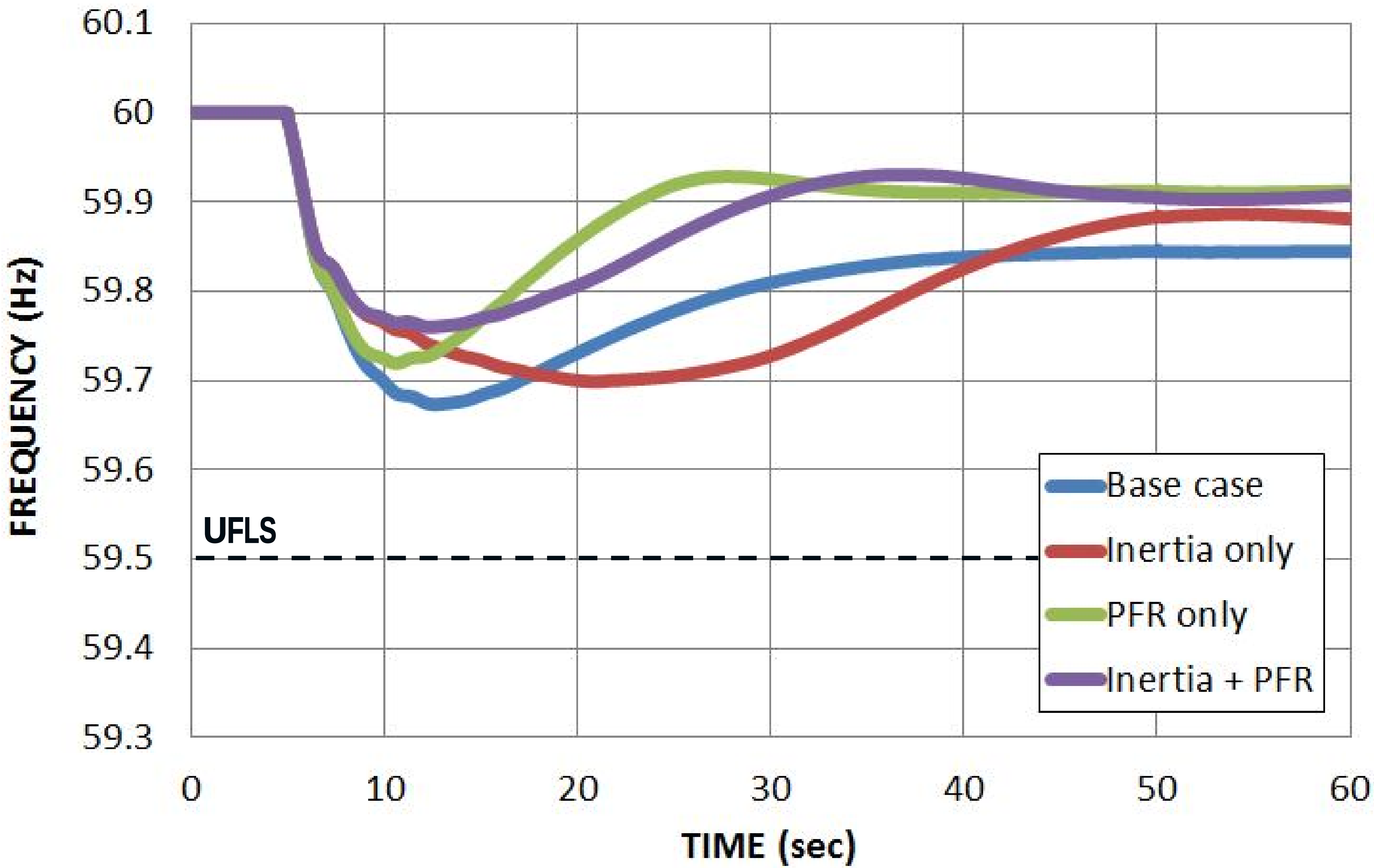
Case	Wind Controls Scenarios			
15% 20% 30% 40% 50% 80%	No inertia, no PFR	Inertia only	PFR only (5% headroom; 5 % droop)	Inertia + PFR (5% headroom; 5% droop)

15% base case



60.1
60
59.9
59.8
59.7
59.6
59.5
59.4
59.3
FREQUENCY (Hz)
UFLS
0
10
20
30
40
50
60
TIME (sec)
Base case
Inertia only
PFR only
Inertia + PFR

20% case



FREQUENCY (Hz)
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59.7
59.6
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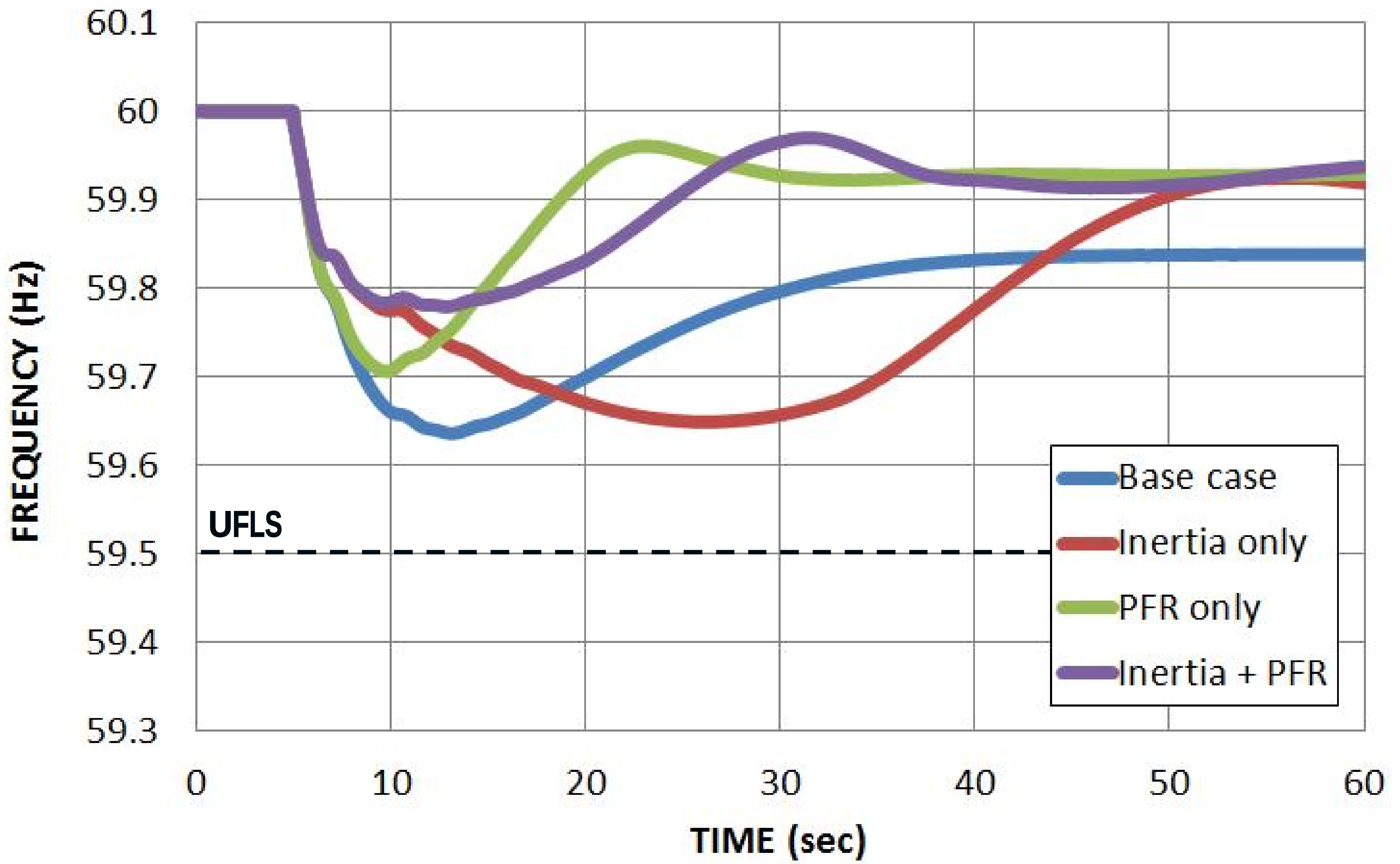
59.4
59.3
UFLS
0
10
20
30
40
50
60
TIME (sec)
Base case
Inertia only
PFR only
Inertia + PFR

30% case



60.1
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59.7
59.6
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59.4
59.3
FREQUENCY (Hz)
UFLS
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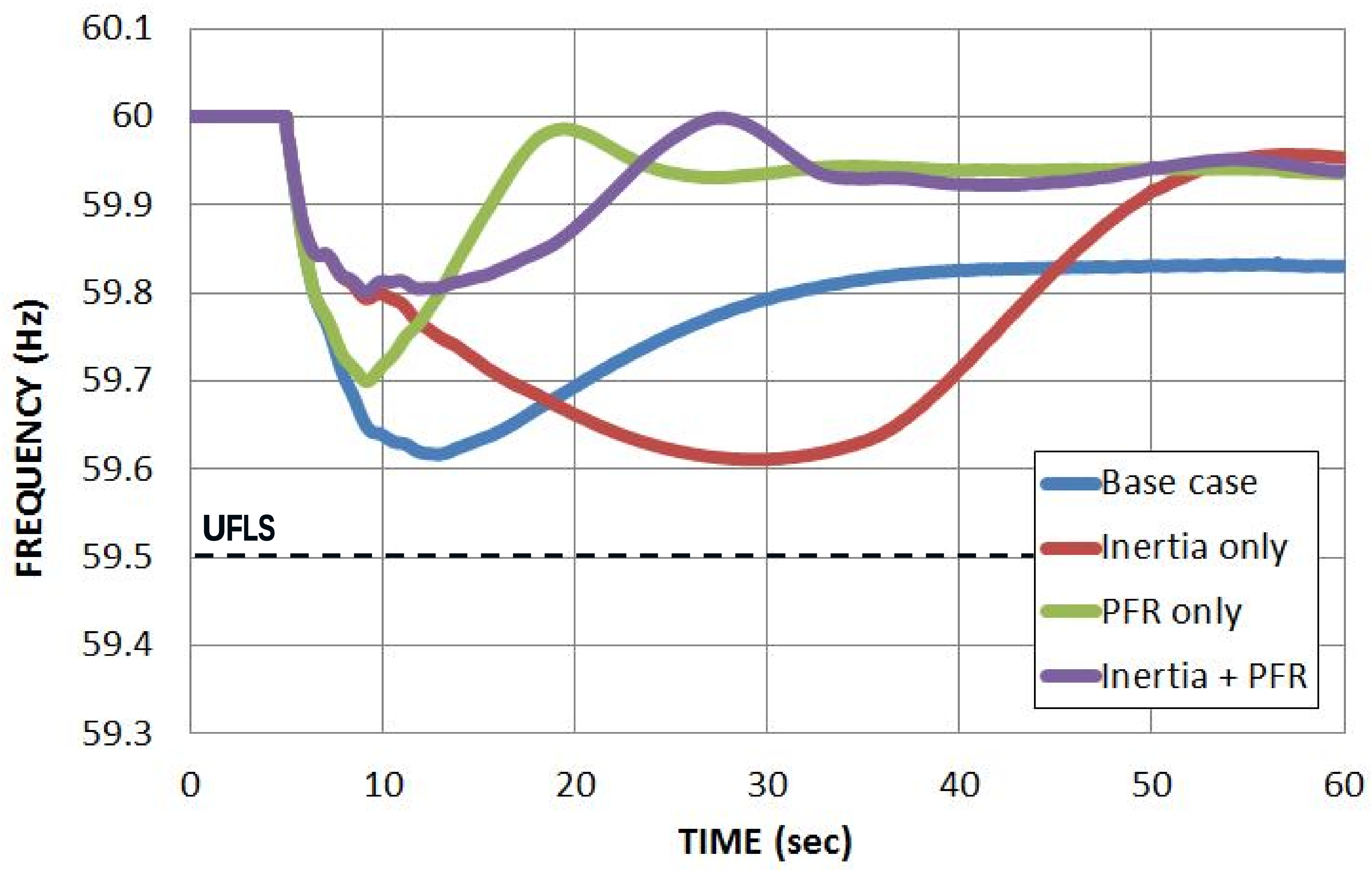
20
30
40
50
60
TIME (sec)
Base case
Inertia only
PFR only
Inertia + PFR

40% case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59.4
59.3
0
10
20
30
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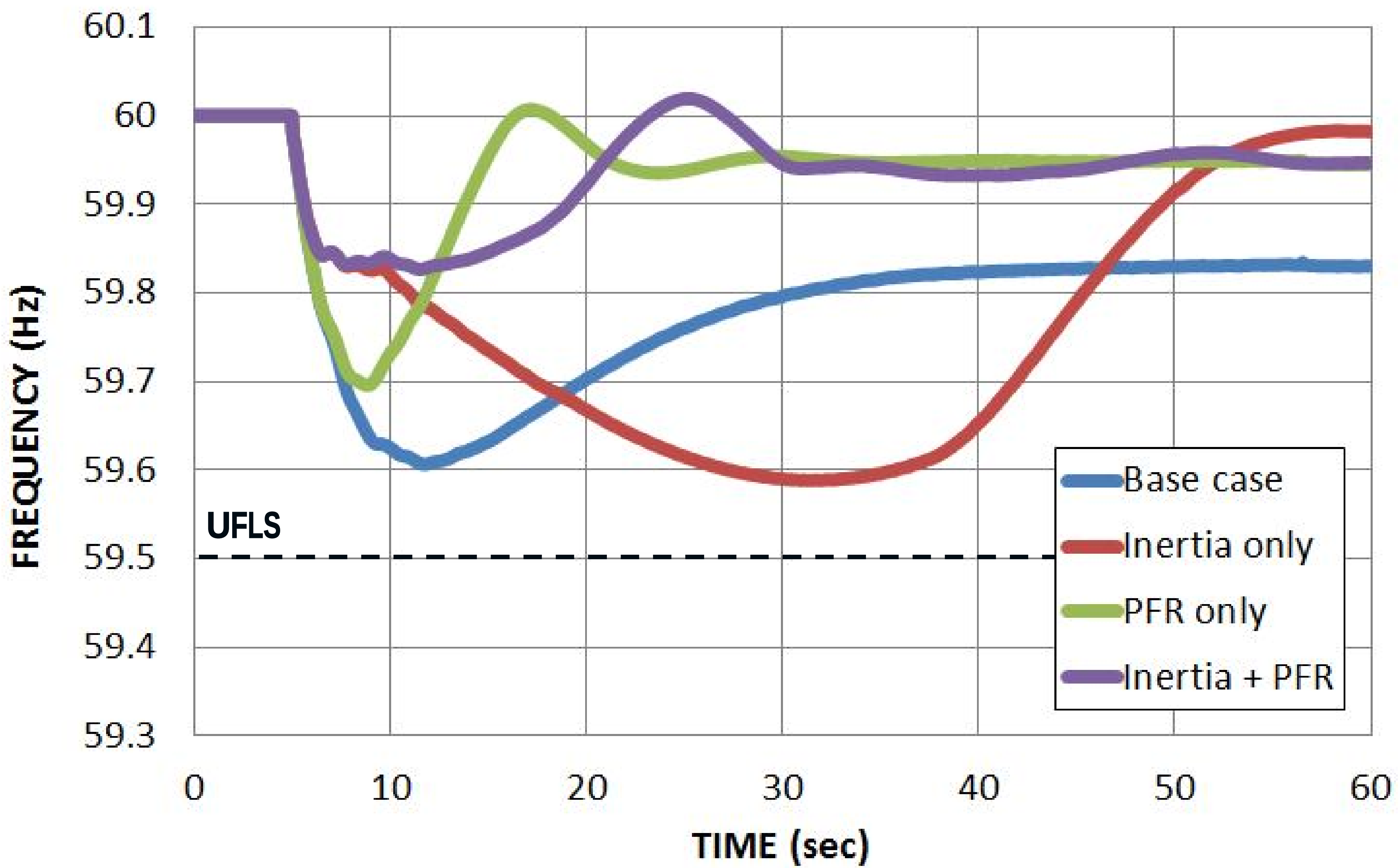
50
60
FREQUENCY (Hz)
TIME (sec)
UFLS
Base case
Inertia only
PFR only
Inertia + PFR

50% case



60.1
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FREQUENCY (Hz)
UFLS
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10
20
30
40
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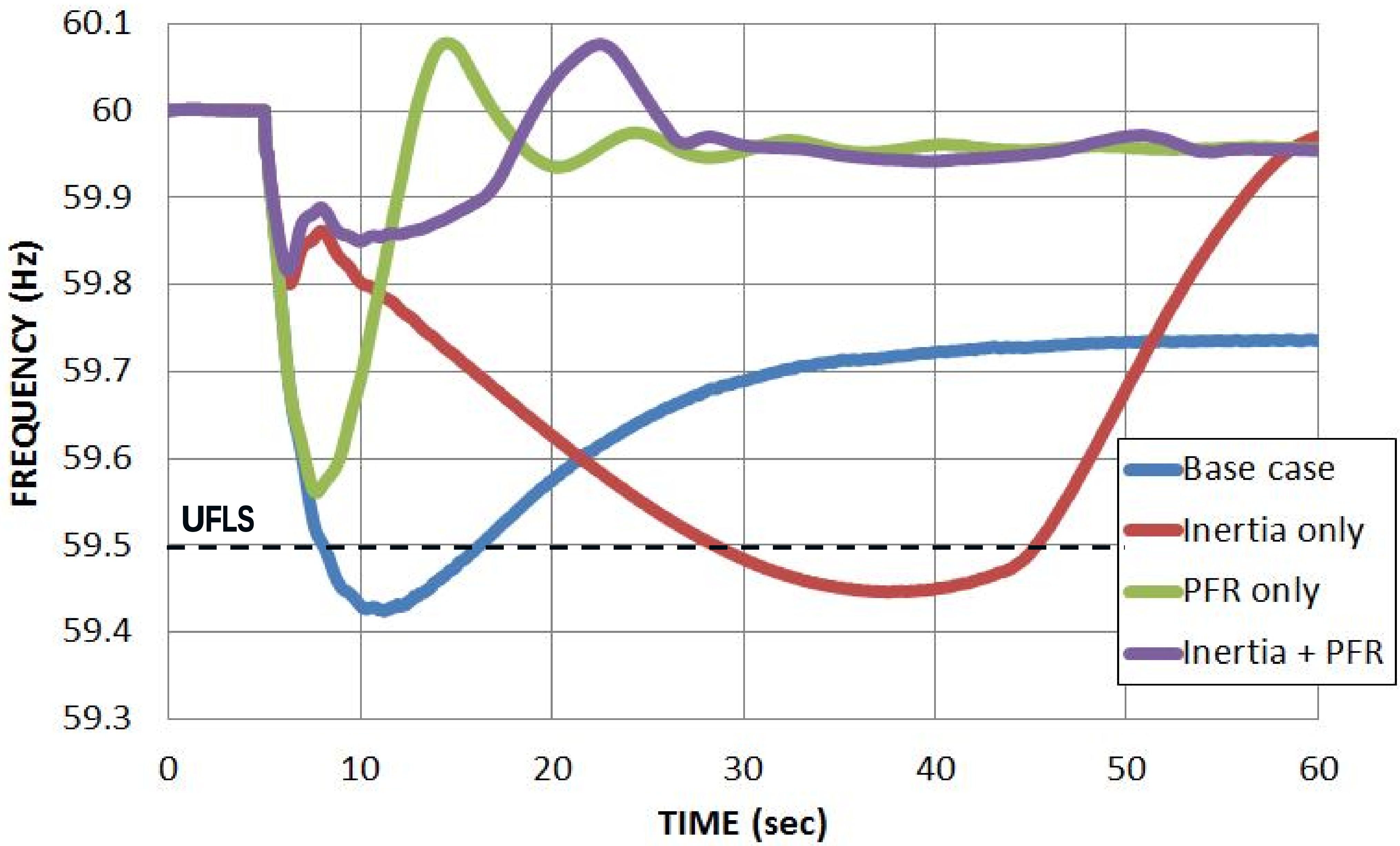
TIME (sec)
Base case
Inertia only
PFR only
Inertia + PFR

80% case



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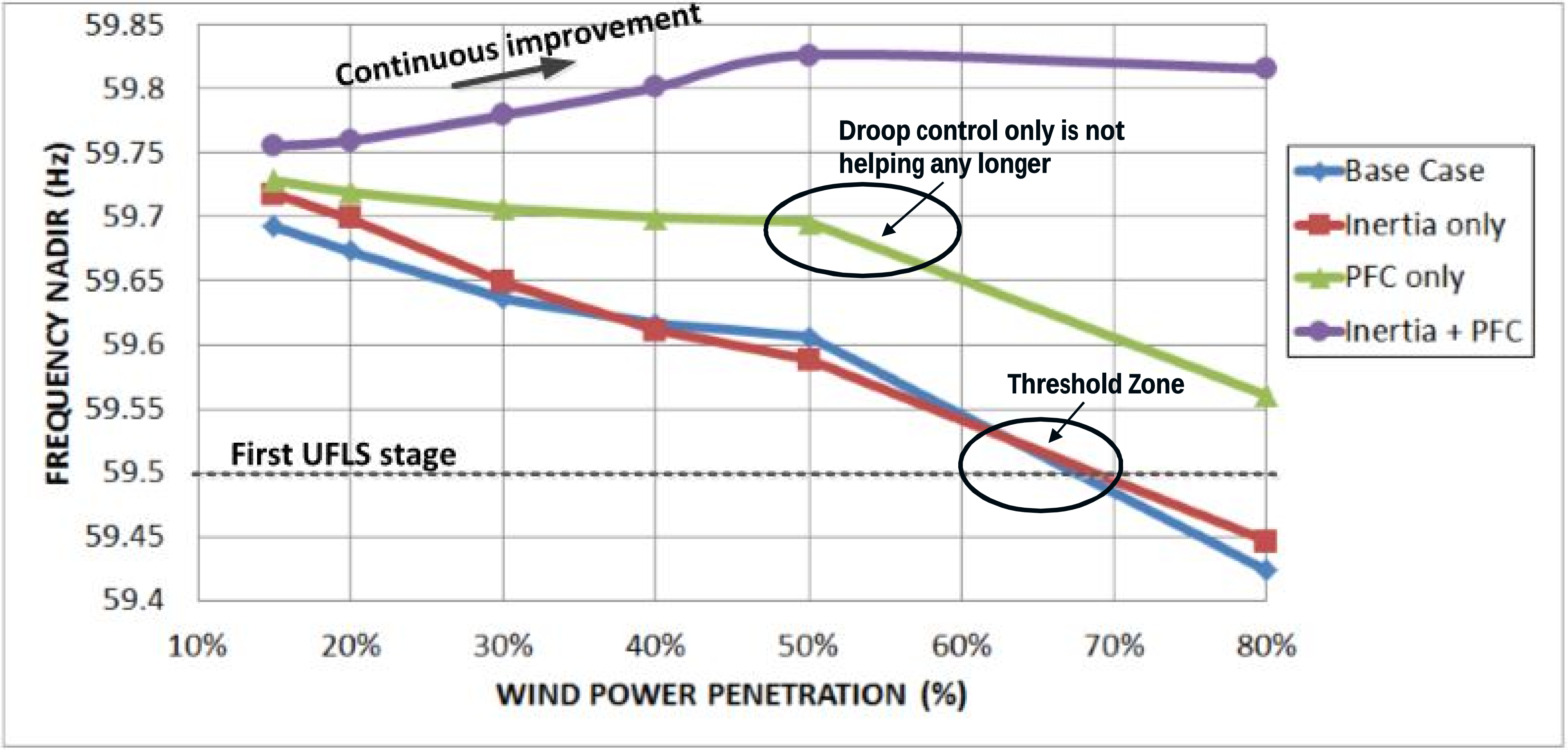
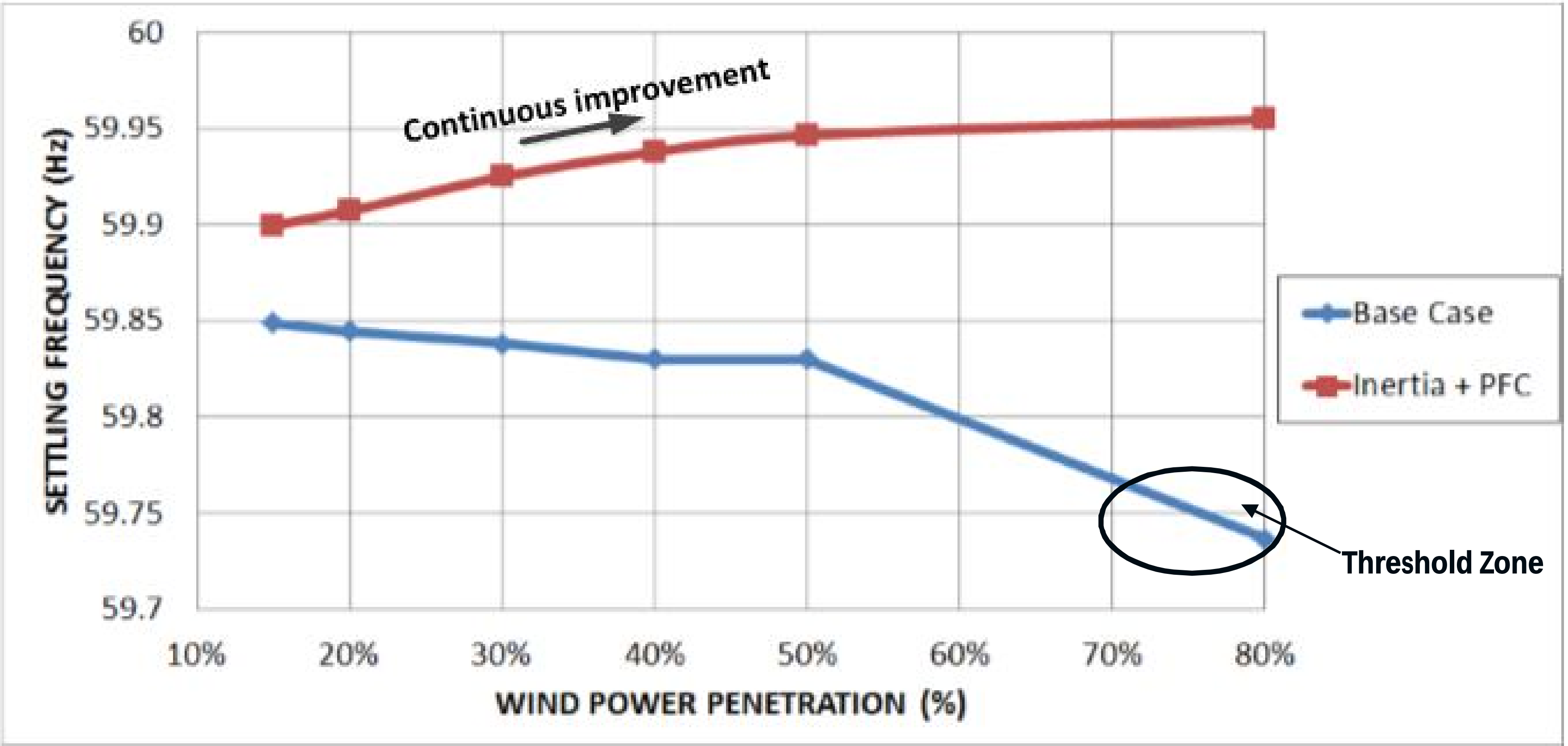
Impact of Wind Controls of Frequency Nadir



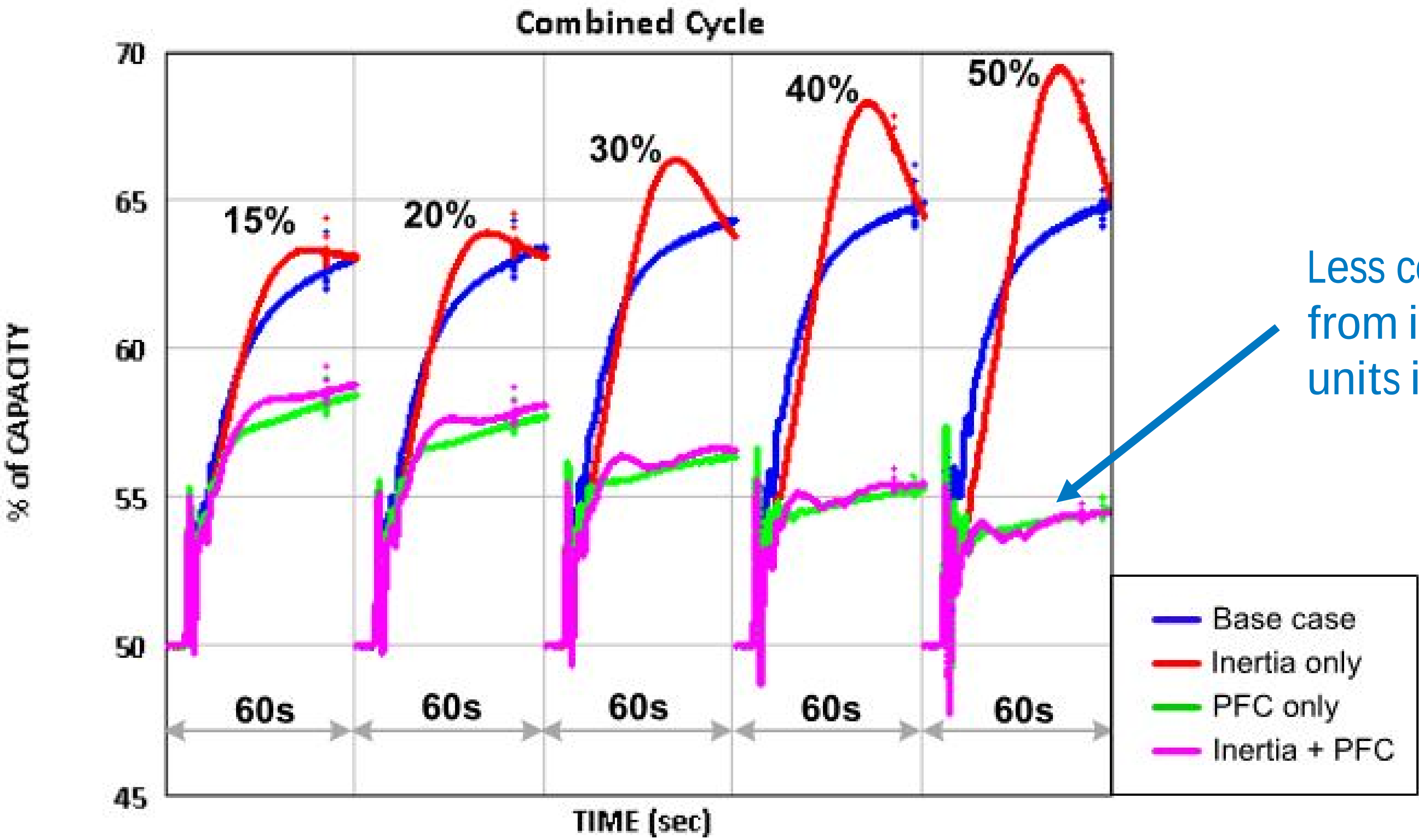
- Combining Inertial and primary frequency controls by wind results in nadir improvement with increasing penetration

Impact of Wind Controls on Settling Frequency



- Combining Inertial and primary frequency controls by wind power results in continuous settling frequency improvement

Impacts on Individual Technologies: combined cycle



Less contribution from individual CC units is needed

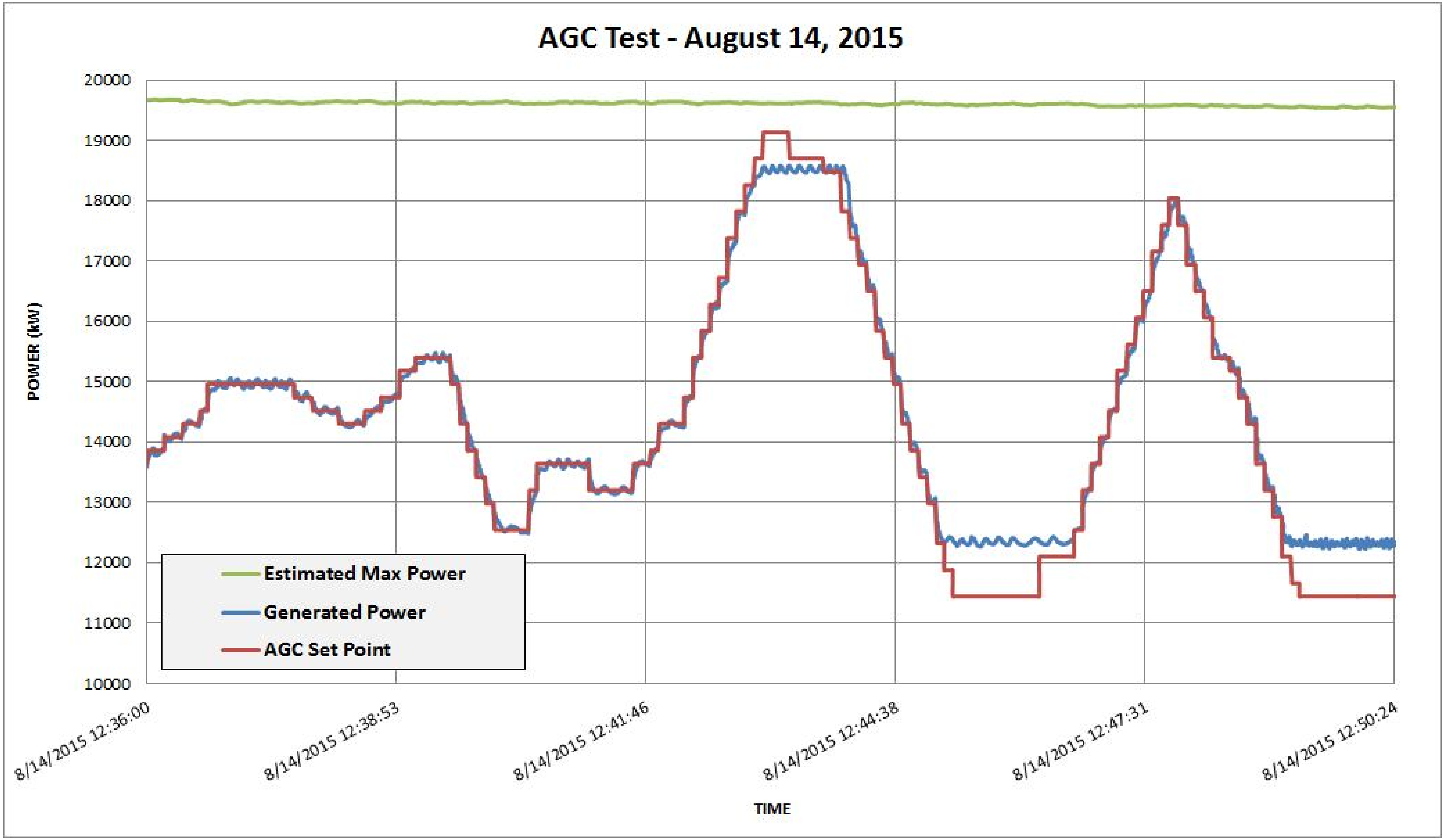
2015 Demonstration Projects in Puerto Rico and Texas

- 20 MW AES Ilumina PV plant
- Location: Guayama, PR
- Testing conducted during August 2015
- Project team: NREL, AES, PREPA, GPTech
- Controls demonstrated:
  - AGC
  - Primary frequency response (PFR)
  - Fast frequency response (FFR)

- 20 MW Pecos Barilla PV plant
- Location: Stockton, TX
- Testing conducted during September 2015
- Project team: NREL, First Solar, ERCOT
- Controls demonstrated:
  - Ramp control
  - AGC
  - PFR
  - FFR
  - Voltage control
  - Reactive power control
  - Power factor control

Project report: www.nrel.gov/docs/fy16osti/65368.pdf

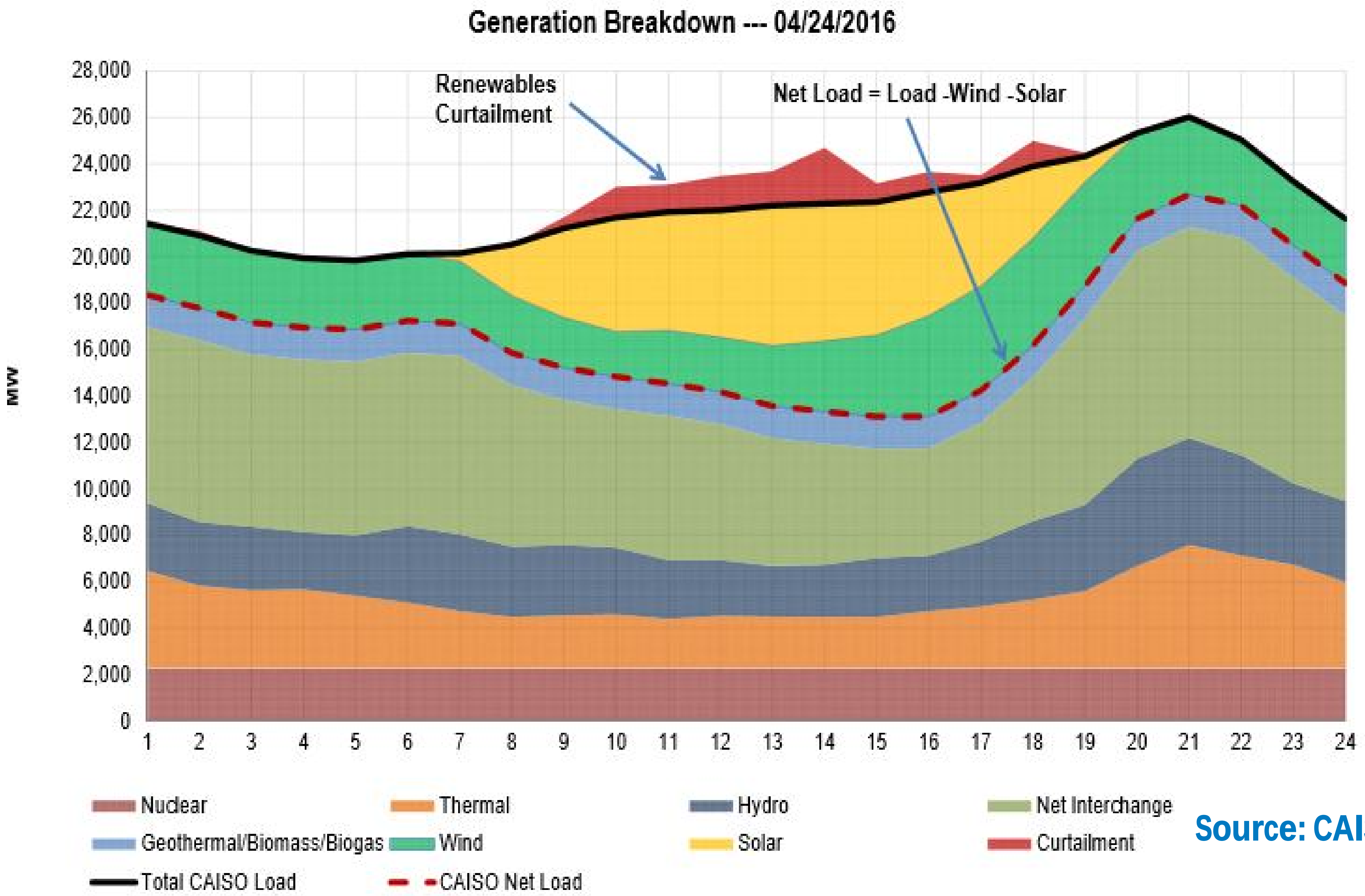
Plant AGC Performance



Snapshot of PREPA AGC Display #4

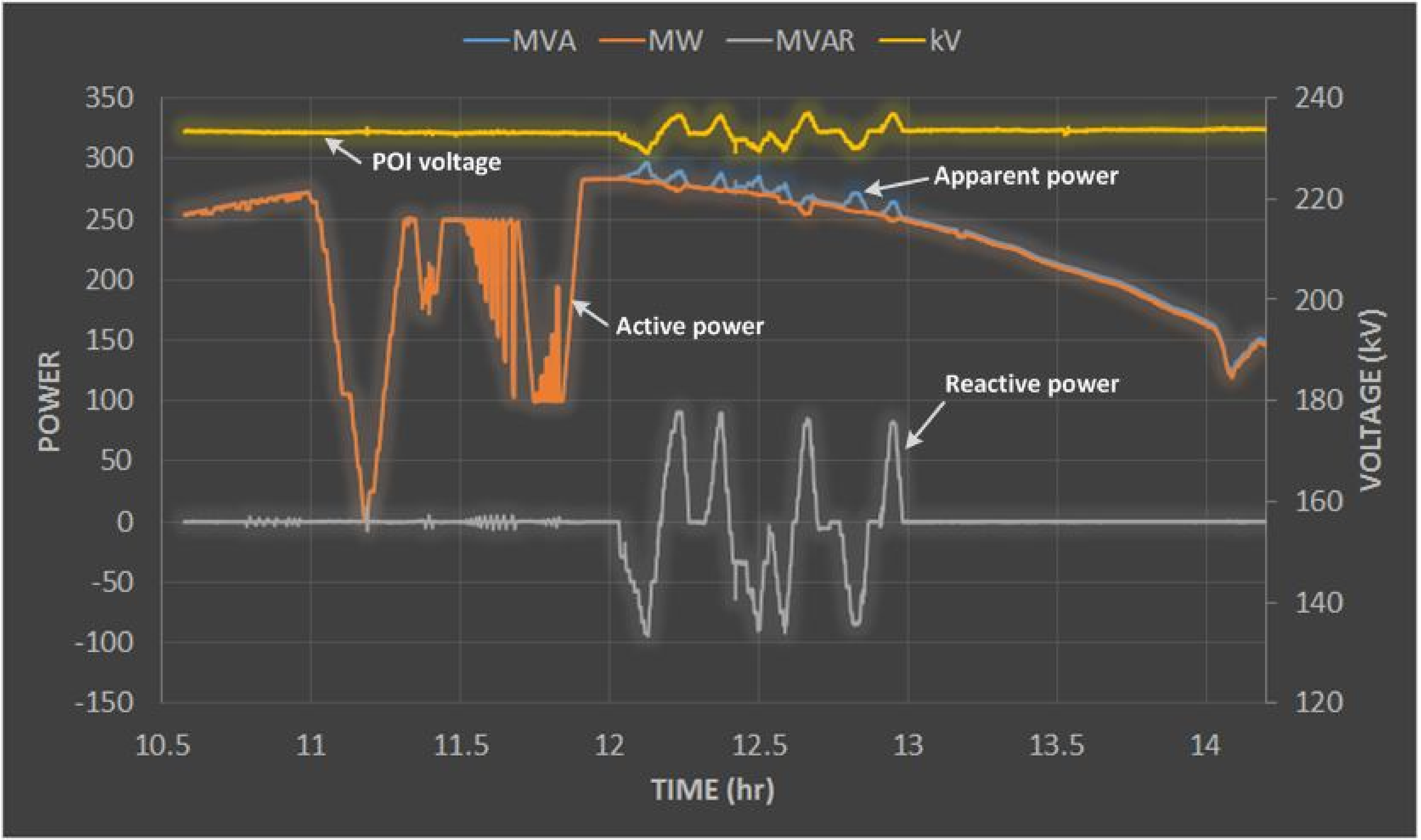
No conventional unit is selected for AGC, AES Ilumina is the only active unit

CAISO Resource Breakdown – April 24, 2016

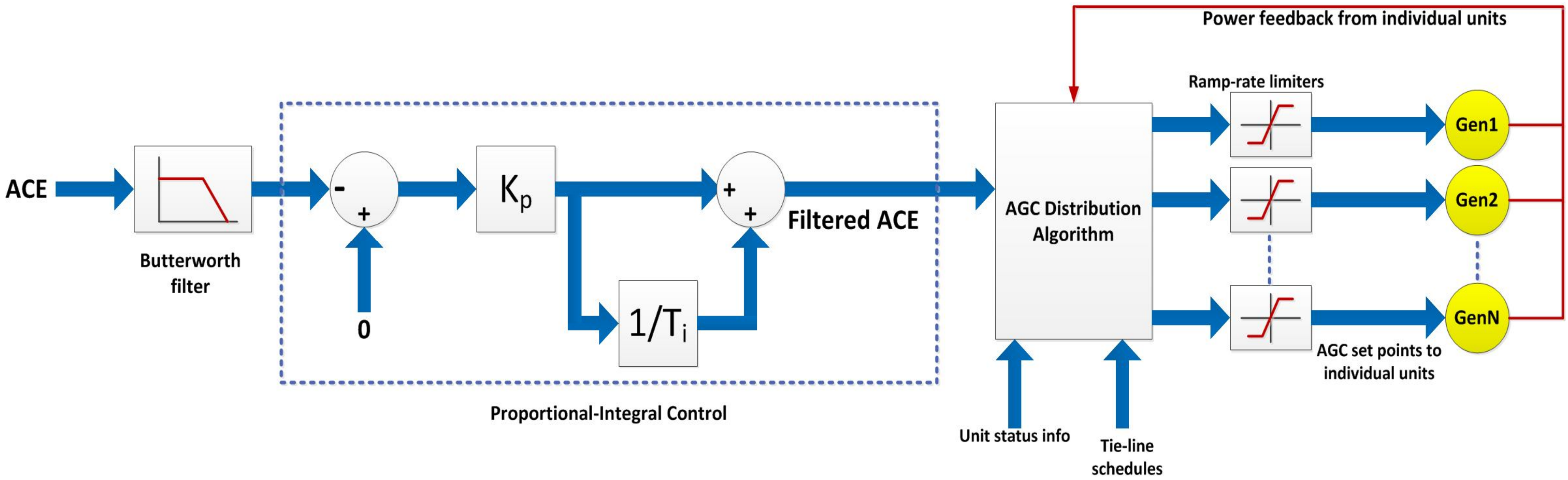


Source: CAISO

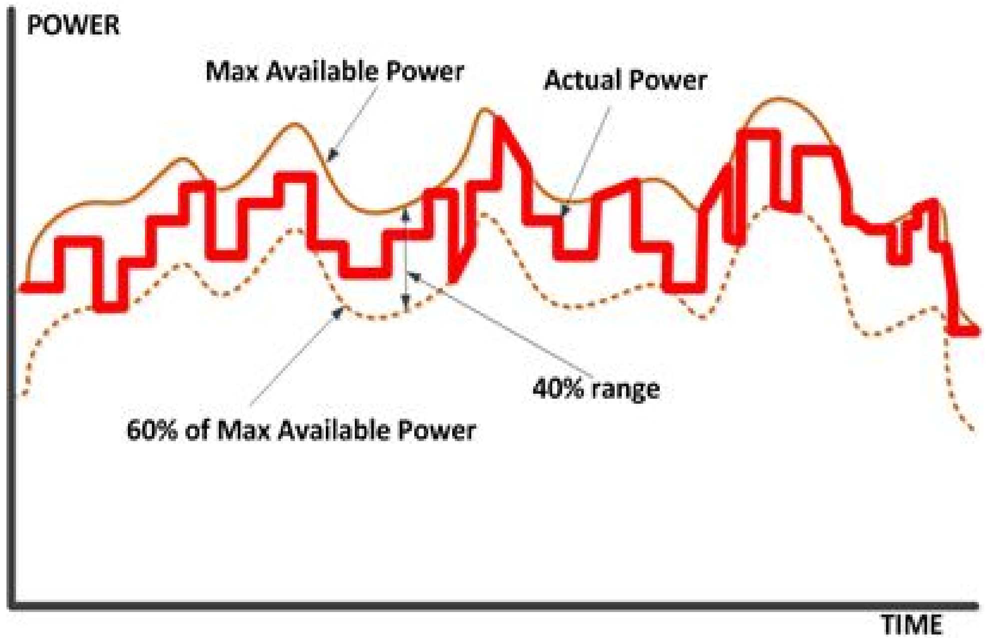
Testing 300 MW PV Plant



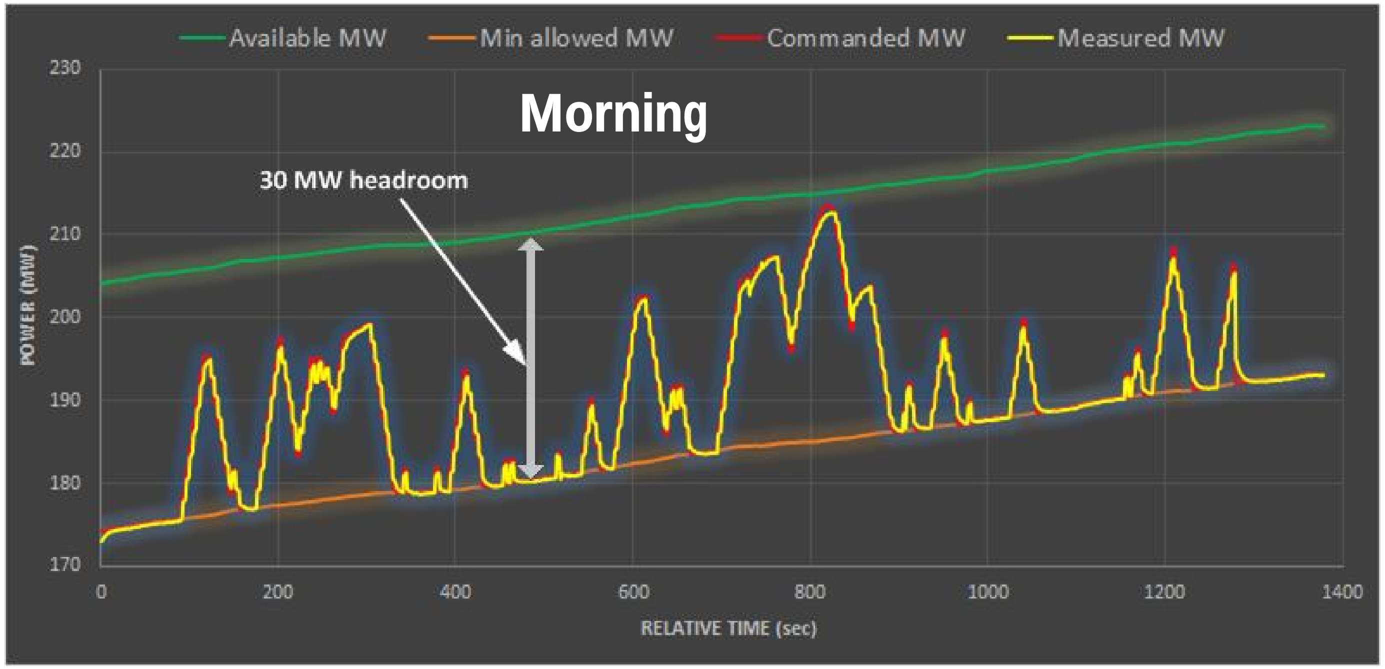
PV Participation in CAISO AGC

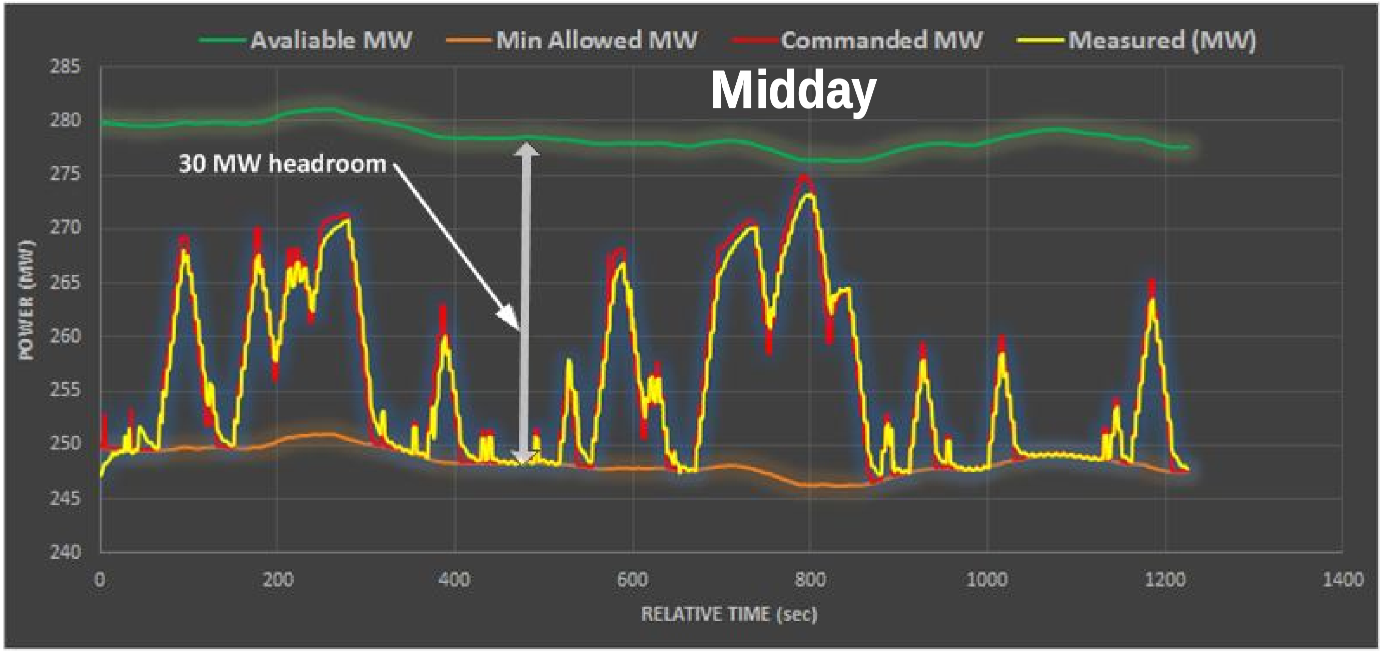


$$ACE = -\Delta P_{tie} - 10B(f_a - f_s) + I_{ME} + I_T$$



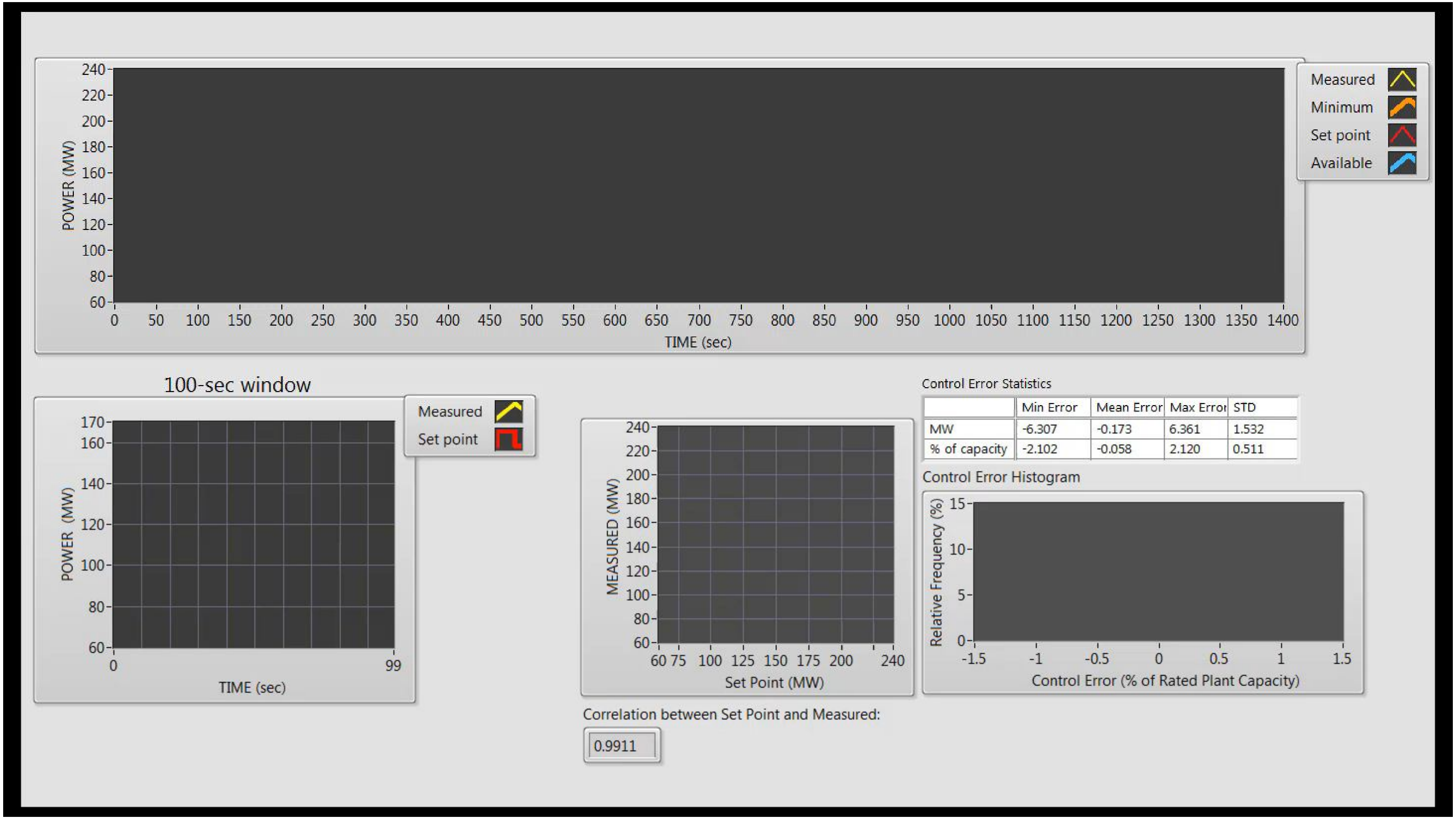
AGC Participation Tests



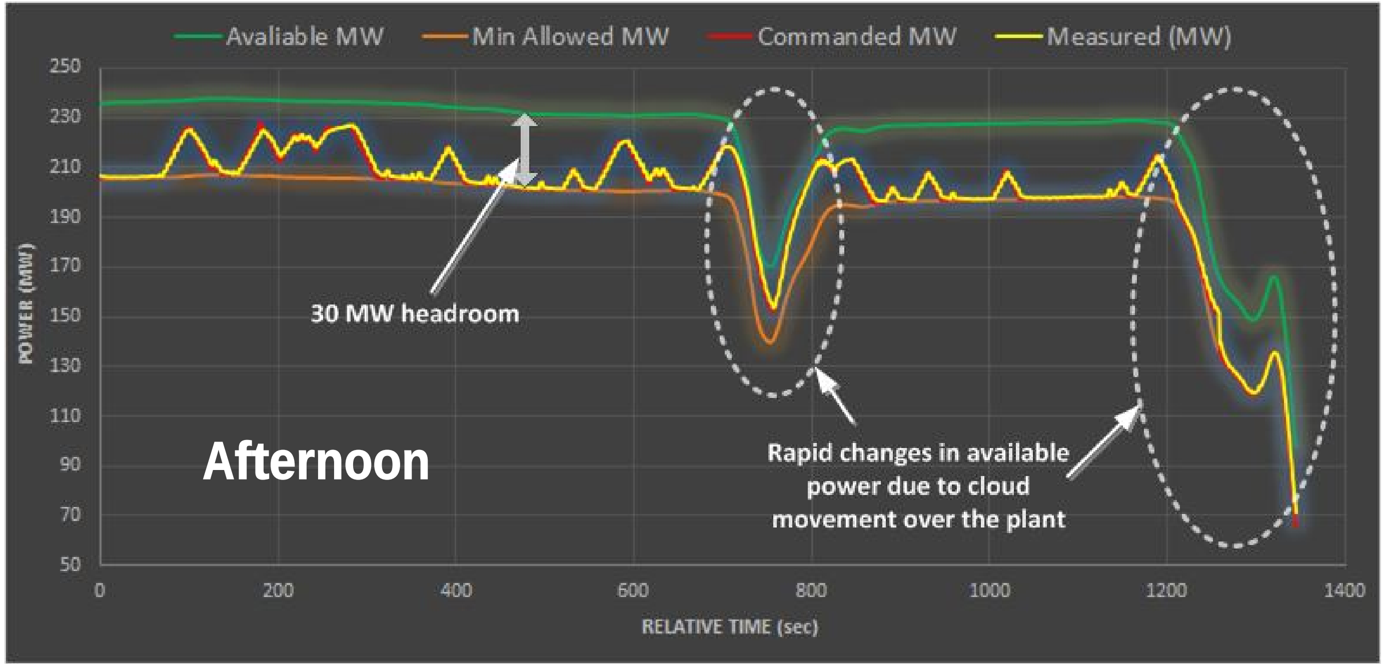


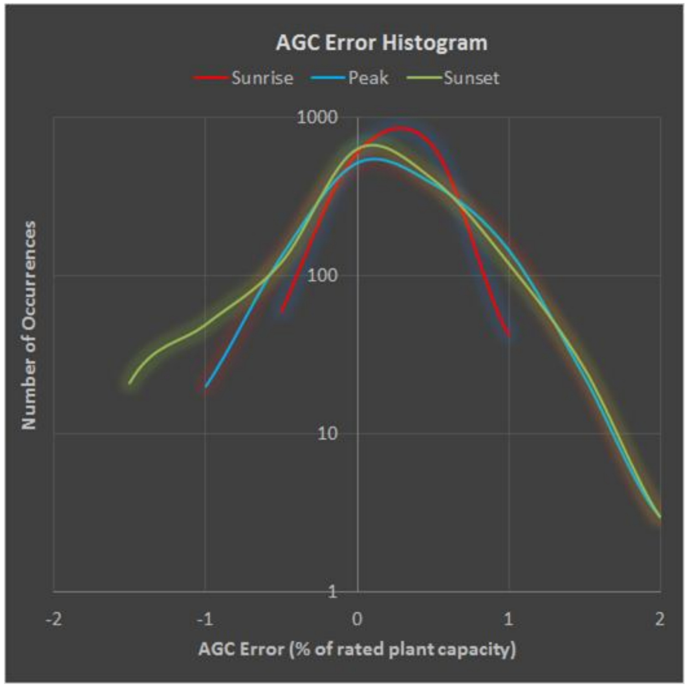
- 4-sec AGC signal provided to PPC
- 30 MW headroom
- Tests were conducted fat three resource intensity conditions (30 minutes at each condition):
  - Sunrise
  - Middle of the day
  - Sunset
- 1-sec data collected by plant PPC

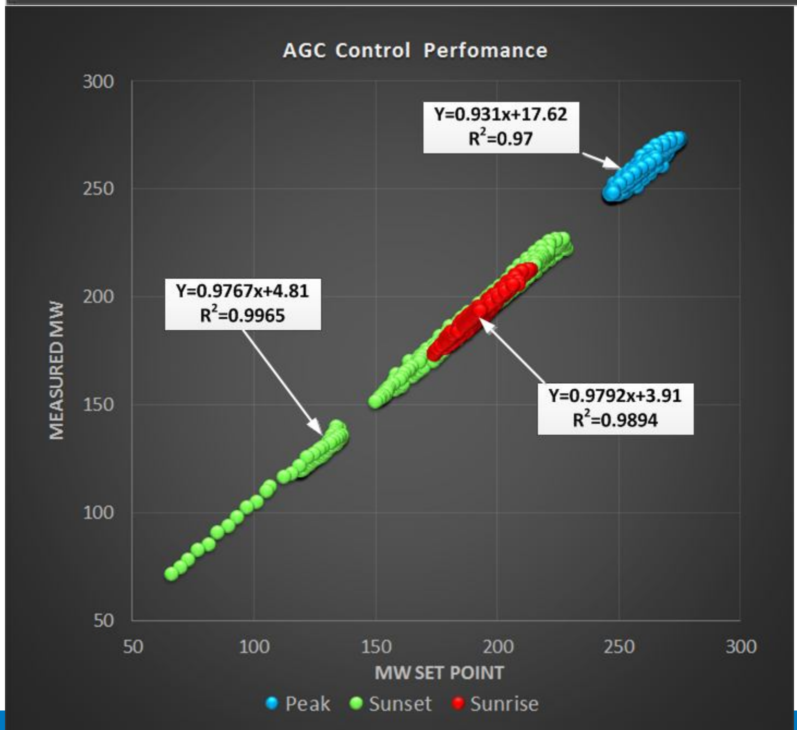
Example of AGC Test Live Data



AGC Participation Tests - continued







AGC Participation Tests- Summary

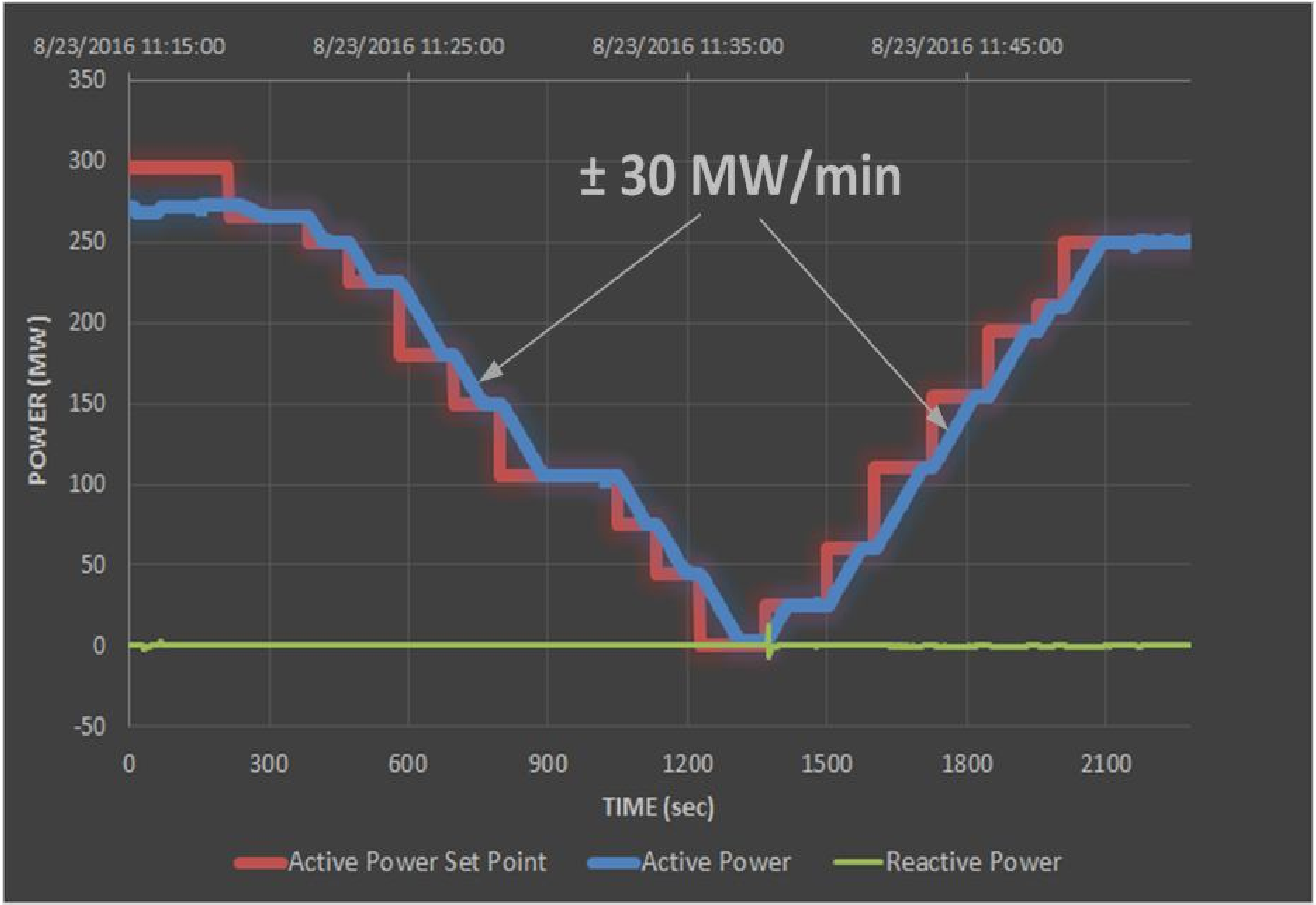
Measured Regulation Accuracy by 300 MW PV Plant

Time Frame	Solar PV Plant Test Results
Sunrise	93.7%
Middle of the day	87.1%
Sunset	87.4%

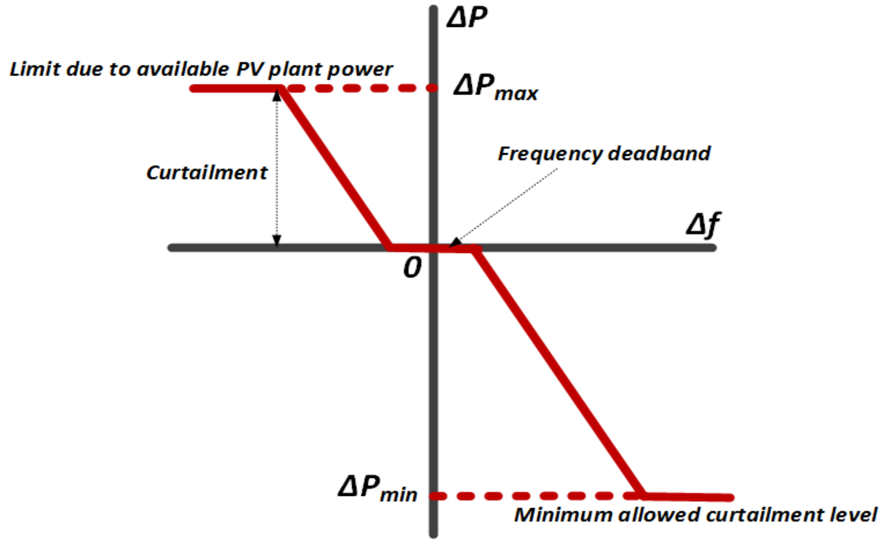
Typical Regulation-Up Accuracy of CAISO Conventional Generation

	Combined Cycle	Gas Turbine	Hydro	Limited Energy Battery Resource	Pump Storage Turbine	Steam Turbine
Regulation-Up Accuracy	46.88%	63.08%	46.67%	61.35%	45.31%	40%

Active Power Curtailment Test

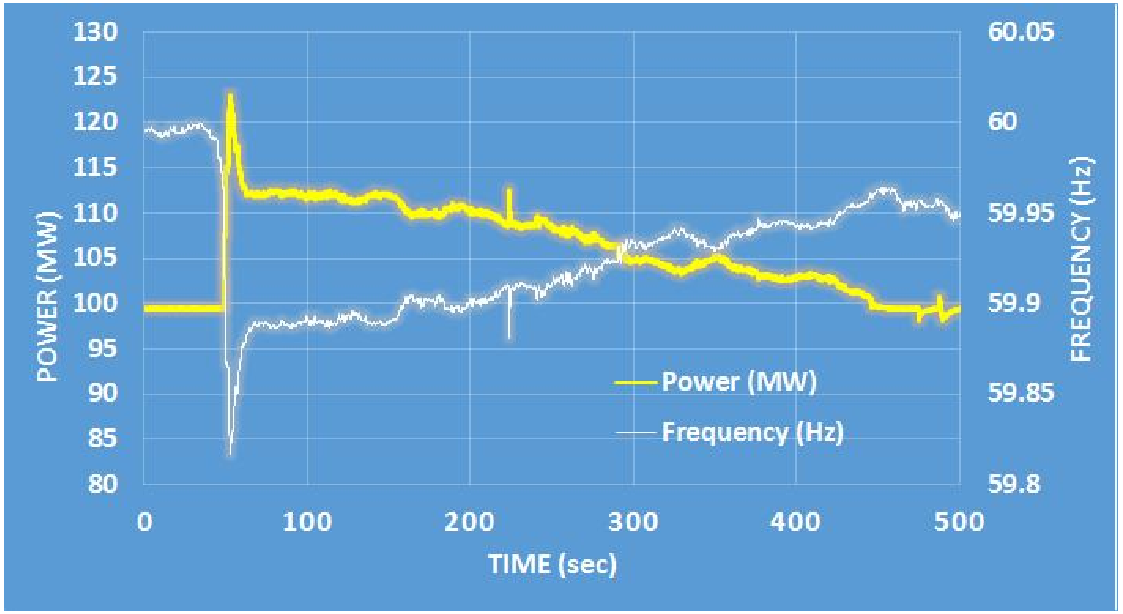


Frequency Droop Tests

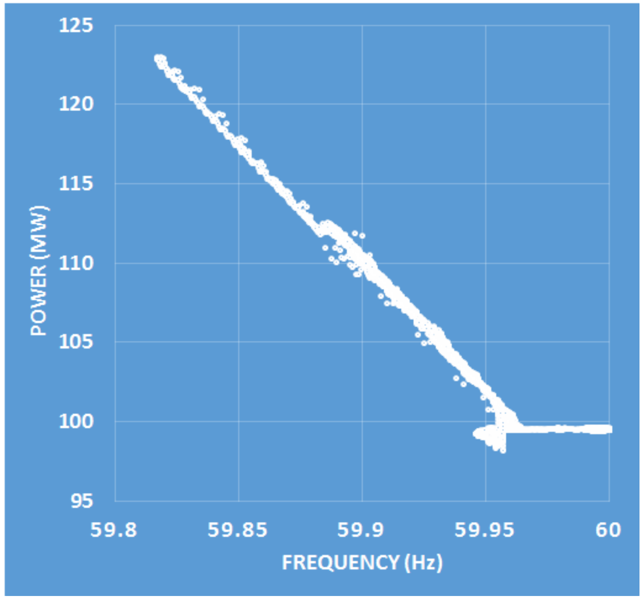


$$\text{Droop} = \frac{\Delta f / 60Hz}{\Delta P / P_{rated}}$$

Example of 3% droop test (under-frequency)

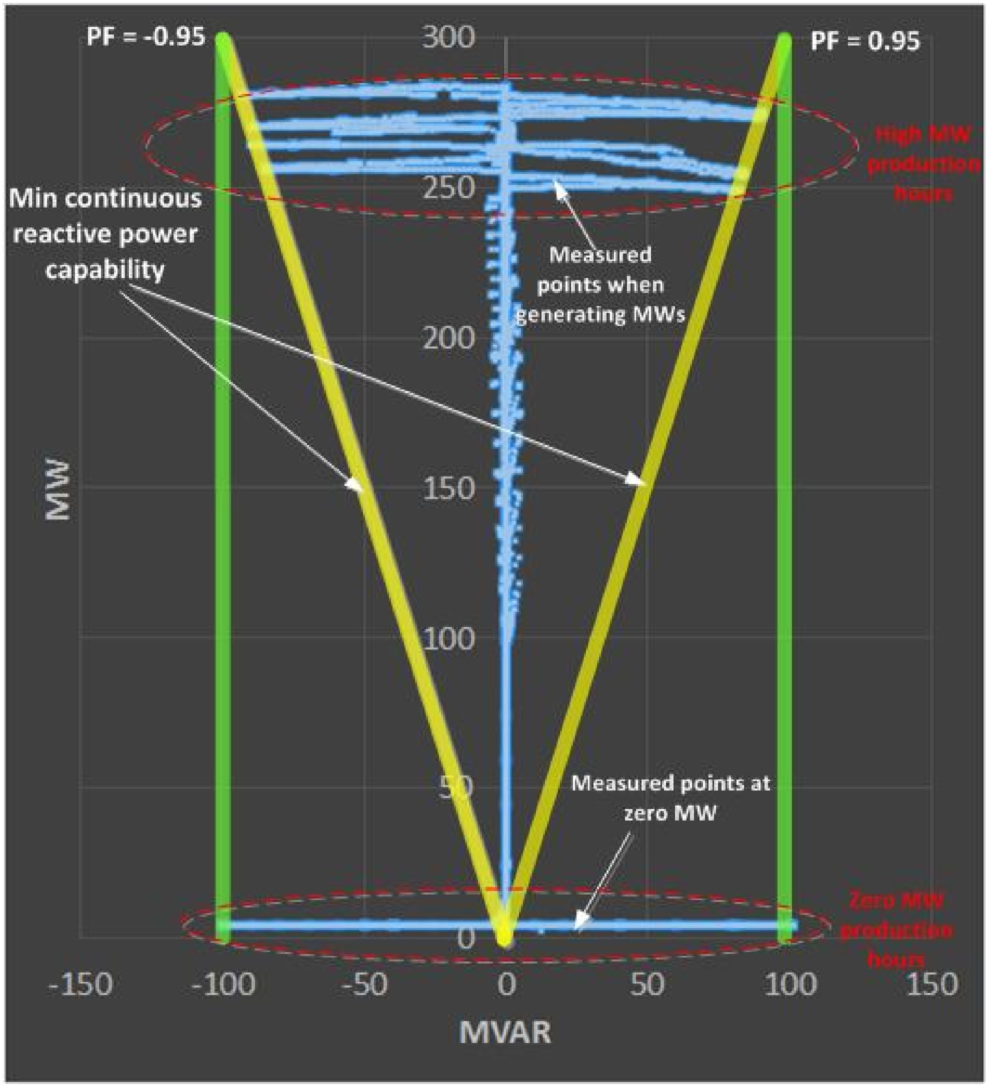


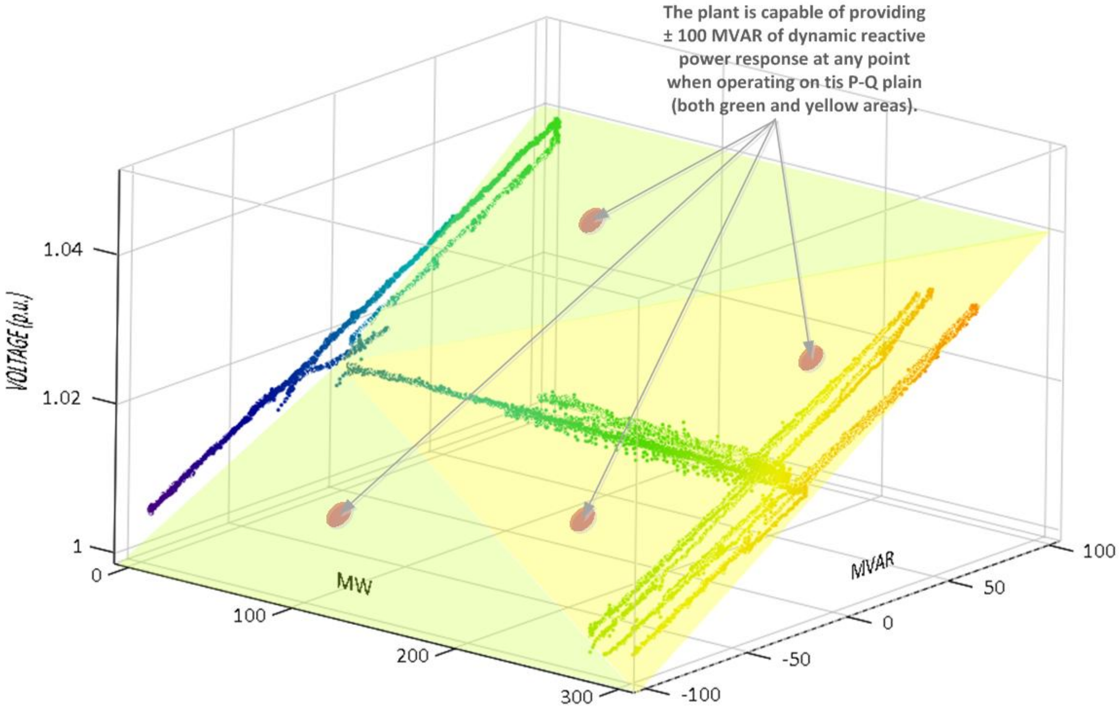
Measured droop response



- 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

Measured Reactive Power Capability and Voltages at POI

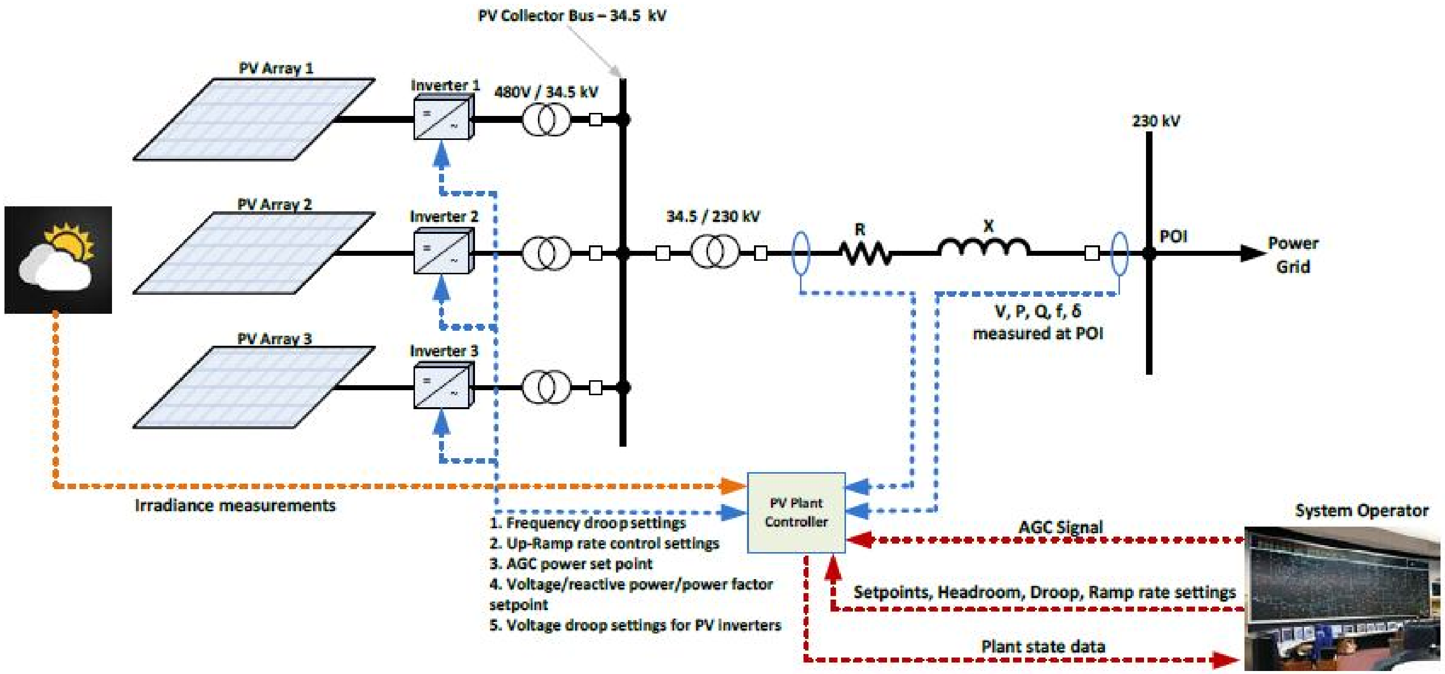




- Reactive power tests at high and low power production levels
- The plant meets the proposed CAISO reactive power requirements

Conclusions

- Modern wind and solar PV power plants:
  - Not just a source of variable energy
  - They can provide all types of reliability services like conventional power plants
- Active and reactive power controls can leverage RE generation's value from being a simple variable energy resource to a resource that provides a wide range of ancillary services.
- New markets incentivizing the participation of renewables in ancillary service markets are evolving in US (CAISO, PJM, ERCOT, Hawaii) and worldwide
- 175 GW Roadmap: Recommended for TNEB to start considering grid services by RE



Thank you!

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