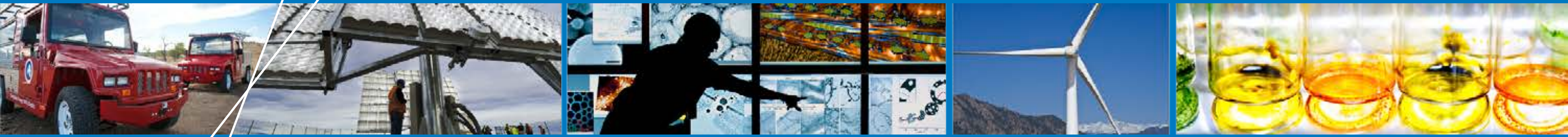
Western Wind & Solar Integration Studies



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Slobodan Pajic, Rob D'Aquila,
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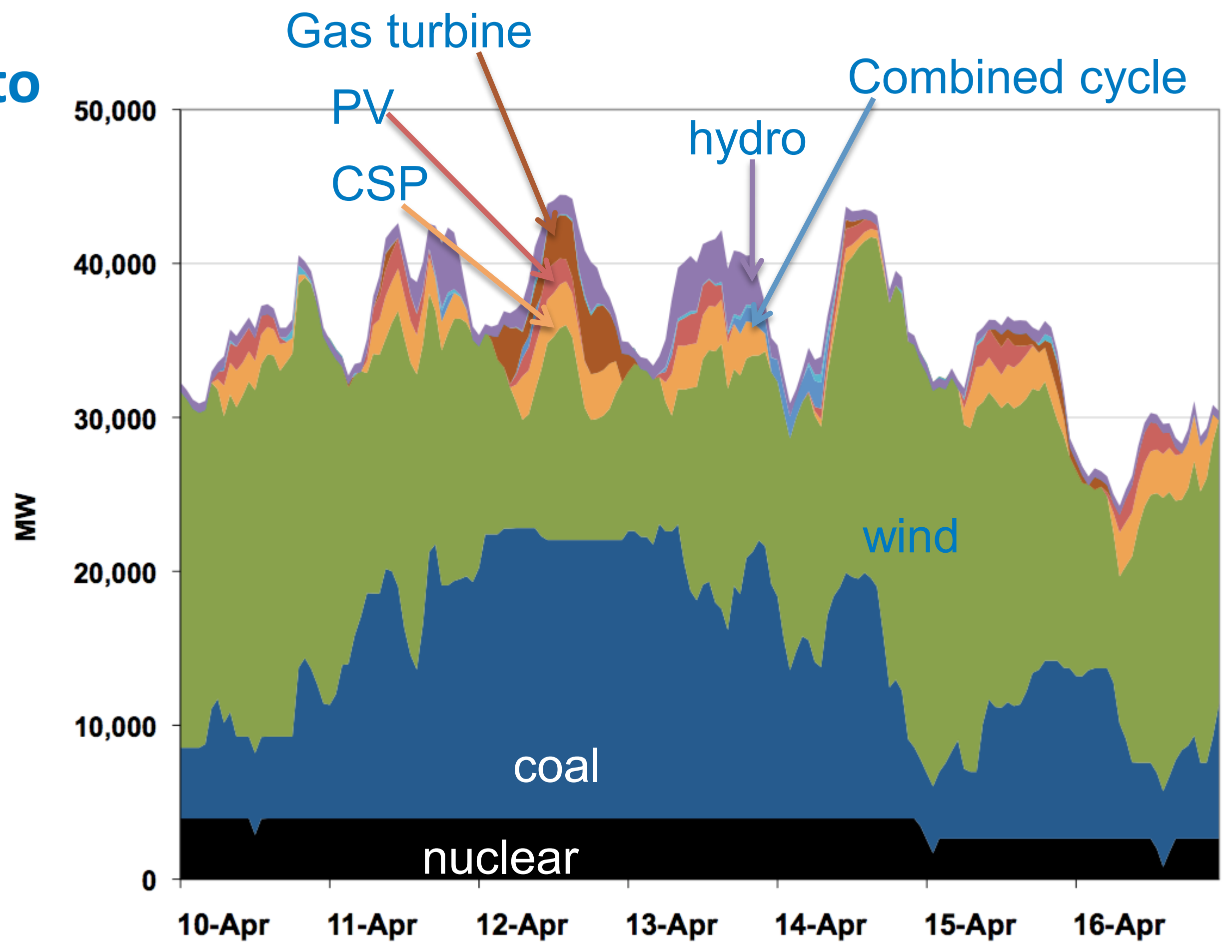
3/22/17

Western Wind & Solar Integration Study - Phase 1

Can we integrate high penetrations of wind and solar (i.e. 35%) into the Western Interconnection?

Yes, but….operational changes needed, such as increased balancing area cooperation, sub-hourly scheduling, access to under used transmission, use of wind and solar forecasts, etc



WWSIS 1: The worst week of three years

Western Wind & Solar Integration Study - Phase 2

What is the impact of 33% wind and solar on the fossil fuel plant cycling and emissions?

	Emission Reduction Due to Renewables	Cycling Impact
CO_2	260–300 billion lbs 29%–34%	Negligible Impact
NO_X	170–230 million lbs 16%–22%	3–4 million lbs
SO_2	80–140 million lbs 14%–24%	3–4 million lbs

Avoided Fuel Costs*
$7 Billion

Cycling Costs*
$35–$157 Million

*High wind and solar scenarios. Capital costs are not reflected.

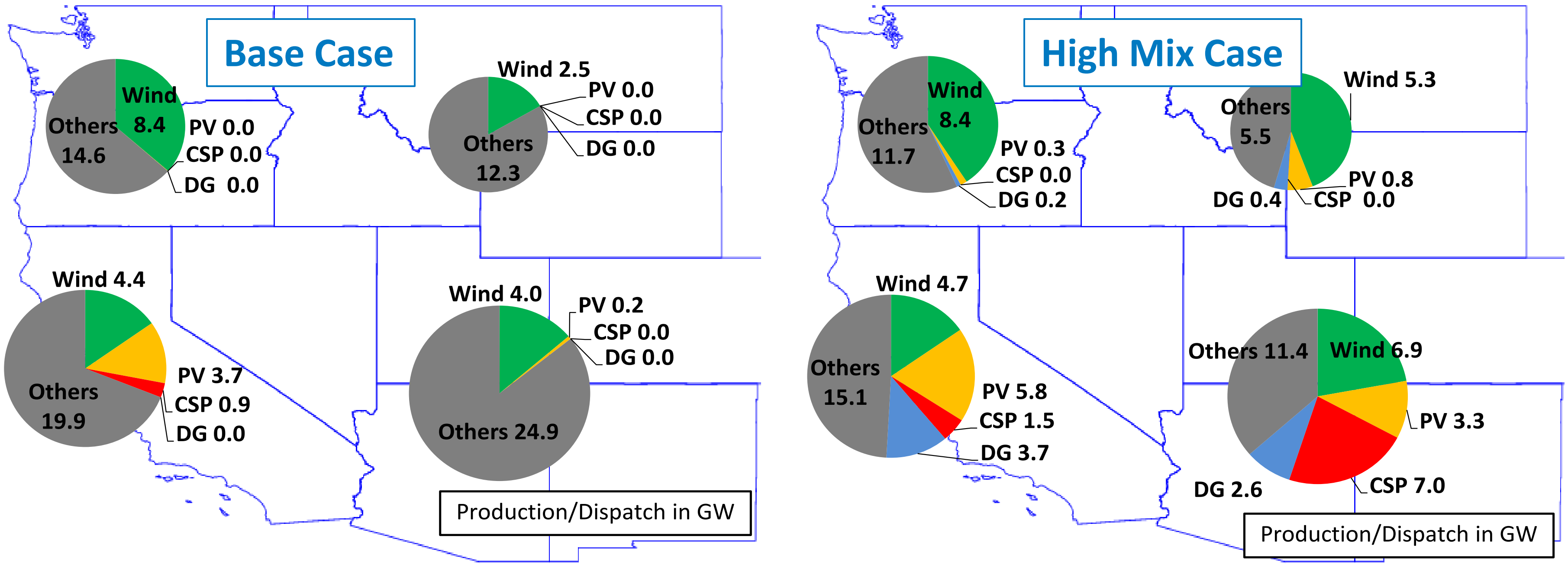
From a system perspective, cycling costs and emissions impacts of cycling are relatively small

Western Wind & Solar Integration Study - Phase 3

How do high penetrations of inverter-based generation resources like wind and PV solar affect system reliability in the first minute after a large disturbance?

- Examine Western Interconnection large scale stability and frequency response with high wind and solar penetration
- Explore how power system reliability can be maintained by mitigating any adverse impact via advanced controls, transmission, storage, etc

WWSIS 3 - Light Spring Load Study Scenarios



WECC-Wide Summary[(1)]	Light Spring Base[(2)]	Light Spring High Mix	Light Spring Extreme Sensitivity
Wind (GW)	20.9	27.2	32.6
Utility-Scale PV (GW)	3.9	10.2	13.5
CSP (GW)	0.9	8.4	8.3
Distributed PV (GW)	0	7.0	10.4
Total (GW) =	25.7	52.8	64.8
Penetration[(3)] (%) =	21%	44%	53%

(1) Western Electricity Coordinating Council includes parts of Canada and Mexico,
(2) Provided by WECC, (3) Penetration is % of total generation for this snapshot.

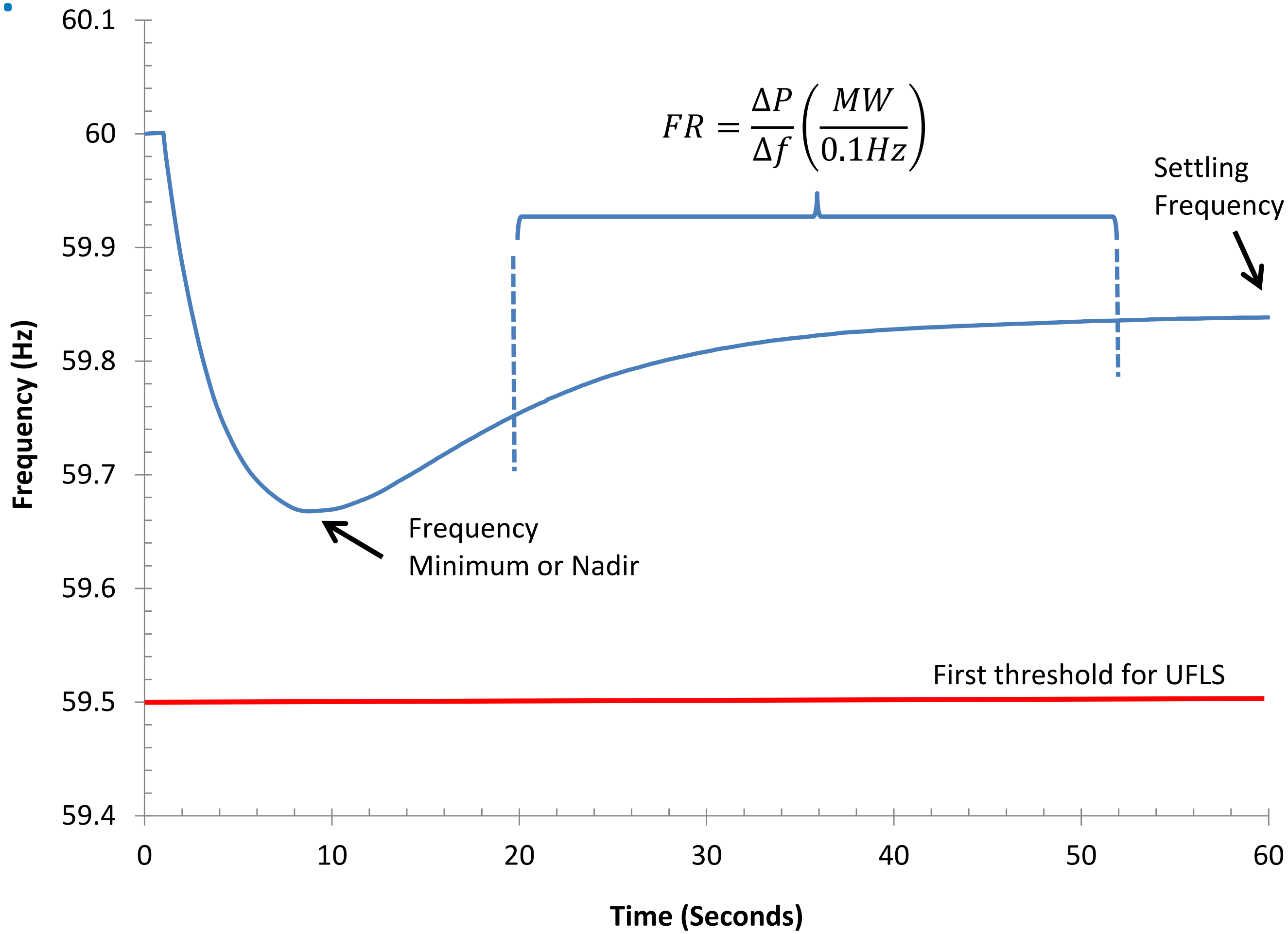
NERC Frequency Stability Criteria

NERC BAL-003-1* sets:

Design-basis outage (2 Palo Verde units =~2750MW)

Frequency response (FR) metric

Interconnection frequency response obligation (IFRO, 840 MW/0.1Hz)



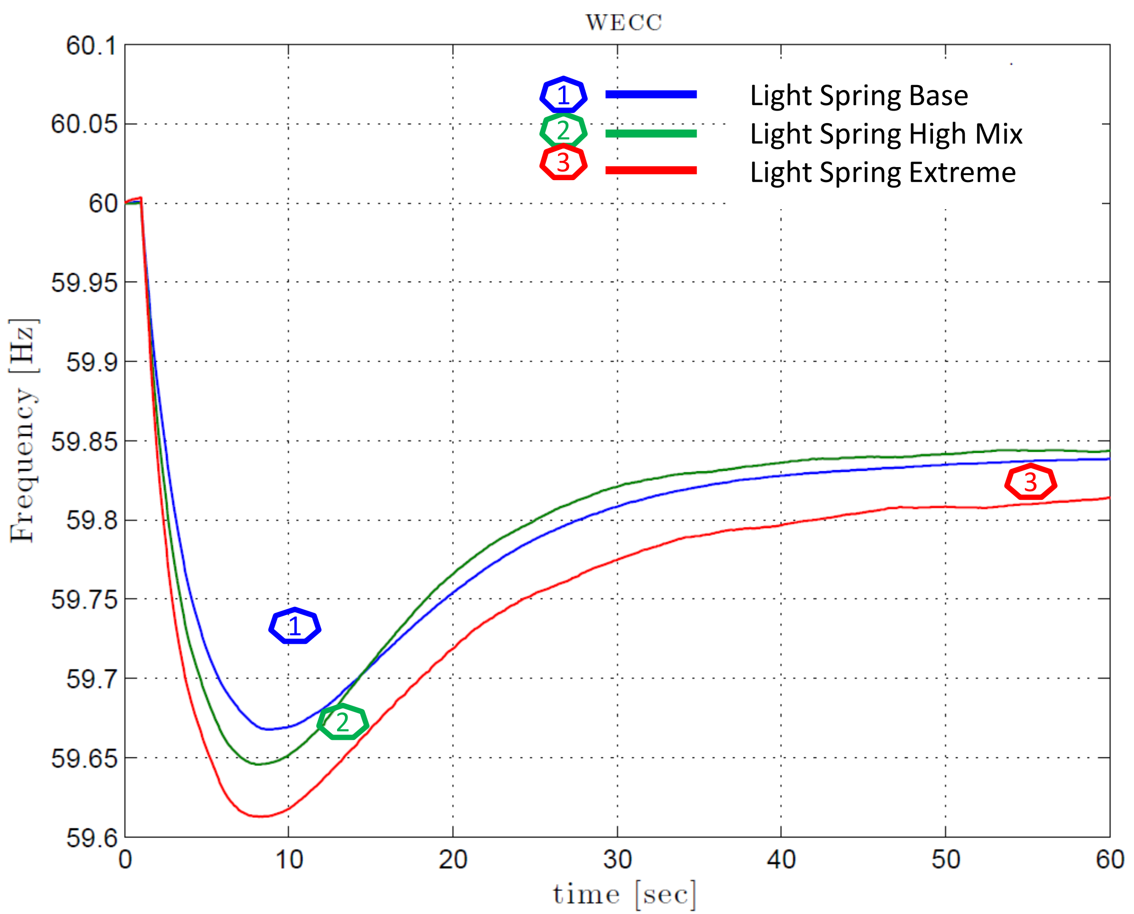
Goals are:

Meet IFRO (840 MW/0.1Hz)

Avoid under-frequency load shedding (UFLS)

*http://www.nerc.com/pa/Stand/Project%20200712%20Frequency%20Response%20DL/BAL-003-1_clean_031213.pdf

WWSIS Phase 3 Frequency Response



Disturbance: Trip 2 Palo Verde units (~2,750MW)

Even at extreme levels of wind and solar, performance meets criteria.

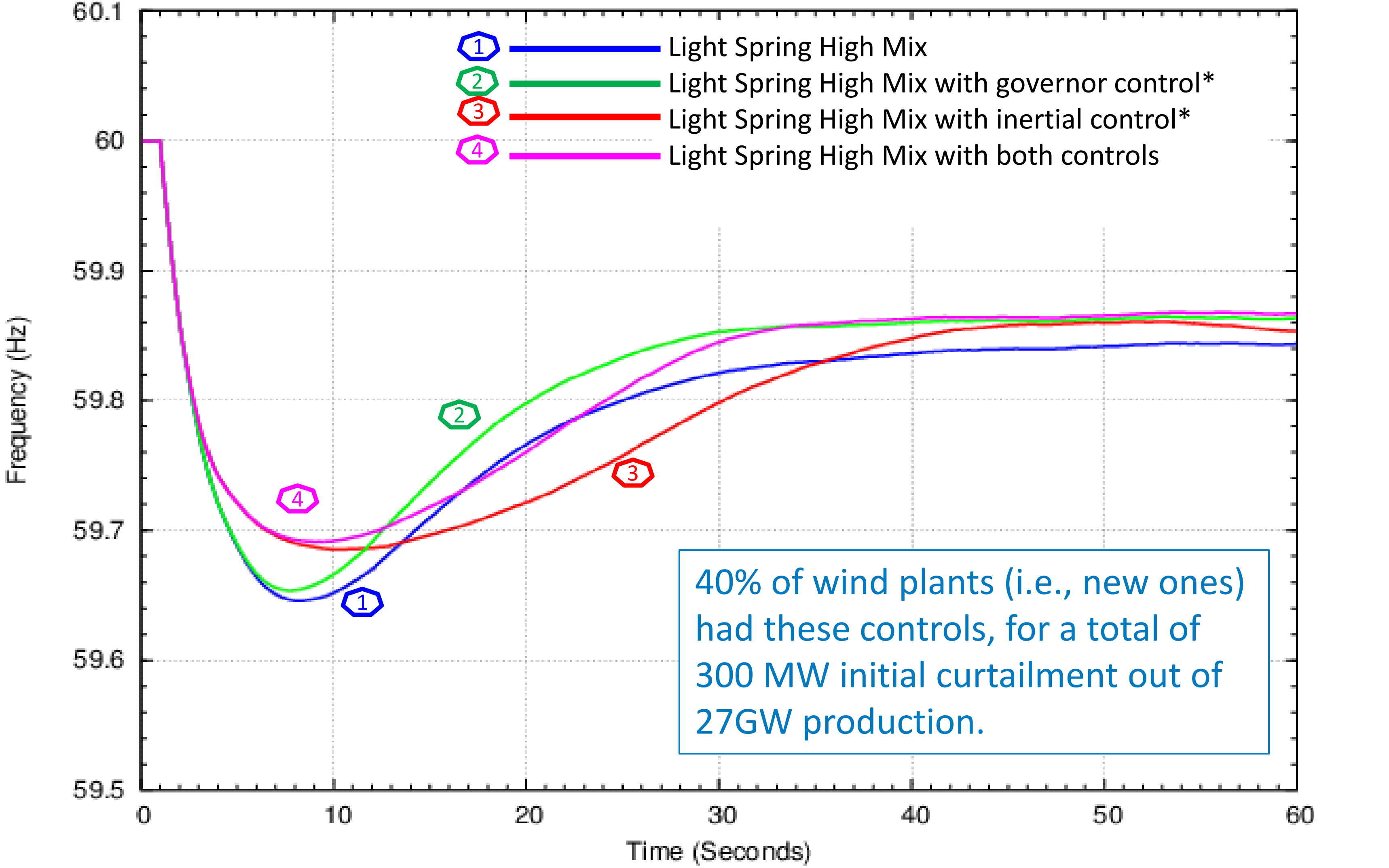
No under-frequency load shedding (UFLS).

Interconnection frequency response > 840 MW/0.1Hz obligation in all cases.

Case	FR (MW/0.1Hz)
Base	1352
High Mix	1311
Extreme	1055

Frequency Control on Wind Plants Improves Performance

Disturbance: Trip 2 Palo Verde units (~2,750MW)



Study Conclusions

- With good system planning, sound engineering practices, and commercially available technologies, the Western Interconnection can withstand the crucial first minute after grid disturbances with high penetrations of wind and solar.
- Local stability, voltage, and thermal problems can be addressed with traditional transmission system reinforcements (e.g., transformers, shunt capacitors, local lines).
- Non-traditional frequency-responsive controls on wind, utility-scale solar PV, CSP plants, and energy storage are effective at improving system performance.
- Load modeling assumptions can have as much impact on system performance as high penetrations of wind and solar. Accurate modeling of load, as well as renewable generation, is extremely important when analyzing high-stress conditions.

Demonstration of Essential Reliability Services by a 300-MW Solar PV Power Plant

V. Gevorgian, NREL

Clyde Loutan, Peter Klauer, Sirajul Chowdhury, Stephen Hall, CAISO

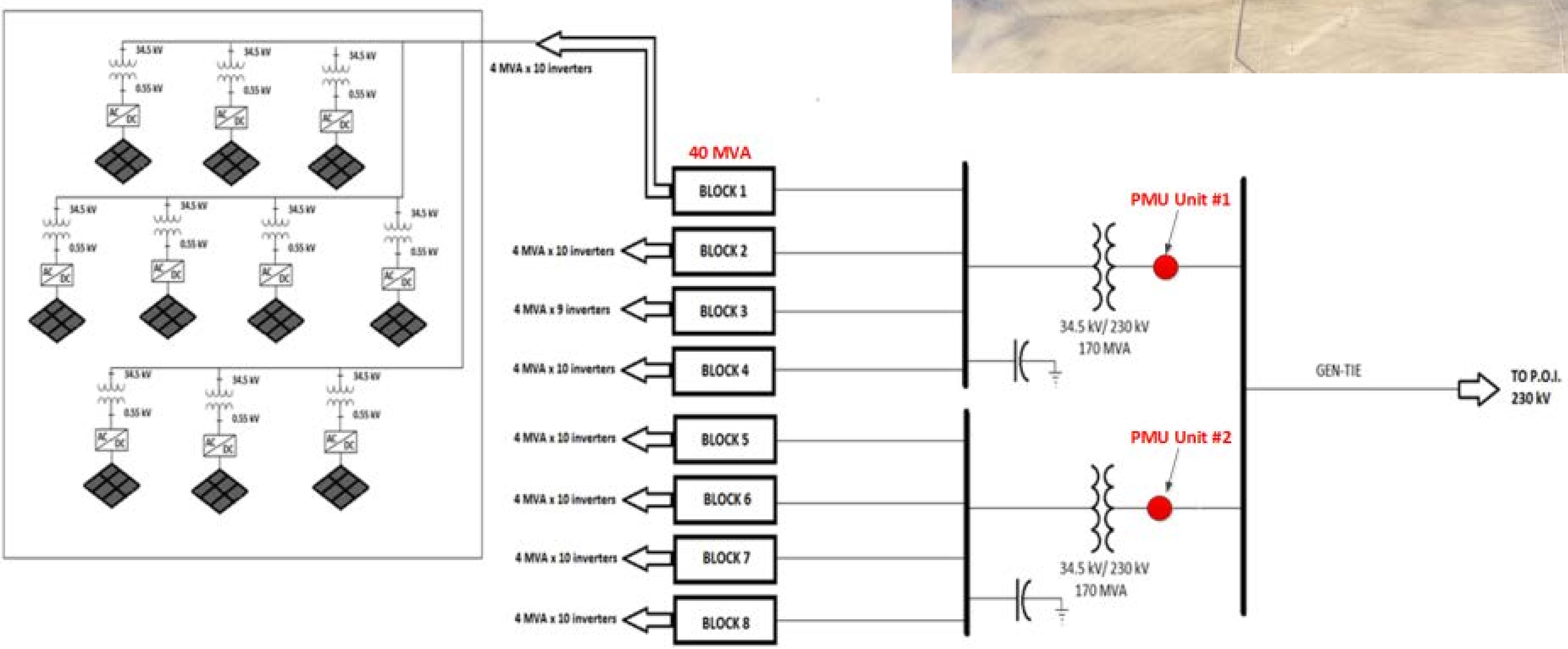
Mahesh Morjaria, Vladimir Chadliev, Nick Milam, Christopher Milan, First Solar

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

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

PV Power Plant Description

- Thin-film Cd-Te PV modules
- 4 MVA PV inverters
- 9 x 40 MVA blocks
- 34.5 kV collector system
- Two 170 MVA transformers
- Tie with 230 kV transmission line
- PMUs collecting data on 230 kV side

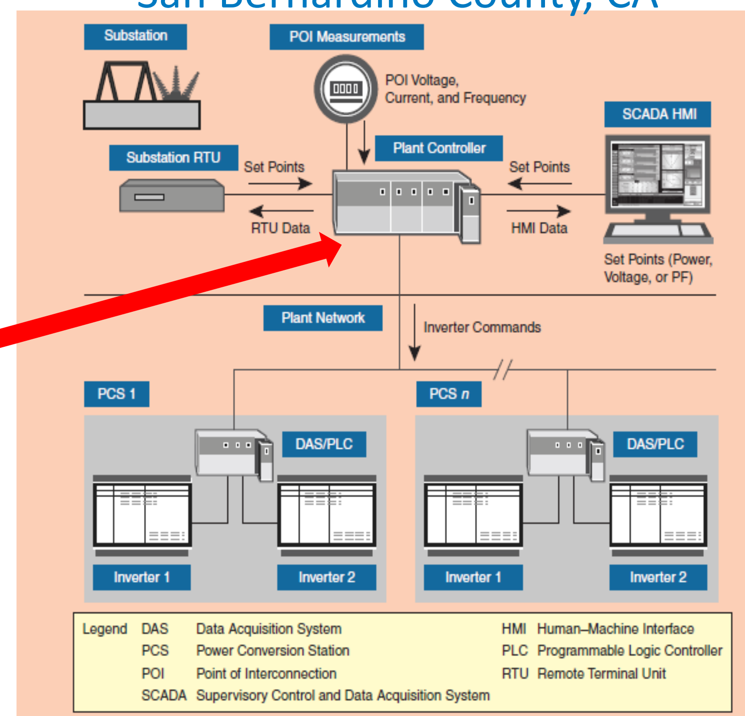


Testing Process

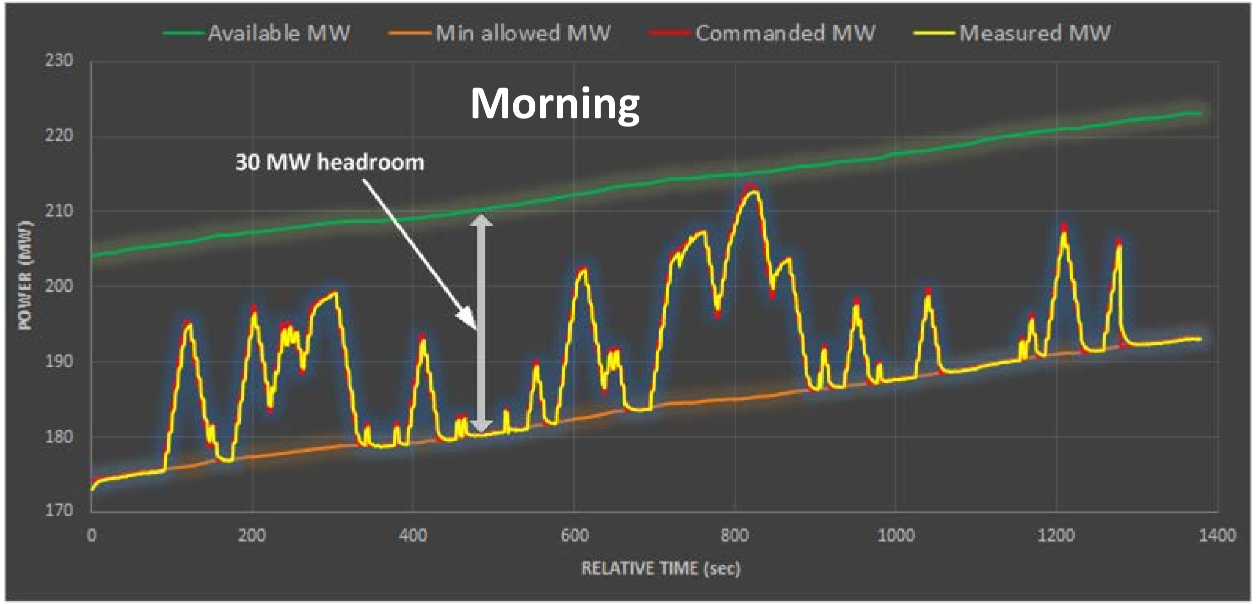
- **Remote testing from First Solar operations center in Tempe, AZ:**
  - Supervision of testing activities
  - Tracking plant performance
  - Making changes in set points and plant control parameters

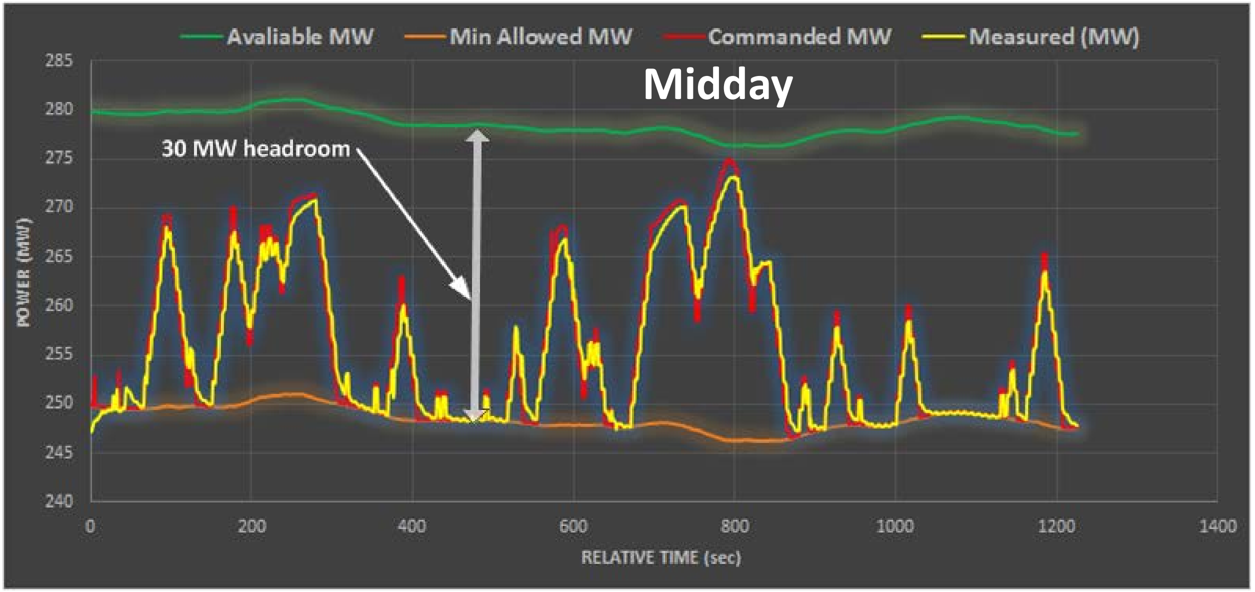
San Bernardino County, CA

Tempe, AZ



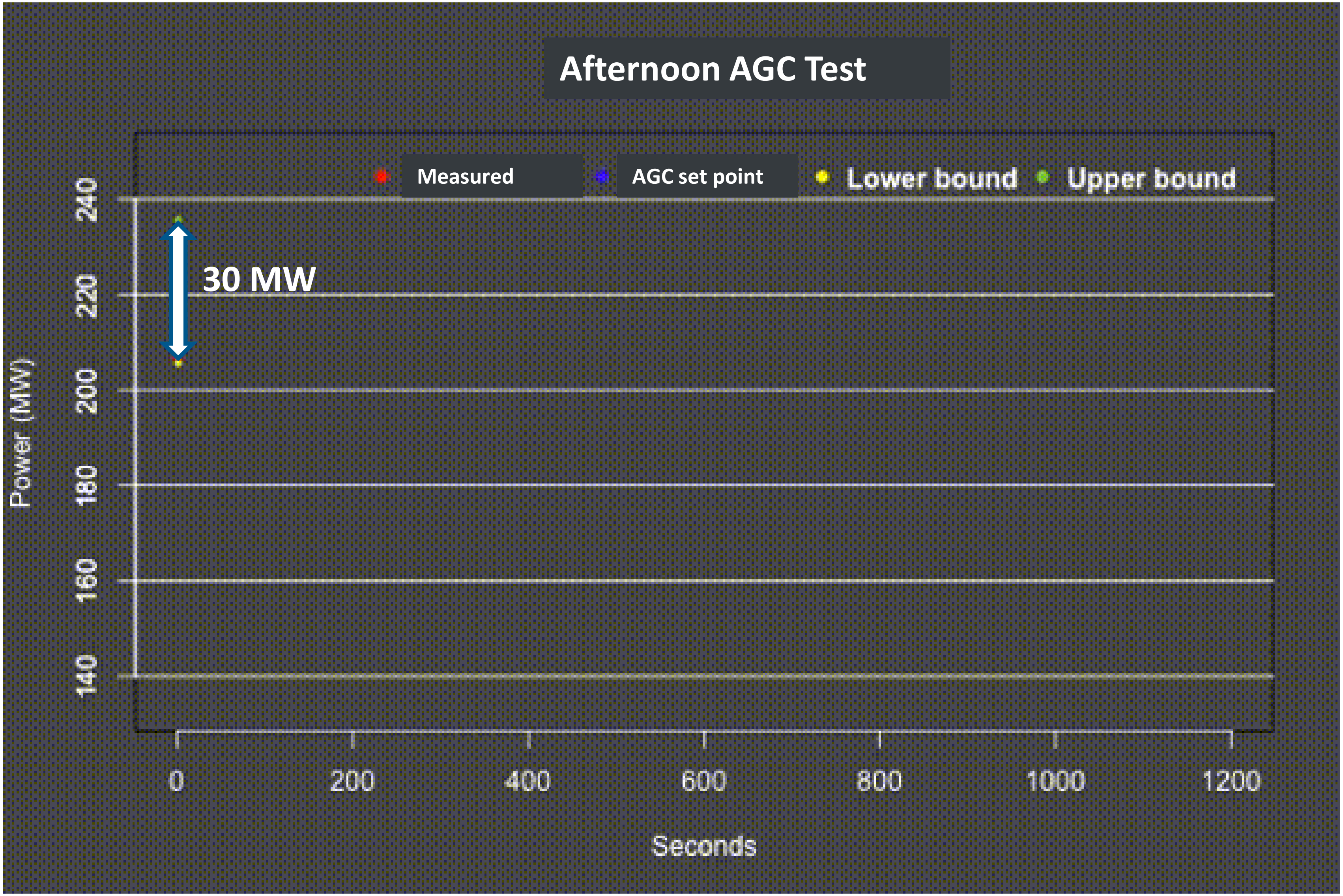
AGC Participation Tests





- **4-sec AGC signal provided to PPC**
- **30 MW headroom**
- **Tests were conducted at three resource intensity conditions (20 minutes at each condition):**
  - Sunrise
  - Middle of the day
  - Sunset
- **1-sec data collected by plant PPC**

AGC Test Data Animation



AGC Participation Tests- Summary

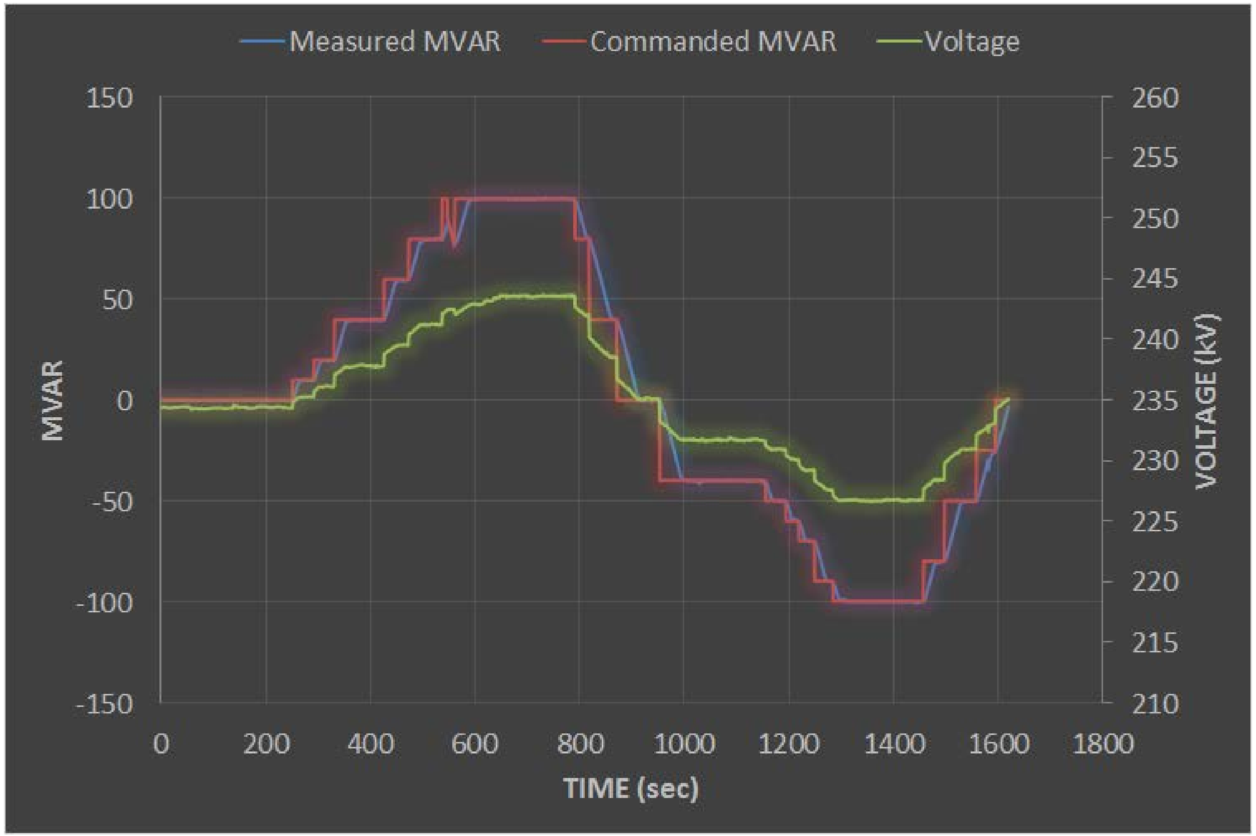
Measured Regulation Accuracy by 300 MW PV Plant

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%

Low Generation Reactive Power Control Test



- **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**

Conclusion

- **Advancements in smart inverter technology combined with advanced plant controls allow solar PV resources to provide regulation, voltage support, and frequency response during various modes of operations.**

References

www.nrel.gov/electricity/transmission/western_wind.html

"Western Wind and Solar Integration Study," NREL report # SR-550-47434.
"Western Wind and Solar Integration Study: Executive Summary," NREL report # SR-550-47781.

"Western Wind and Solar Integration Study Phase 2," NREL Report # TP-5500-55588.
"Western Wind and Solar Integration Study Phase 2: Executive Summary," NREL report # TP-5500-58798.

"Western Wind and Solar Integration Study Phase 3- Frequency Response and Transient Stability," NREL report # SR-5D00-62906.
"Western Wind and Solar Integration Study Phase 3- Frequency Response and Transient Stability: Executive Summary," NREL report # SR-5D00-62906-ES.
"WWSIS-3: Technical Overview" NREL fact sheet # FS-5D00-65410.