WWSIS - 3: Western Frequency Response and Transient Stability Study

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The draft report is under review by the TRC and by DOE.

Therefore, all of the results and statements in this presentation **MUST** be regarded as **preliminary** and subject to further review and modification.

Key Points

What: Stability – for the 1st minute after a big disturbance – is critically important limitation in the West

Why: Widespread worry that lots of wind and solar, especially combined with lots of coal diretirements will irreparably disrupt grid stability.

In the context of ERSTF: will essential reliability services be affected (i.e. depleted, altered, enhanced…)

What we learned: The Western Interconnection can be made to work well with both high wind and solar and substantial coal displacement, using good, established planning & engineering practice and commercially available technologies.

Team….

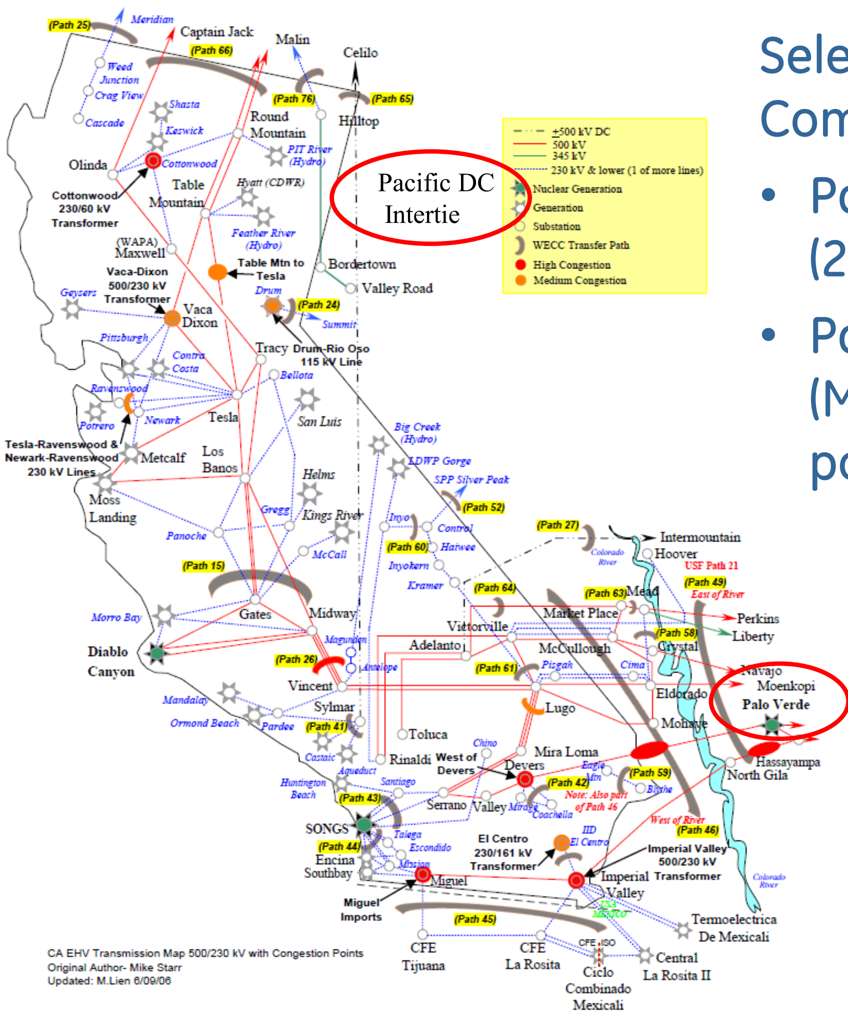
Who:

- Project Co-funded by DOE Wind and Solar Programs
- Project Management by NREL: Kara Clark
- Subcontract to GE Energy Consulting

Technical Review Committee:

- North American Electric Reliability Corporation
- PacifiCorp
- Public Service of New Mexico
- Western Area Power Administration
- Tucson Electric Power,
- Western Electricity Coordinating Council,
- California ISO
- Xcel Energy
- Sacramento Municipal Utility District
- Arizona Public Service,
- Bonneville Power Administration
- Western Governors Association
- Electric Reliability Council of Texas
- Utility Variable-generation Interest Group
- DOE
- Electric Power Research Institute
- Sandia NL
- Lawrence Berkeley NL
- Iowa State University
- University College Dublin
- Arizona State University

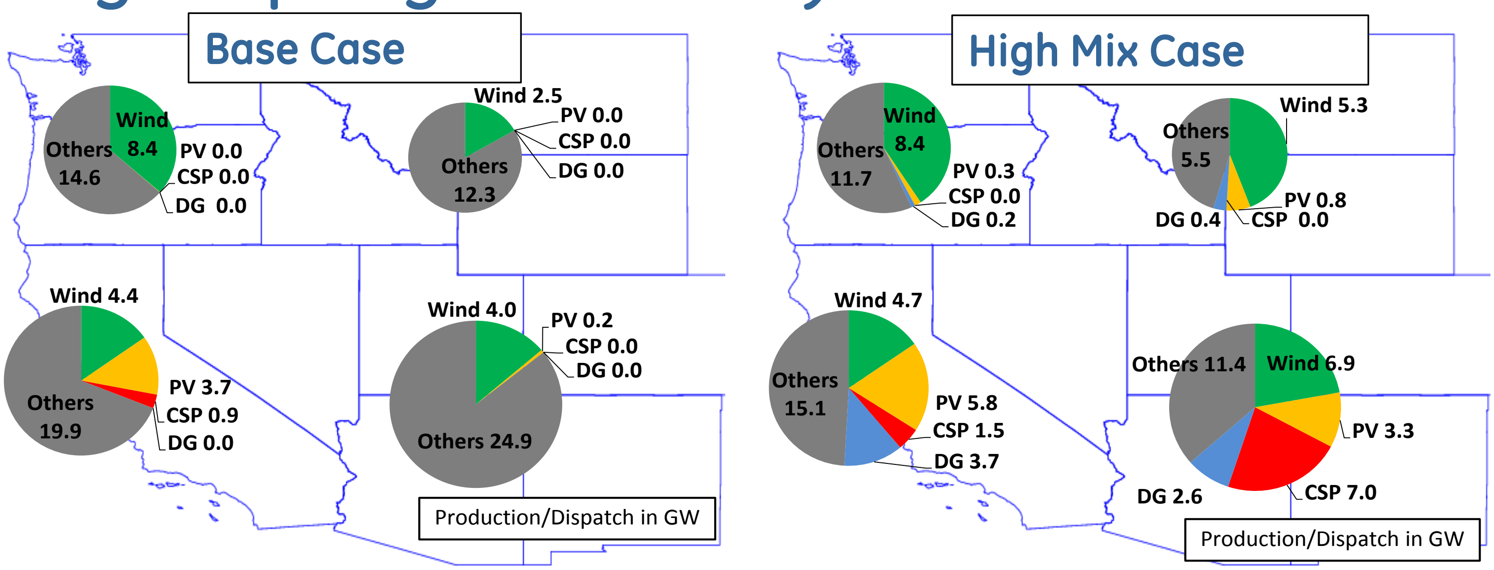
Critical Disturbances in the West



Selected by Technical Review Committee:

- Palo Verde Nuclear Plant (2 of 3 units for ~2,750 MW)
- Pacific DC Intertie (Maximum north-to-south power flow ~3,100 MW)

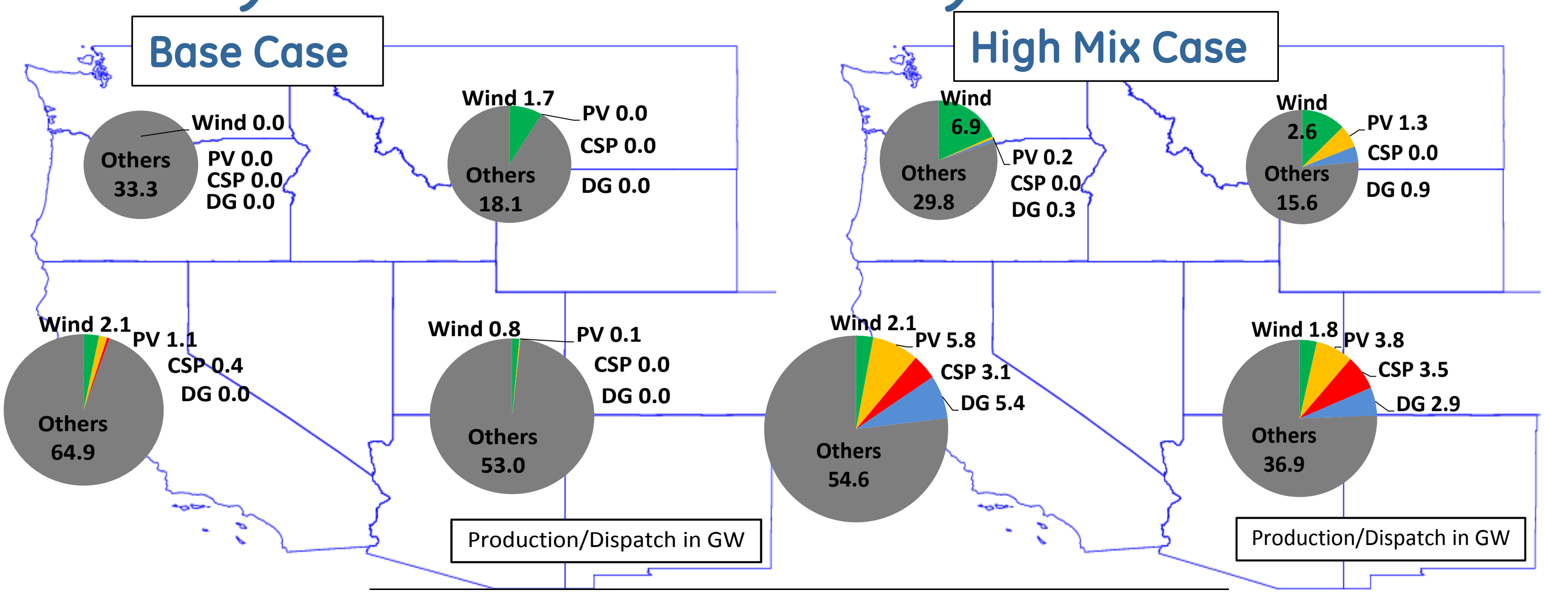
Light Spring Load Study Scenarios



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.

Heavy Summer Load Study Scenarios

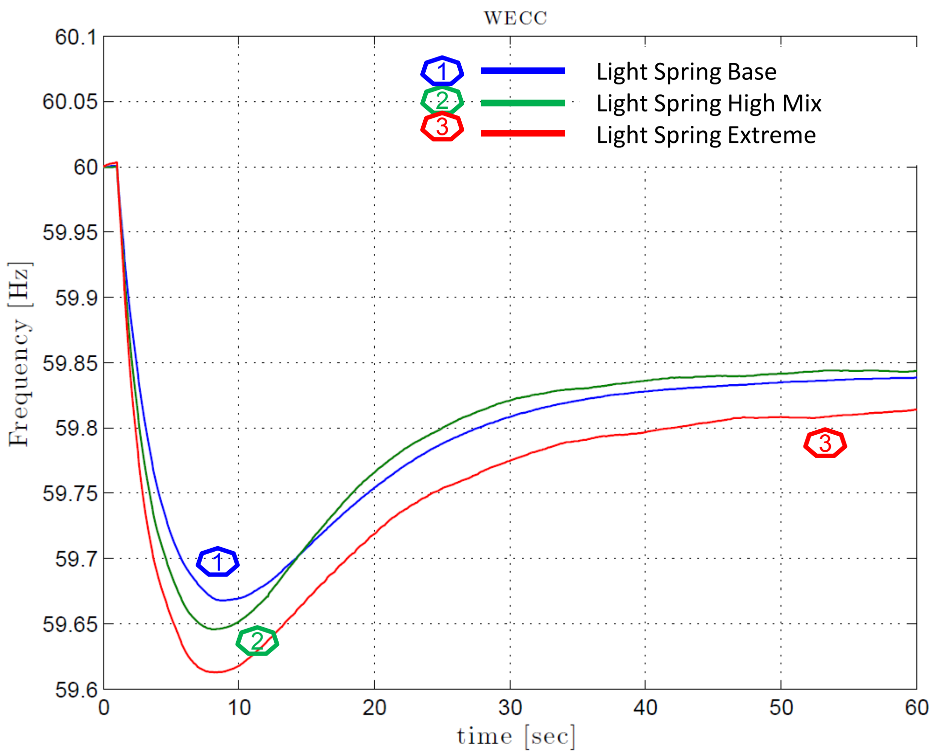


WECC-Wide Summary(1)	Heavy Summer Base(2)	Heavy Summer High Mix
Wind (GW)	5.6	14.3
Utility-Scale PV (GW)	1.2	11.2
CSP (GW)	0.4	6.6
Distributed PV (GW)	0.0	9.4
Total =	7.2	41.5
Penetration(3) (%) =	4%	20%

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

Frequency Response Analysis

Frequency Response with High Renewables



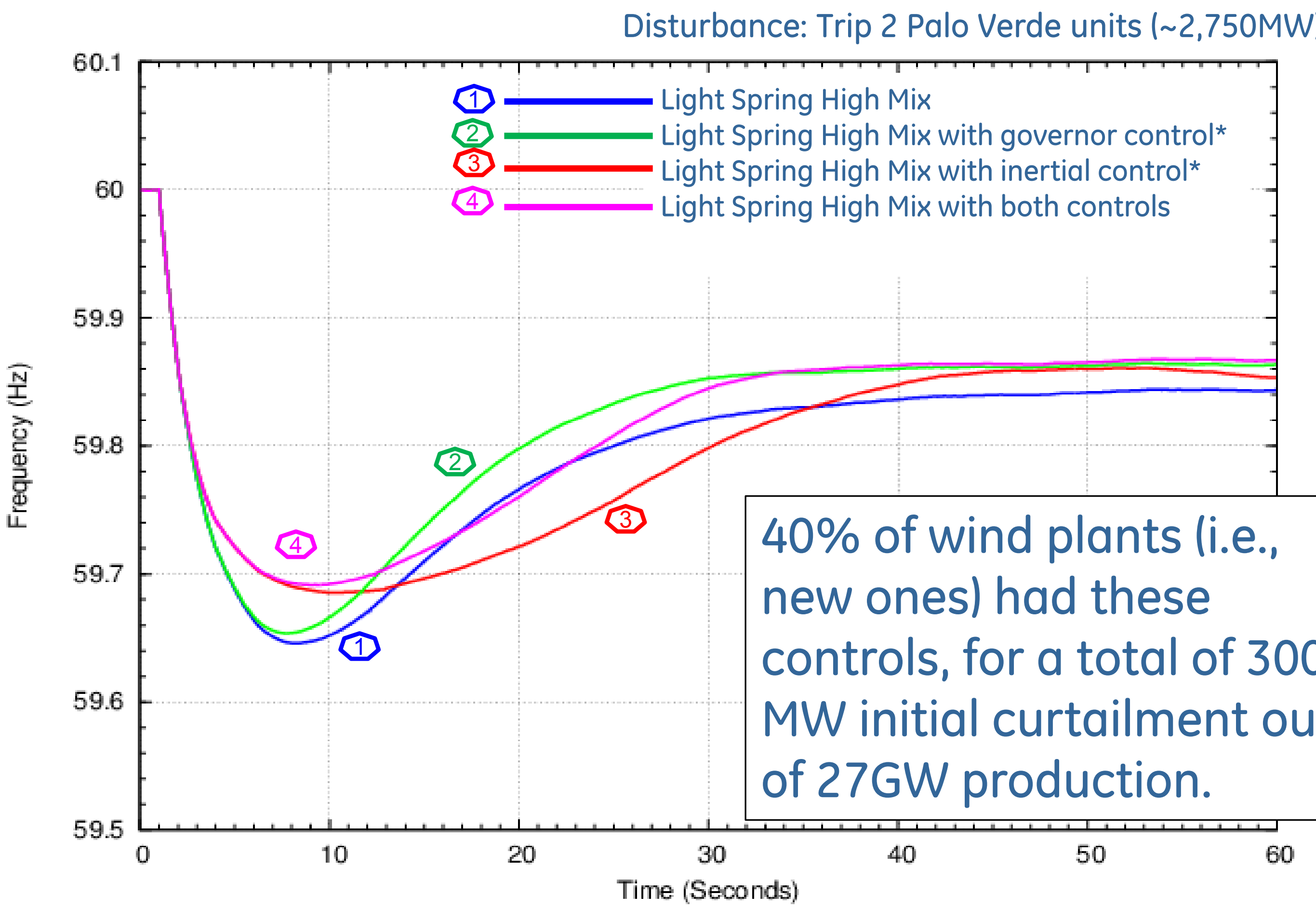
Disturbance: Trip 2 Palo Verde units (~2,750MW)

Interconnection frequency response > 840 MW/0.1Hz threshold in all cases.
No under-frequency load shedding (UFLS).

Wind Plant Frequency Responsive Controls

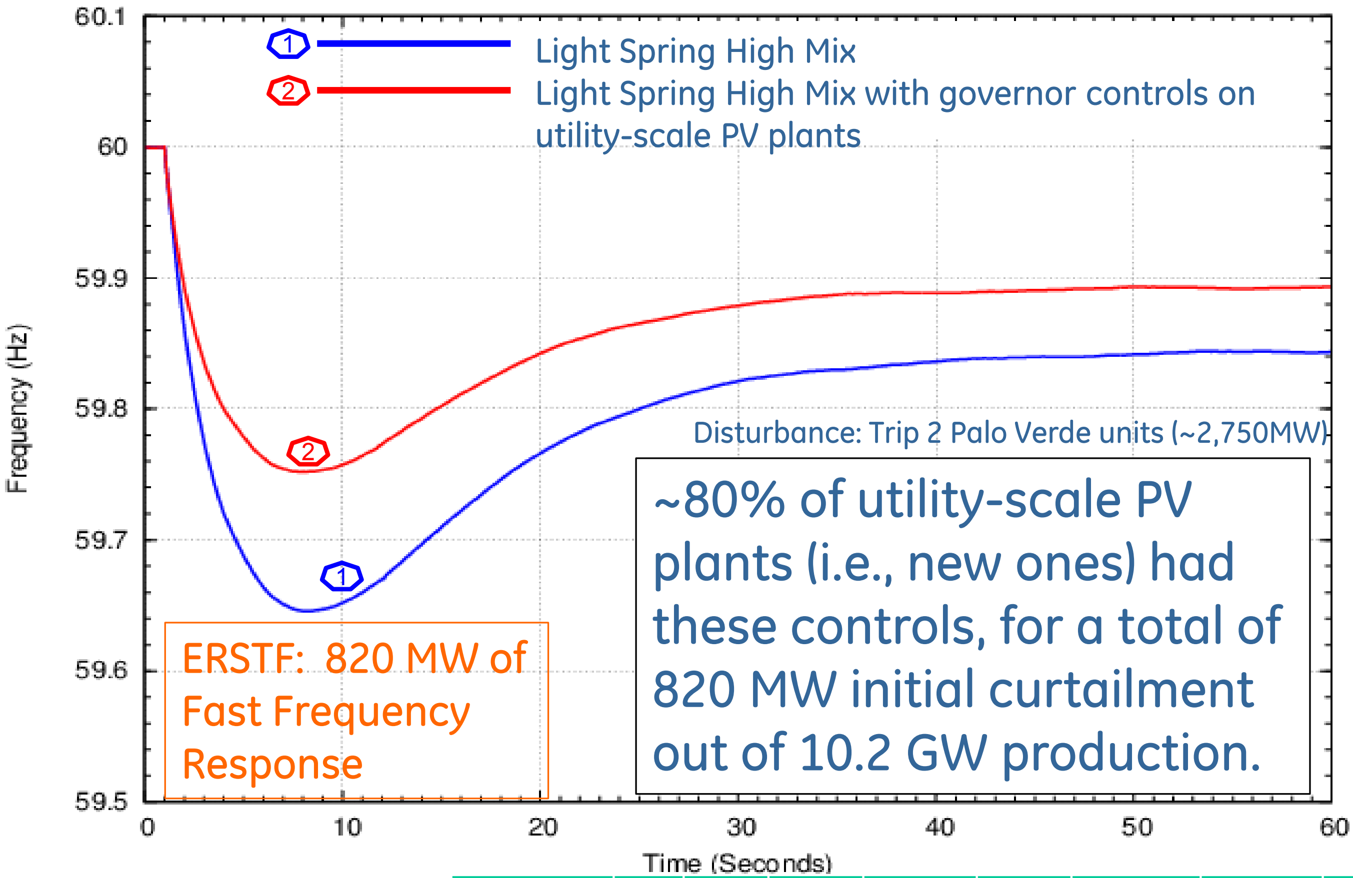
- Inertial control responds
  - to frequency drops only
  - in 5-10 second time frame
  - uses inertial energy from rotating wind turbine to supply power to system
  - requires energy recovery from system to return wind turbines to nominal speed
  - more responsive at higher wind speeds
  - ERSTF: this is Fast Frequency Response, NOT System Inertial Response
- Governor control responds
  - to both frequency drops and increases
  - in 5-60 second time frame
  - requires curtailment to be able to increase power
  - ERSTF: this is either Fast Frequency Response, or Primary Frequency Response (depending on aggresiveness of the control)

Frequency Control on Wind Plants



40% of wind plants (i.e., new ones) had these controls, for a total of 300 MW initial curtailment out of 27GW production.

Frequency Control on Utility-scale PV Plants



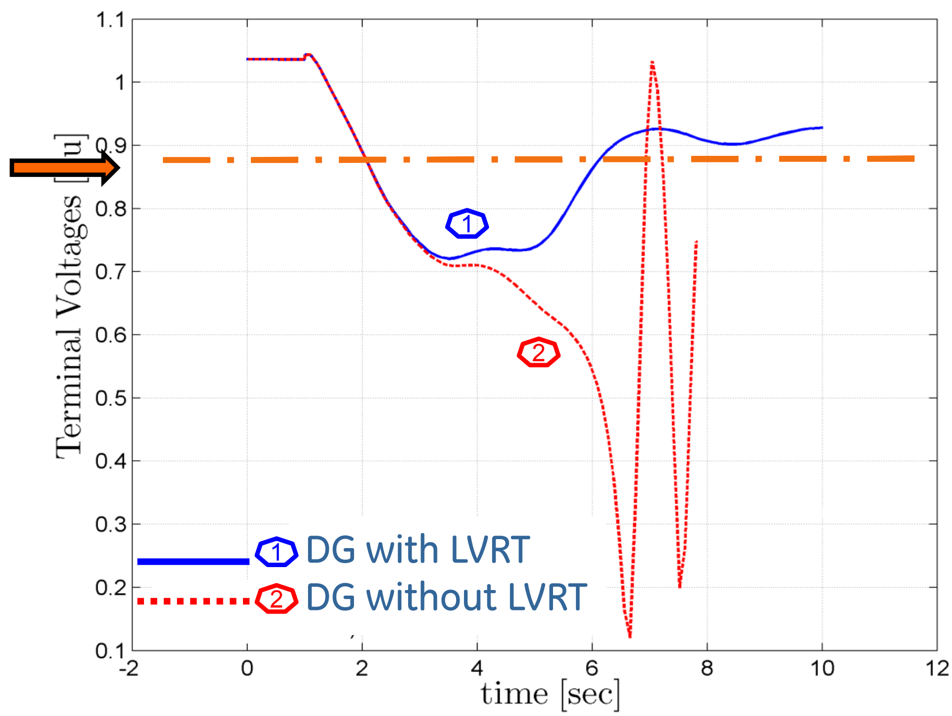
	FRO	Base	Hi-Mix	Wind Governor Control	Wind Inertial Control	Wind Governor and Inertial Controls	Utility-scale PV Governor Control	Energy Storage with Governor Control	Extreme Hi-Mix
WECC	840	**1352**	**1311**	1610	1323	1571	2065	1513	**1055**

Fault Ride Through Needed with High Levels of DG

Pessimistic approximation to worst case 1547 under-voltage tripping (88%, no delay)

Pacific DC Intertie trips

Widespread, common mode tripping of DG (i.e. distributed solar PV results in system collapse



Disturbance: Trip Pacific DC Intertie

Frequency Response Conclusions

For the conditions studied, system-wide frequency response can be maintained with high levels of wind and solar generation with both traditional and non-traditional approaches.

Traditional transmission system reinforcements to address local stability, voltage, and thermal problems include:

- Transformers
- Shunt capacitors, (dynamic reactive support)
- Local lines

Traditional approaches to meeting frequency response obligations are to commit synchronous generators with governors and to provide all response within an individual balancing authority area

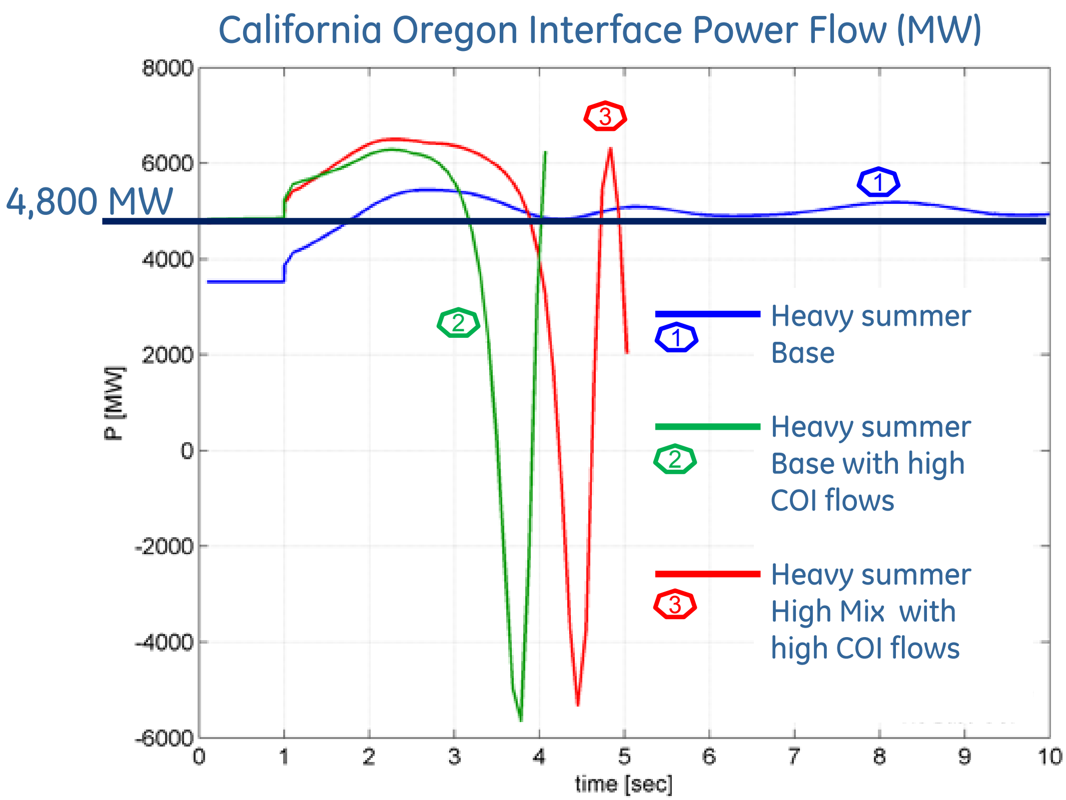
Non-traditional approaches are also effective at improving frequency response including:

- Sharing frequency response resources
- Frequency-responsive controls on inverter-based resources
  - Wind
  - Utility-scale PV
  - CSP
  - Energy storage, (demand response)

There are caveats in report

Transient Stability Analysis

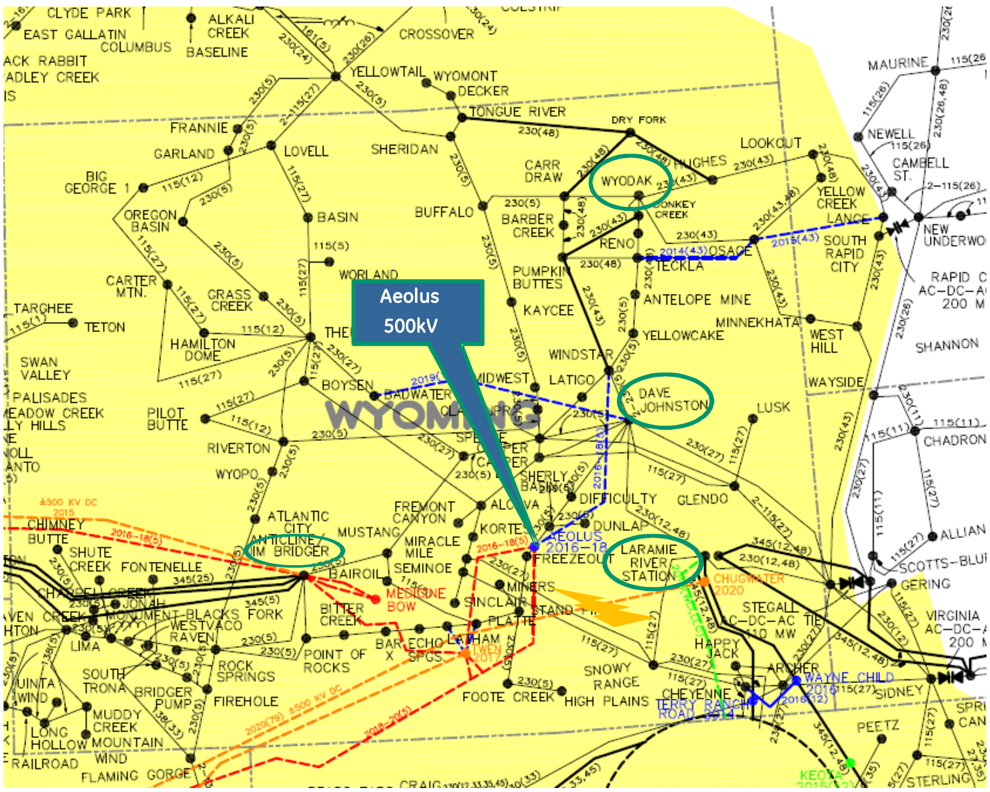
Heavy Power Transfer Affects Response More than High Wind and Solar



High power transfer drives performance in both Base case and High Renewables case.

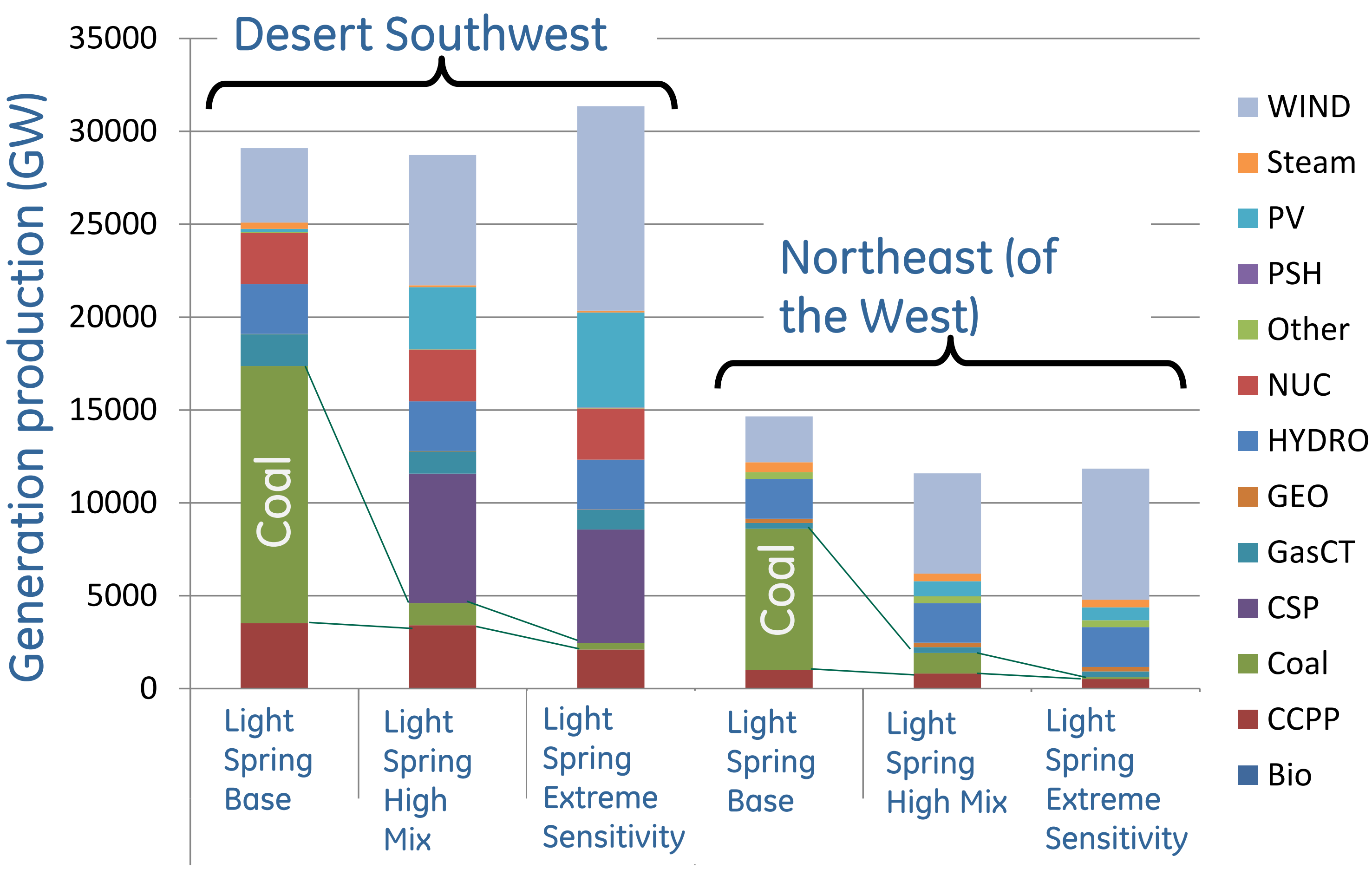
Disturbance: Trip Pacific DC Intertie… **NO RAS enabled**

Transient Stability in Northeastern WECC



Large Coal Plants

Coal Displacement in Light Spring Scenarios

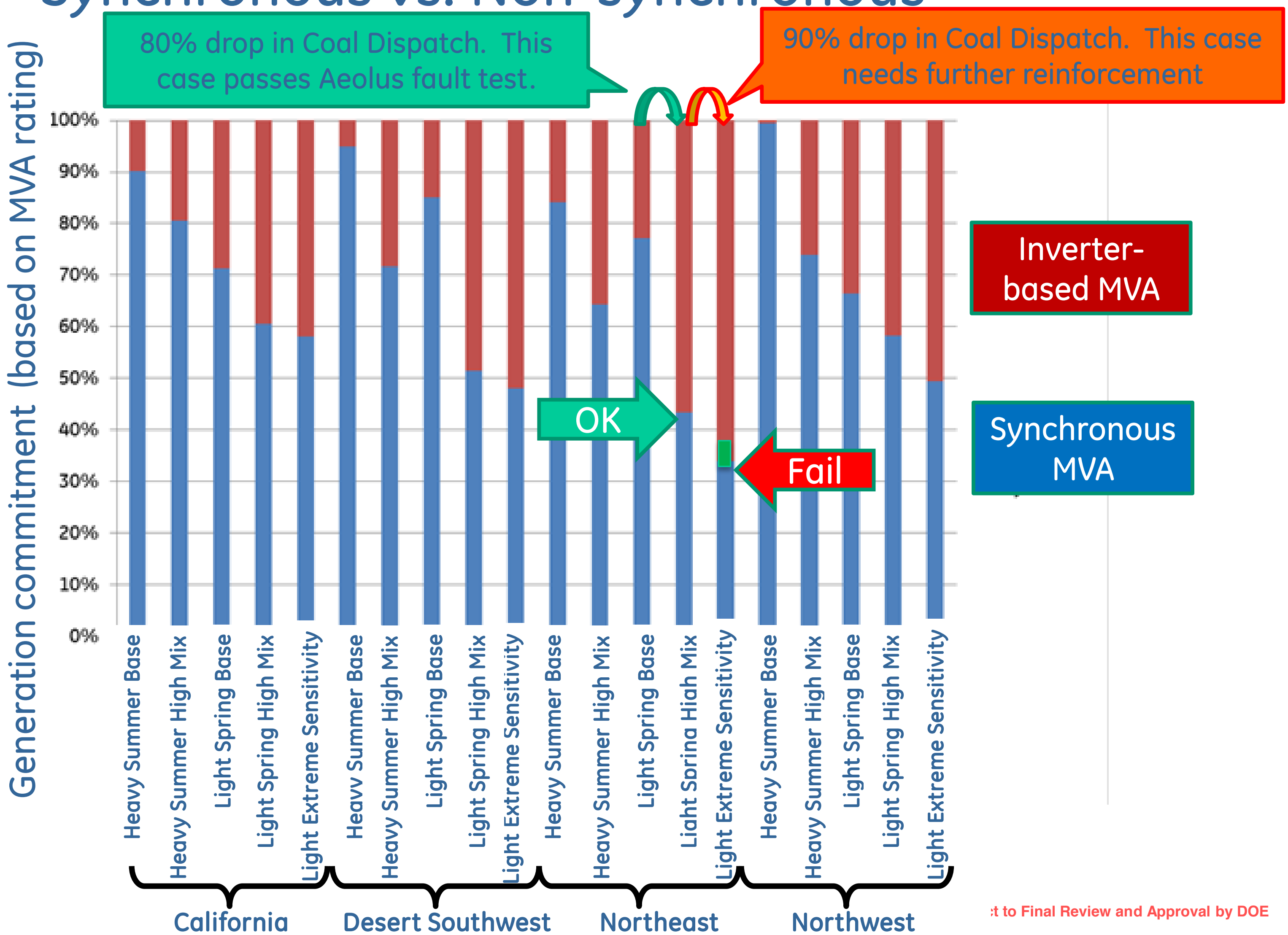


PV=photo voltaic, PSH=pumped storage hydro, NUC =nuclear, GEO=geothermal, GasCT=gas fired combustion turbine, CSP=concentrating solar power, CCPP=combined cycle power plant, Bio=biomass

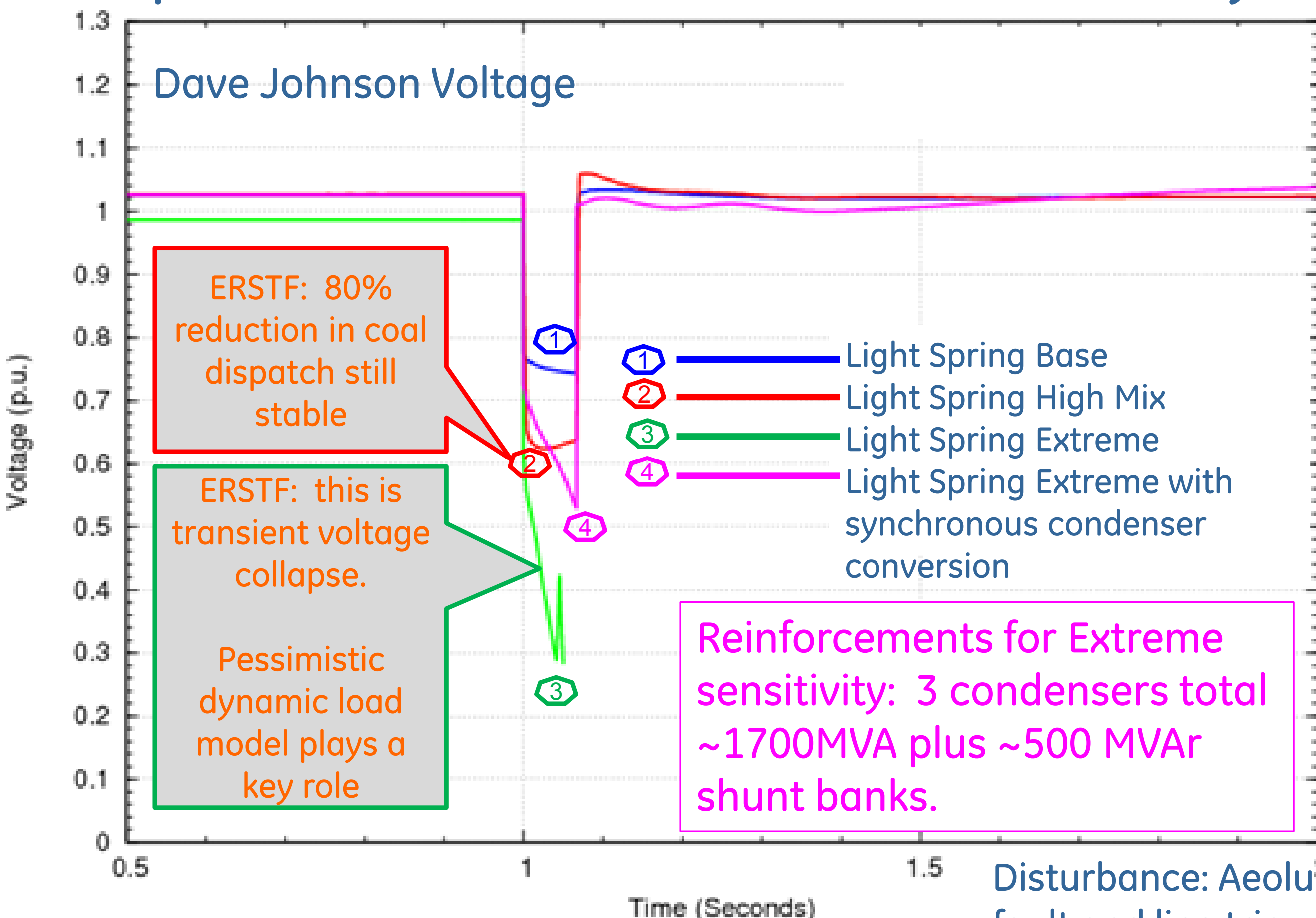
System Non-Synchronous Penetration (SNSP)

- Percent of non-synchronous generation (i.e., inverter-based generation like wind and solar) compared to synchronous generation in a system
- EirGrid (Irish grid operator) presently has 50% cap on the amount of non-synchronous generation allowed at any time
- ERSTF: a SNSP cap is similar to a SIM, but reflects restrictions on short-circuit strength as well as inertia

Synchronous vs. Non-synchronous



Synchronous Condenser Conversion Results in Acceptable Performance in Extreme Sensitivity



Disturbance: Aeolus bus fault and line trip

Transient Stability Conclusions

For the conditions studied, system-wide transient stability can be maintained with high levels of wind and solar generation with both traditional and non-traditional approaches.

Traditional transmission system reinforcements to address stability, voltage, and thermal problems include:

- Transformers
- Shunt capacitors, (dynamic reactive support)
- Local lines

Non-traditional approaches are also effective at improving transient stability including:

- Synchronous condenser conversions
- New wind and solar controls

There are caveats in report.

Study Conclusions

The Western Interconnection can be made to work well in the first minute after a big disturbance with both high wind and solar and substantial coal displacement, using good, established planning and engineering practice and commercially available technologies.

The following detailed conclusions were word-smithed by Technical Review Committee and include the appropriate caveats.

Frequency Response Conclusions

For the conditions studied:

- System-wide FR can be maintained with high levels of wind and solar generation if local stability, voltage, and thermal problems are addressed with traditional transmission system reinforcements (e.g., transformers, shunt capacitors, local lines).

- Limited application of non-traditional frequency-responsive controls on wind, solar PV, CSP plants, and energy storage are effective at improving both frequency nadir and settling frequency, and thus FR. Refinements to these controls would further improve performance.

- Individual BA FR may not meet its obligation without additional FR from resources both inside and outside the particular area. As noted above, non-traditional approaches are effective at improving FR. Current operating practice uses more traditional approaches (e.g., committing conventional plants with governors) to meet all FR needs.

- Using new, fast-responding resource technologies (e.g., inverter-based controls) to ensure adequate FR adds complexity, but also flexibility, with high levels of wind and solar generation. Control philosophy will need to evolve to take full advantage of easily adjustable speed of response, with additional consideration of the location and size of the generation trip.

- For California, adequate FR was maintained during acute depletion of headroom from afternoon drop in solar production, assuming the ability of California hydro to provide FR.

Transient Stability Conclusions

For the conditions studied:

- System-wide transient stability can be maintained with high levels of wind and solar generation if local stability, voltage, and thermal problems are addressed with traditional transmission system reinforcements (e.g., transformers, shunt capacitors, local lines). With these reinforcements, an 80% reduction in coal plant commitment, which drove SNSP to 56%, resulted in acceptable transient stability performance.

- With further reinforcements, including non-standard items such as synchronous condenser conversions, a 90% reduction in coal plant commitment, which drove SNSP to 61%, resulted in acceptable transient stability performance.

- Additional transmission and CSP generation with frequency-responsive controls are effective at improving transient stability.

Other Conclusions

- Accurate modeling of solar PV, CSP, wind, and load behavior is extremely important when analyzing high-stress conditions, as all of these models had an impact on system performance.

- Attention to detail is important. Local and locational issues may drive constraints on both FR and transient stability.

- The location of generation tripping, e.g., DG vs. central station, is not as important as the amount of generation that is tripped. However, widespread deliberate or common-mode DG tripping after a large disturbance has an adverse impact on system performance. It is recommended that practice adapt to take advantage of new provisions in IEEE 1547 that allow for voltage and frequency ride-through of DG to improve system stability.

- Further analysis is needed to determine operational limits with low levels of synchronous generation in order to identify changes to path ratings and associated remedial action schemes, as well as quantify the impact of DG on transmission system performance.

- Because a broad range of both conventional and non-standard operation and control options improved system performance, further investigation of the most economic and effective alternatives is warranted. This should include consideration of the costs and benefits of constraining commitment and dispatch to reserve FR, as well as the capital and operating costs of new controls and equipment.


Thank you!
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imagination at work