# WWSIS III: Western Frequency Response and Transient Stability Study

GE Energy

Nicholas W. Miller

TRC Proposed Project Review
December 12, 2012

imagination at work

# Outline

- Study Objectives and Background
- Task 1 - Define Study Databases and Establish Initial Conditions
- Task 2 - Evaluate WECC Frequency Response
- Task 3 - Evaluate WECC Transient Stability
- Task 4 - Evaluate Factors Affecting Dynamic Performance
- Task 5 - Evaluate Mitigation Measures
- Task 6 - Final Report
- Discussion

# Study Overview

- Illustrate the frequency response and transient stability of the US WECC to large disturbances, including generation outages and critical tie-line disturbances, under a variety of system conditions.
- Explore the potential impact of substantially increased levels of wind and solar generation on frequency response and transient stability
- Test various operational and control options to improve system frequency response and transient stability
- Examine and test metrics of system conditions intended to provide operational assistance in positioning the system for adequate frequency and transient stability performance.
  - Consider how possible additional dynamic constraints on system performance might be included in economic simulations

# WWSIS Background and Related Work

- WWSIS I and II established longer term operational and economic performance of US WECC under various high levels of wind & solar power
- Analysis included detailed examination of reserves for balancing and addressing incremental variability, and inter-area transmission constraints (both established and future)
- But, (traditional) system dynamics for WECC under these conditions have not been examined in those studies
  - Interface limits (in WECC) are heavily influenced or established solely by stability performance
  - Frequency response concerns and obligations must be addressed
- Dynamic behavior of wind and solar generation is substantively different from that of synchronous generation, and may alter constraints.

# Related Work

- GE, following internally funded work, completed a WECC study with CAISO in '11, focusing on California frequency response in high wind and solar conditions. That work is published.
- GE and NREL are now wrapping up the "Eastern Frequency Response Study", in which the frequency performance of EI was tested with high levels of wind; various means to improve modeling and system response were tested. That work will be published shortly.
- GE and NREL have been working (both together and separately) on design, modeling and understanding of frequency responsive controls for wind plants.
- GE has field validation work underway that is likely to complement or help validate performance characteristics important to the work proposed here.

[*relevant results from these projects will be used throughout the rest of this presentation to illustrate the character of several of the expected outcomes*]

# Outline

- Study Objectives and Background
- Task 1 - Define Study Databases and Establish Initial Conditions
- Task 2 - Evaluate WECC Frequency Response
- Task 3 - Evaluate WECC Transient Stability
- Task 4 - Evaluate Factors Affecting Dynamic Performance
- Task 5 - Evaluate Mitigation Measures
- Task 6 - Final Report
- Discussion

# Task 1 - Study Databases & Establish Initial Conditions

- Model:
  - WWSIS II  Baseline and High Mix Scenarios for Renewable Penetration
  - Full c. 2018  WECC loadflow and stability
- Siting:
  - By BA, based on WWSIS scenario
  - Local/intra-BA changes minimal  (we are focused on bulk WECC system issues, not local constraints)
- Initial Conditions:
  - High stress, e.g. time of high EOR or COI flow or times of low load and (potentially) high variable generation
  - (2 or 3 conditions to be evaluated in detail
  - Calculate key (initial) metrics
- Incremental Commitment and Dispatch (for added wind & solar)
  - Critical to credible and comparable cases
- Incremental (but minimal) transmission reinforcements

# Task 1 - Study Databases & Establish Initial Conditions

Incremental Commitment and Dispatch (for added wind & solar): proposed method

- Use WWSIS II Plexos Results
- Mine for Hours with similar characteristics to study initial conditions (load level, season, approx. time).
- Establish incremental w/s generation by BA; set initial loading (instantaneous CF) accordingly
- Establish "rules" for decommitment/redispatch by BA, using trends established by comparison of baseline vs. high mix hourly solutions from PLEXOS cases.
    - This is an extension (and is expected to be a substantive improvement) over previous (GE) 1/3 : 2/3 "rule" extracted from WWSIS I results
- Recommit and dispatch cases/conditions with wind & solar added.

# Task 1 - Study Databases & Establish Initial Conditions

## Incremental Transmission: proposed method

- Following recommitment and redispatch of all study cases, test for static violations (thermal and voltage).
- Compare transmission (path) upgrades used for WWSIS II Plexos with capability of base case loadflow (thermal and voltage only). Note paths with substantive differences.
- Use convolution of difference *and* violations to select (gross) transmission reinforcements. Trim voltages and modify dispatch/commitment to establish reasonable initial conditions.
- Process is expected to be heuristic.
- Result will be deliberately skewed towards *under* building new transmission…(see mitigation)

# Key to Case Summary Metrics

| | |
|---|---|
| GR Pgen (GW) | Power generation of units with governor response |
| GR MWCAP (GW) | Power generation capability of units with governor response |
| GR Headroom (GW) | Headroom of units with governor response |
| GR MVA (1000 MVA) | MVA of units with governor response |
| | |
| NG and BL Pgen (GW) | Power generation of units without governor response |
| Wind Pgen (GW) | Power generation of Wind |
| | |
| GW Capability | MW capability of all online generation units |
| CU Pgen (GW) (GR + BL + NG) | Power generation of conventional units |
| Total Pgen (GW) | System generation |
| Total Load (GW) | System load |
| | |
| Wind Pgen/Total Pgen | Wind energy penetration |
| Kt | The ratio between generation with governor response (GR) and other conventional units with inactive governors (for under frequency) |

From NREL/GE Eastern Frequency Response Study - 2012

GR-Governor Response; BL-Base Load; NG-No Governor; CU-Conventional Unit

# Generation Summary for New Base Case

| | EI | | NPCC | | PJM | | SERC/FRCC | | SPP | | MISO | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | # of Units | | # of Units | | # of Units | | # of Units | | # of Units | | # of Units |
| GR Pgen (GW) | 67.3 | 1180 | 15.1 | 332 | 12.4 | 153 | 32.5 | 446 | 3.0 | 67 | 4.3 | 182 |
| GR MWCAP (GW) | 102.5 | | 20.4 | | 18.1 | | 51.8 | | 4.9 | | 7.3 | |
| GR Headroom (GW) | 35.2 | | 5.3 | | 5.7 | | 19.3 | | 1.9 | | 3.0 | |
| GR MVA (1000 MVA) | 114.7 | | 22.1 | | 19.6 | | 59.8 | | 5.2 | | 8.1 | |
| | | | | | | | | | | | | |
| NG and BL Pgen (GW) | 213.4 | 1156 | 29.4 | 396 | 70.2 | 275 | 81.7 | 289 | 12.7 | 57 | 19.5 | 139 |
| Wind Pgen (GW) | 0.7 | | 0.3 | | 0.0 | | 0.0 | | 0.3 | | 0.0 | |
| | | | | | | | | | | | | |
| GW Capability | 316.6 | | 50.1 | | 88.3 | | 133.5 | | 17.9 | | 26.8 | |
| CU Pgen (GW) (GR + BL + NG) | 280.7 | 2336 | 44.5 | 728 | 82.6 | 428 | 114.2 | 735 | 15.7 | 124 | 23.8 | 321 |
| Total Pgen (GW) | 281.4 | | 44.8 | | 82.6 | | 114.2 | | 16.0 | | 23.8 | |
| Total Load (GW) | 272.1 | | 41.4 | | 80.8 | | 107.2 | | 16.6 | | 26.0 | |
| | | | | | | | | | | | | |
| Wind Pgen/Total Pgen | 0.2% | | 0.7% | | 0.0% | | 0.0% | | 1.9% | | 0.0% | |
| Kt | 32.4% | | 40.7% | | 20.5% | | 38.8% | | 27.4% | | 27.2% | |

- Same generation dispatch as MMWG Reduced Kt case
- Add load controller (generation withdrawal)

Case 1: Clean MMWG

From NREL/GE Eastern Frequency Response Study - 2012

Case 7: Governor and Inertial Response from WTGs

imagination at work

Preliminary Proposal Not for Further Distribution or Citation

# Outline

- Study Objectives and Background
- Task 1 - Define Study Databases and Establish Initial Conditions
- Task 2 - Evaluate WECC Frequency Response
- Task 3 - Evaluate WECC Transient Stability
- Task 4 - Evaluate Factors Affecting Dynamic Performance
- Task 5 - Evaluate Mitigation Measures
- Task 6 - Final Report
- Discussion

# Task 2 - Evaluate WECC Frequency Response

- Disturbance: 2x Palo Verde NPS trip event; (NERC BAL-003 design basis event)
- Renewables without frequency responsive controls

# Generation Summary for Weekend Morning – High CAISO Wind and Solar Base Case

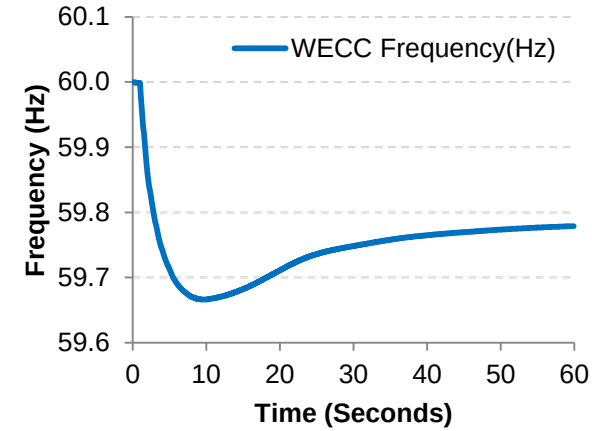
| | WECC | | CA | | Non-CA | |
|---|---|---|---|---|---|---|
| | | # of Units | | # of Units | | # of Units |
| GR Pgen (MW) | 48529 | 808 | 5514 | 127 | 43015 | 681 |
| GR MWCAP (MW) | 65984 | | 9785 | | 56199 | |
| GR Headroom (MW) | 17455 | | 4271 | | 13184 | |
| BL Pgen (MW) | 35116 | 381 | 9477 | 155 | 25639 | 226 |
| NG Pgen (MW) | 10972 | 460 | 1757 | 121 | 9215 | 339 |
| Wind Pgen (MW) | 12720 | | 8645 | | 3386 | |
| Solar Pgen (MW) | 6810 | | 6666 | | 144 | |
| | | | | | | |
| MW Capability | 131602 | | 36330 | | 94583 | |
| CU Pgen (MW) (GR + BL + NG) | 94617 | 1649 | 16748 | 403 | 77869 | 1246 |
| Total Pgen (MW) | 114775 | | 30525 | | 84250 | |
| Total Load (MW) | 110798 | | 35155 | | 75643 | |
| | | | | | | |
| Wind Pgen/Total Pgen | 11.1% | | 28.3% | | 4.0% | |
| Solar Pgen/Total Pgen | 5.9% | | 21.8% | | 0.2% | |
| Kt | 50.1% | | 26.9% | | 59.4% | |
| GR Pgen/CU Pgen | 51.3% | 49.0% | 32.9% | 31.5% | 55.2% | 54.7% |
| [illegible] | 42.3% | | 18.1% | | 51.1% | |
| [illegible] | 18.4% | | 25.5% | | 16.9% | |
| [illegible] | 15.2% | | 14.0% | | 15.6% | |

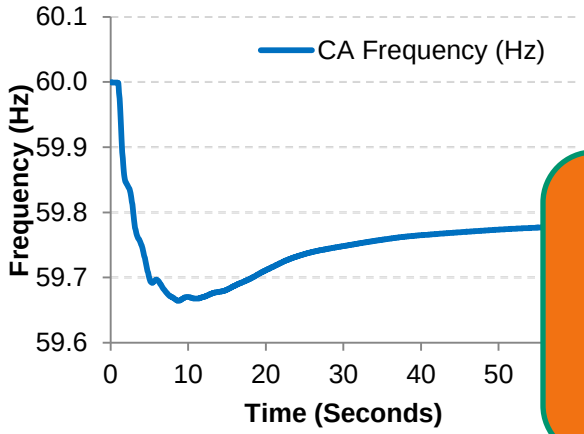
From GE/CAISO California Frequency Response Study - 2011

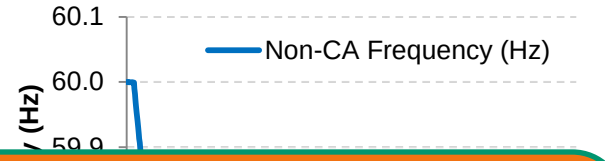
**Penetration of wind and solar generation in California is 50%**

# Frequency and Governor Response to Loss of Two Palo Verde Units

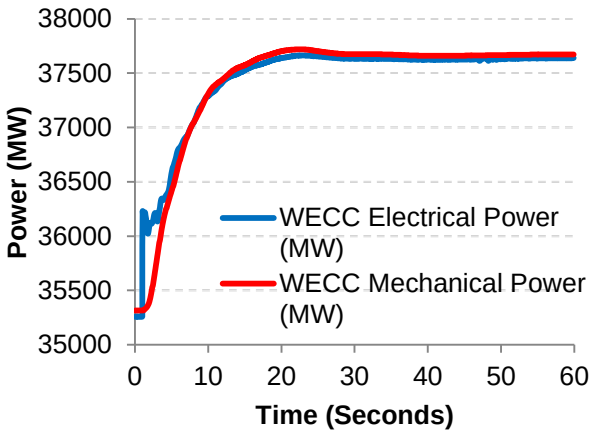
## Winter Low Load – High CAISO Wind Base Case

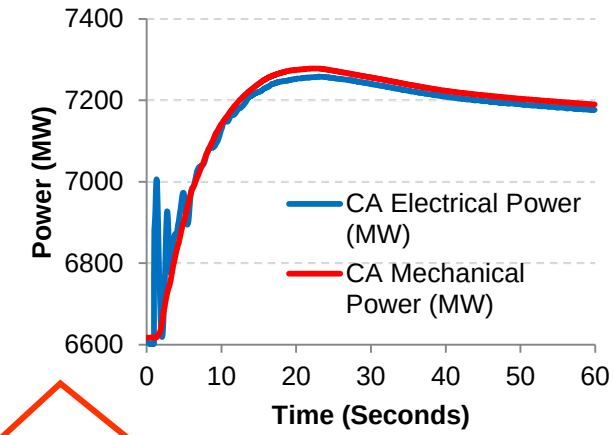


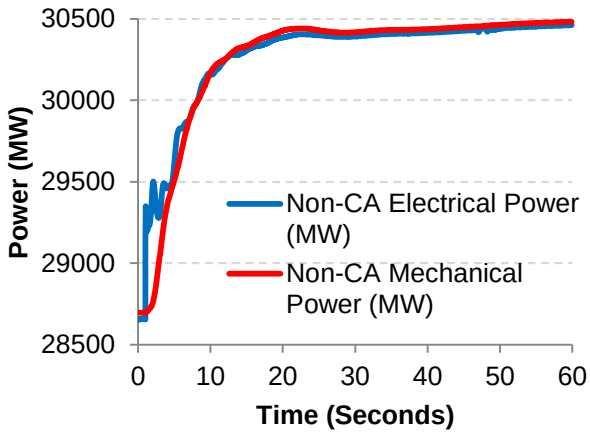




From GE/CAISO California Frequency Response Study - 2011



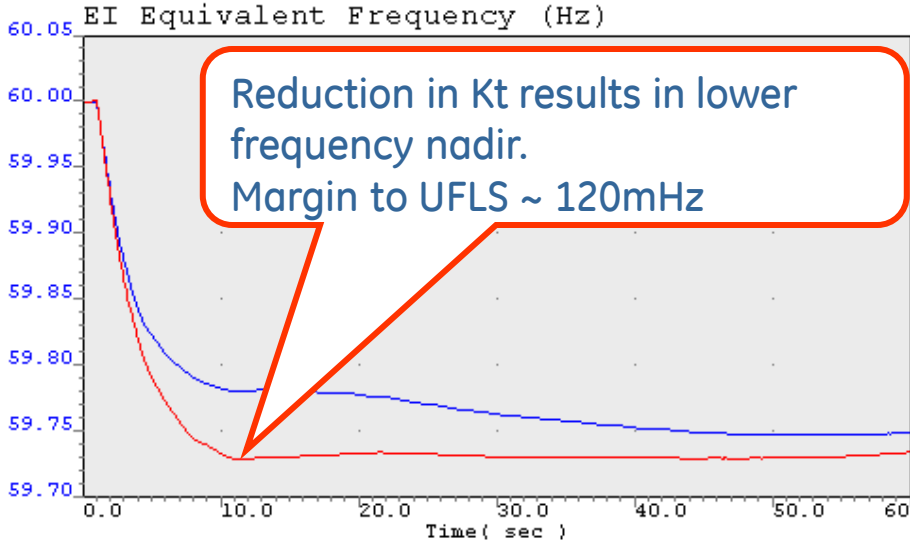



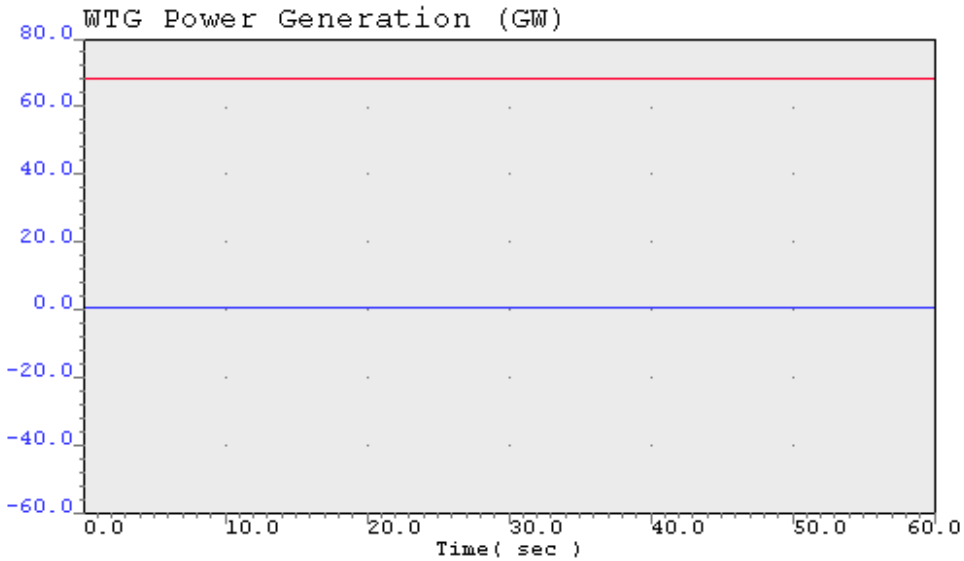

Governor responsive generation only

imagination at work

# Frequency and Governor Response to Loss of 4455 MW Generation - High Wind Penetration Case

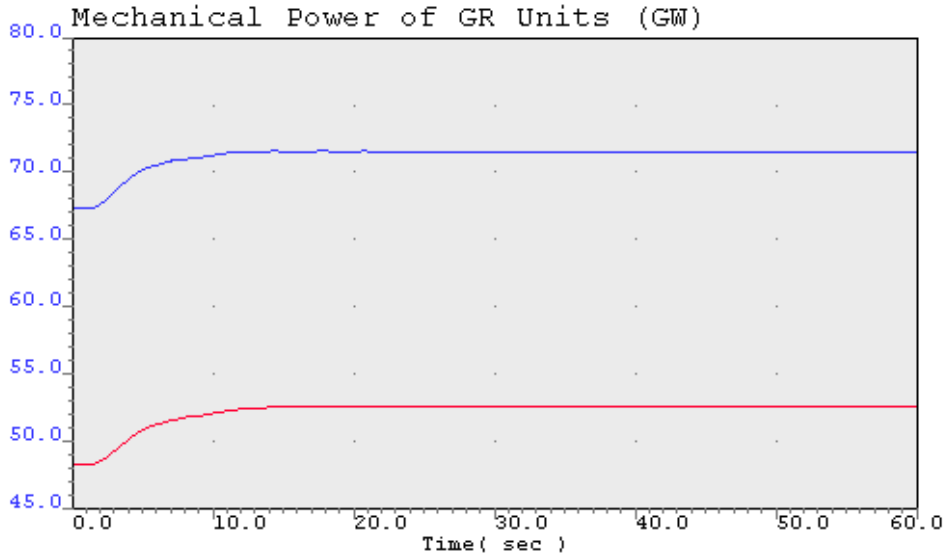



Reduction in Kt results in lower frequency nadir.
Margin to UFLS ~ 120mHz




Case 1: Clean MMWG

Case 2: MMWG Reduced Kt




From NREL/GE Eastern Frequency Response Study - 2012

imagination at work



Preliminary Proposal Not for Further Distribution or Citation

# Outline

- Study Objectives and Background
- Task 1 - Define Study Databases and Establish Initial Conditions
- Task 2 - Evaluate WECC Frequency Response
- Task 3 - Evaluate WECC Transient Stability
- Task 4 - Evaluate Factors Affecting Dynamic Performance
- Task 5 - Evaluate Mitigation Measures
- Task 6 - Final Report
- Discussion

# Task 3 - Evaluate WECC Transient Stability

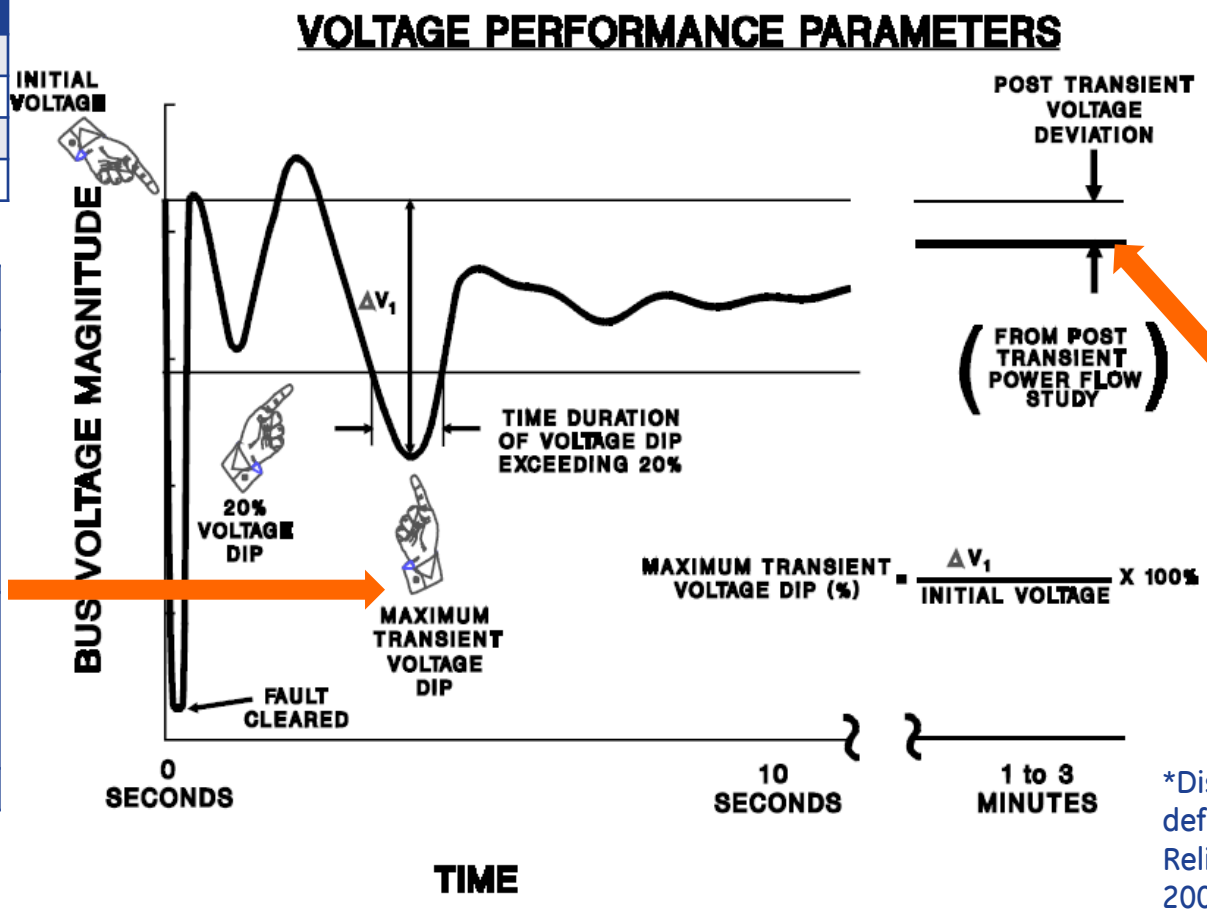
- Multiple critical disturbances for transient stability will be evaluated.
- Candidate events (e.g. from Path Handbook)
  - Fault & Trip Palo Verde – Devers
  - 1 Pole PDCI
  - Fault & Trip a COI Line
  - Fault & Trip a Bridger or Colstrip Line
  - Others
- Impose WECC stability criteria
- Particular attention to separation events

# WECC Reliability Criteria

## - Addition to NERC requirement

| Disturbance Class | Outage Frequency Associated with Performance Category |
|---|---|
| A | NA |
| B | ≥ 0.33 |
| C | 0.033-0.33 |
| D | <0.033 |

| Disturbance Class | Transient Voltage Dip |
|---|---|
| A | NERC |
| B | Not to exceed 25% at load buses or 30% at non-load buses. Not to exceed 20% for more than 20 cycles at load buses. |
| C | Not to exceed 30% at any bus. Not to exceed 20% for more than 40 cycles at load buses. |
| D | NERC |




| Disturbance Class | Minimum Transient Frequency Standard |
|---|---|
| A | NERC |
| B | Not below 59.6 Hz for 6 cycles or more at a load bus. |
| C | Not below 59.0 Hz for 6 cycles or more at a load bus. |
| D | NERC |

| Disturbance Class | Post Transient Voltage Deviation Standard |
|---|---|
| A | NERC |
| B | Not to exceed 5% at any bus |
| C | Not to exceed 10% at any bus |
| D | NERC |

*Disturbance category is defined in the WECC Reliability Criteria, April 2003

imagination at work

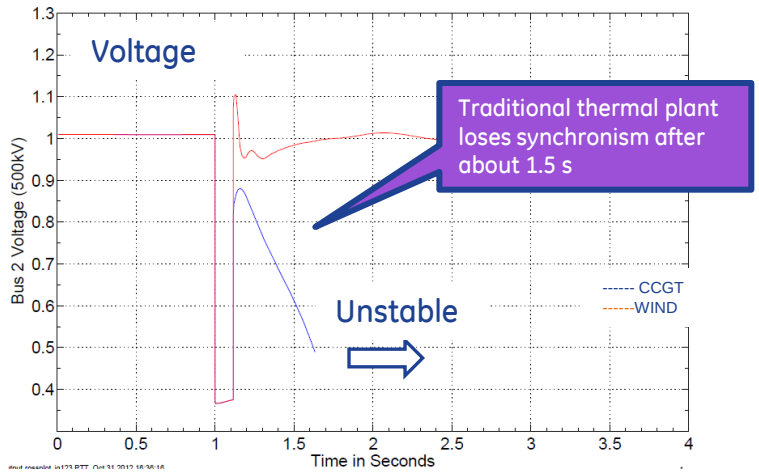


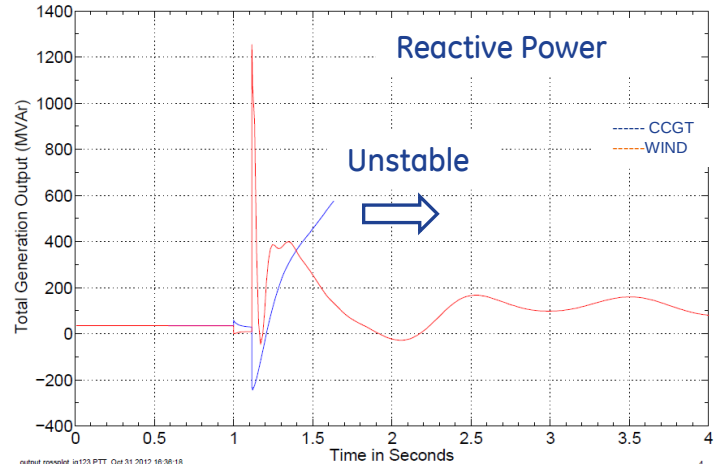
Copyright 2012 General Electric Company. All Rights Reserved.
This material may not be copied or distributed in whole or in part, without prior written permission of the copyright owner.

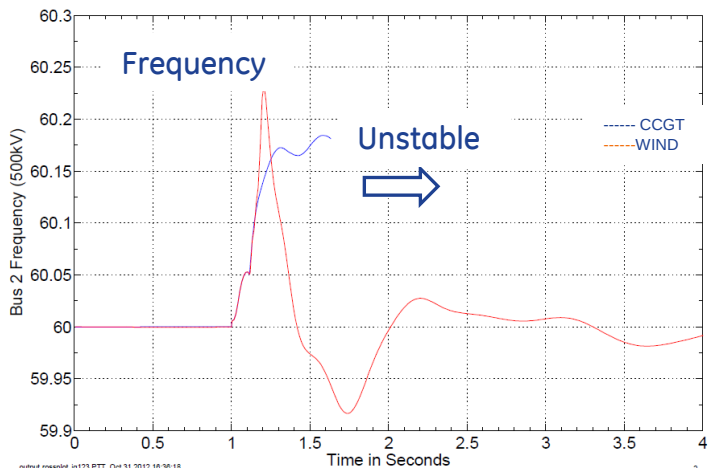
# Transient Stability CCGT vs Wind Plant

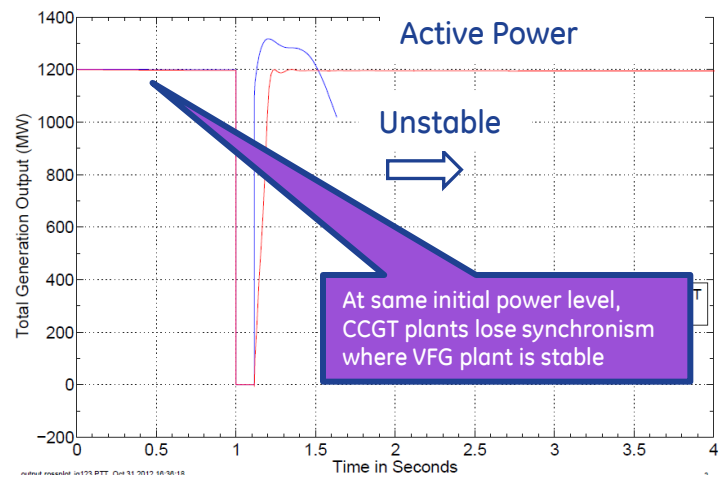
## - 230kV Fault at 100% Output (1200MW)

From GE Internal Study - 2012




Full power operation of conventional plant violates reliability criteria

imagination at work

# Outline

- Study Objectives and Background
- Task 1 - Define Study Databases and Establish Initial Conditions
- Task 2 - Evaluate WECC Frequency Response
- Task 3 - Evaluate WECC Transient Stability
- Task 4 - Evaluate Factors Affecting Dynamic Performance
- Task 5 - Evaluate Mitigation Measures
- Task 6 - Final Report
- Discussion

# Task 4 - Evaluate Factors Affecting Dynamic Performance

- Sensitivity Cases
  - Kt;  sensitivity to initial loading; commitment strategies.
  - Speed of response (for frequency)
  - Reactive compensation and voltage control (for transient stability)
  - Interface Loading



Preliminary Proposal Not for Further Distribution or Citation

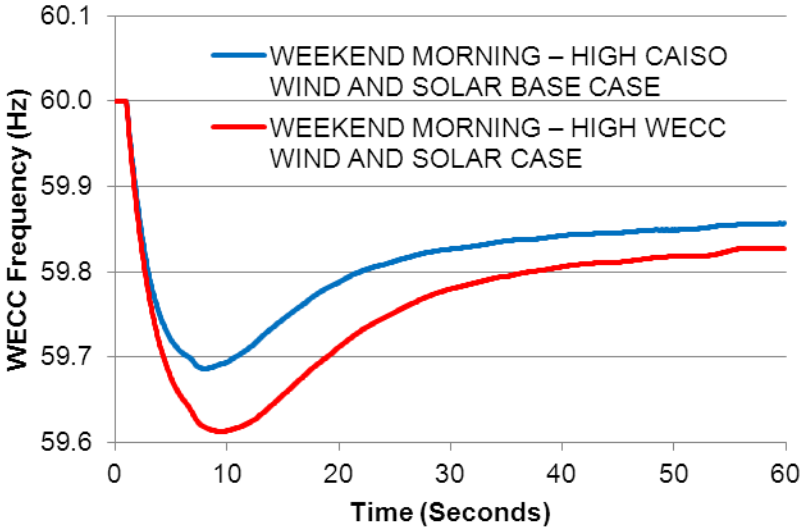
# Comparison of Impact of Increasing Levels of Wind on Frequency Performance to Loss of Two Palo Verde Units

More wind has worse but acceptable frequency response.

California's frequency response improves (from 287 to 311 MW/0.1 Hz – well above the 205 MW/0.1Hz target) .

The fractional contribution in California increases greatly, from 20% to 27%.

The behavior of resources outside of California has

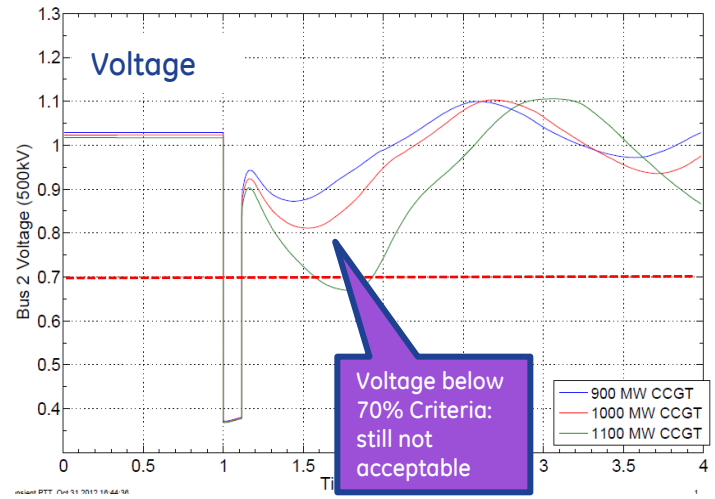


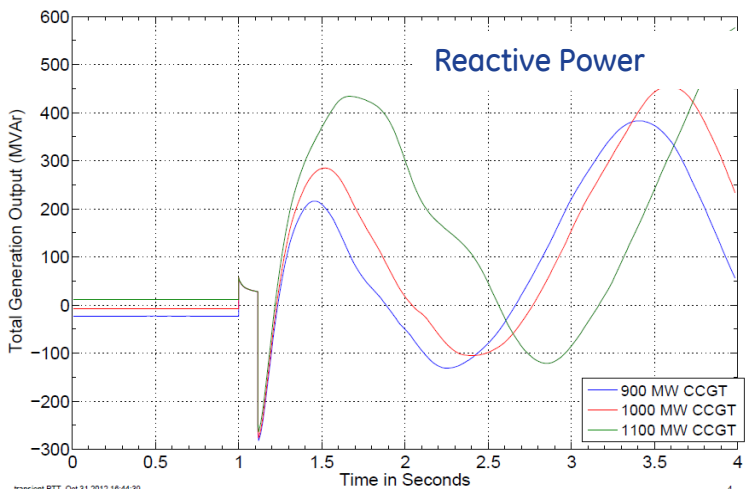

| | Weekend Morning – High CAISO Wind and Solar Base Case | | | Weekend Morning – High WECC Wind and Solar Case | | |
|---|---|---|---|---|---|---|
| | WECC | CA | Non-CA | WECC | CA | Non-CA |
| Frequency Nadir (Hz) | 59.69 | 59.68 | 59.68 | 59.61 | 59.61 | 59.61 |
| Frequency Nadir Time (Seconds) | 8.0 | 8.8 | 7.8 | 9.7 | 9.9 | 9.1 |
| LBNL-Nadir Based Frequency Response (MW/0.1Hz) | 858 | 852 | 853 | 695 | 684 | 697 |
| GE-CAISO Nadir Based ncy Response (MW/0.1Hz) | 658 | 134 | 503 | 515 | 140 | 354 |
| f Total (%) | | 20.0 | 76.0 | | 27.0 | 69.0 |
| requency (Hz) | 59.86 | 59.85 | 59.86 | 59.83 | 59.82 | 59.83 |
| equency Response Hz) | 1878 | 1824 | 1893 | 1565 | 1520 | 1578 |
| O Settling Based y Response (MW/0.1Hz) | 1440 | 287 | 1116 | 1158 | 311 | 802 |
| f Total (%) | | 20.0 | 78.0 | | 27.0 | 69.0 |

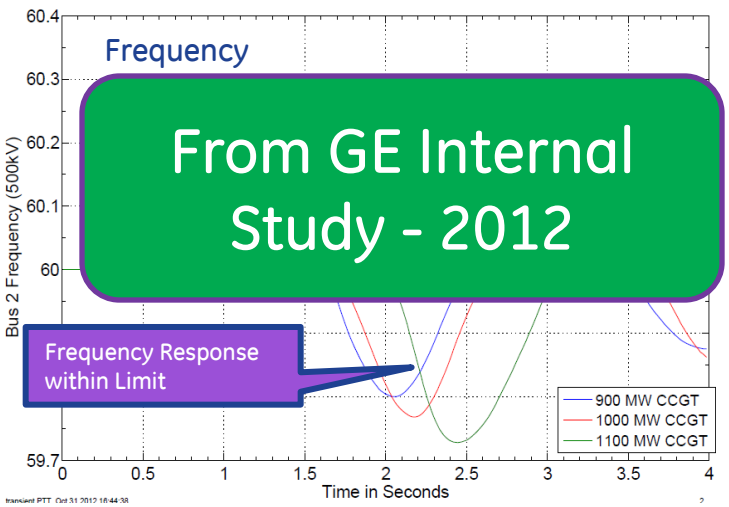
From GE/CAISO California Frequency Response Study - 2011

# Transient Stability Example

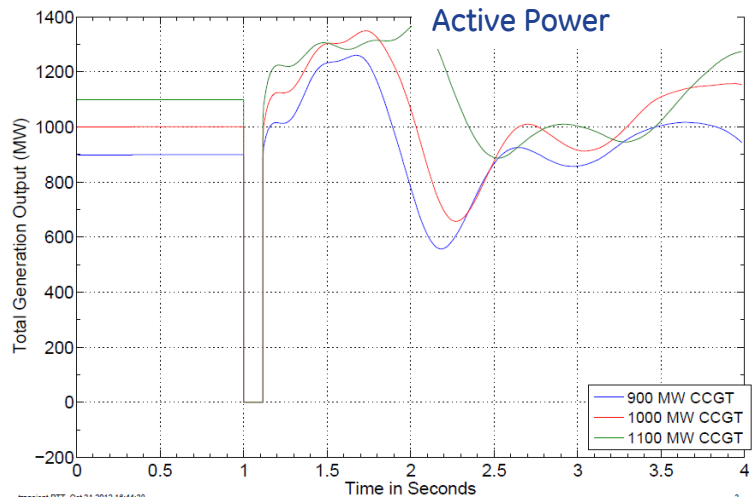
## - 230kV Fault: reducing power dispatch to maintain satisfactory stability performance




From GE Internal Study - 2012




imagination at work

Power reduction of about 10% (~120MW) required for conventional plant to meet transient stability criteria

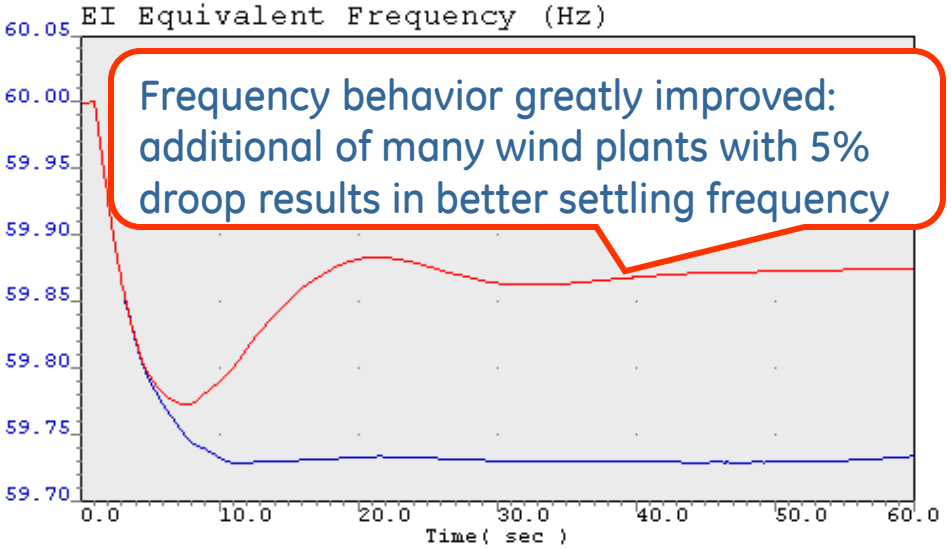
# Outline

- Study Objectives and Background
- Task 1 - Define Study Databases and Establish Initial Conditions
- Task 2 - Evaluate WECC Frequency Response
- Task 3 - Evaluate WECC Transient Stability
- Task 4 - Evaluate Factors Affecting Dynamic Performance
- Task 5 - Evaluate Mitigation Measures
- Task 6 - Final Report
- Discussion

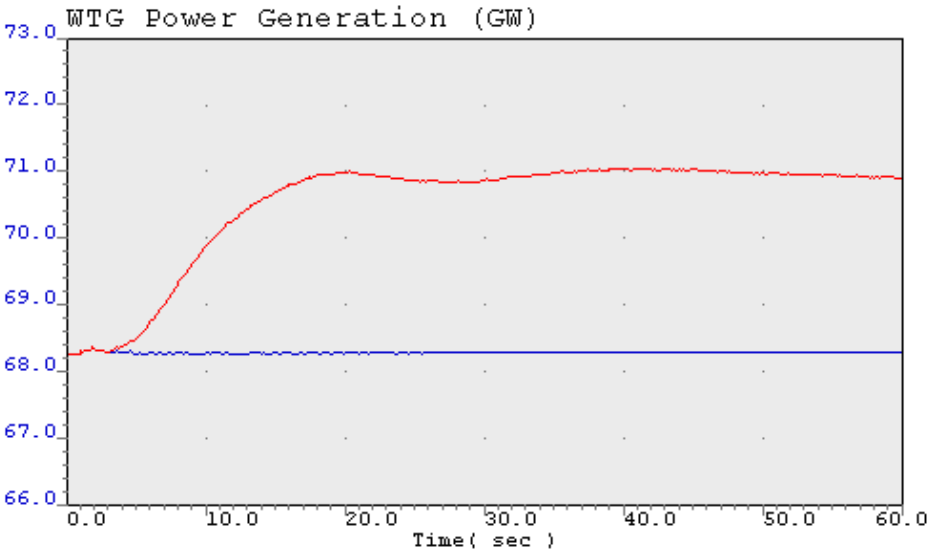
# Task 5 - Evaluate Mitigation Measures

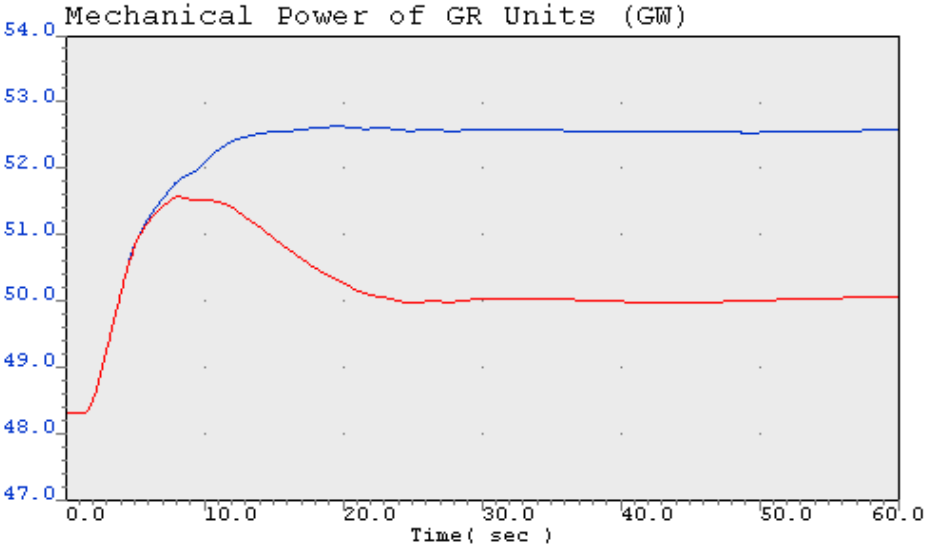
- Explore means to improve performance and reduce constraints
- Candidate measures may include:
  - Changes to unit commitment/dispatch procedures
  - Changes to spinning reserve requirements
  - Governor and Inertial controls on wind plants
  - Modified reactive power and voltage control strategies on wind and solar plants
  - RAS and WAMS strategies
  - Addition or reinforcement of transmission lines
  - Other measures, e.g. energy storage, load participation
  - Selected combinations of the above Selection of measures will be based on characteristics of performance and limitations observed.
  - Not exhaustive.

# Frequency and Governor Response to Loss of 4455 MW Generation - Governor Response from WTGs Case




Frequency behavior greatly improved: additional of many wind plants with 5% droop results in better settling frequency




Case 1: Clean MMWG

Case 2: MMWG Reduced Kt

onse from WTGs

or and Inertial
e from WTGs

From NREL/GE Eastern Frequency Response Study - 2012

imagination at work



Preliminary Proposal Not for Further Distribution or Citation

# Balancing Authority FR - Governor Response from WTGs Case

From NREL/GE Eastern Frequency Response Study - 2012

| | FR [MW/0.1 Hz] | | | % of EI FR total | FRO** | |
|---|---|---|---|---|---|---|
| | GR | Wind | Total | | | |
| EI | 1325 | 2126 | 3541 | 100 | 1406* | |
| NPCC | 417 | 553 | 970 | 27.4 | 218 | |
| PJM | 78 | 1054 | 1132 | 32.0 | 414 | |
| SERC/FLA | 668 | 0 | 668 | 18.9 | 559 | |
| SPP | 76 | 204 | 282 | 8.0 | 85 | |
| MISO | 86 | 317 | 403 | 11.4 | 130 | 273 |

*based on Attachment A BAL-003-1 Frequency Response and Frequency Bias Setting Supporting Document, February 21, 2012 (EI FRO = 1406 MW/0.1 Hz)

** based on our load flow case and EI FRO= 1406 MW/0.1 Hz from Attachment A BAL-003-1 Frequency Response and Frequency Bias Setting Supporting Document, February 21, 2012

| | FR [MW/0.1 Hz] | | | % of EI FR total | FRO** | Margin FRO**-FR |
|---|---|---|---|---|---|---|
| | GR | Wind | Total | | | |
| EI | 1325 | 2126 | 3541 | 100 | 1002# | 2539 |
| NPCC | 417 | 553 | 970 | 27.4 | 155 | 815 |
| PJM | 78 | 1054 | 1132 | 32.0 | 295 | 837 |
| SERC/FLA | 668 | 0 | 668 | 18.9 | 399 | 269 |
| SPP | 76 | 204 | 282 | 8.0 | 61 | 221 |
| MISO | 86 | 317 | 403 | 11.4 | 93 | 310 |

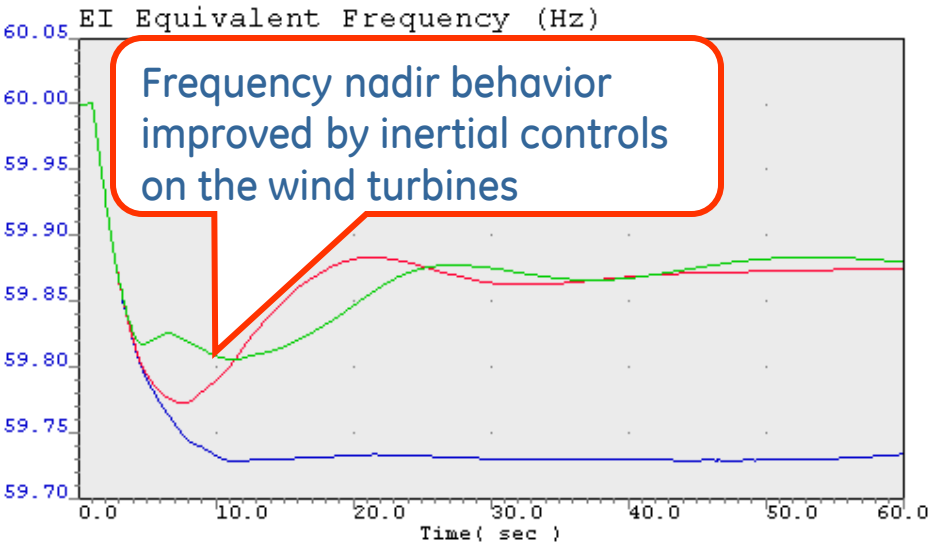
#based on Attachment A BAL-003-1 Frequency Response and Frequency Bias Setting Supporting Document, October 1, 2012 (EI FRO = 1002 MW/0.1 Hz)

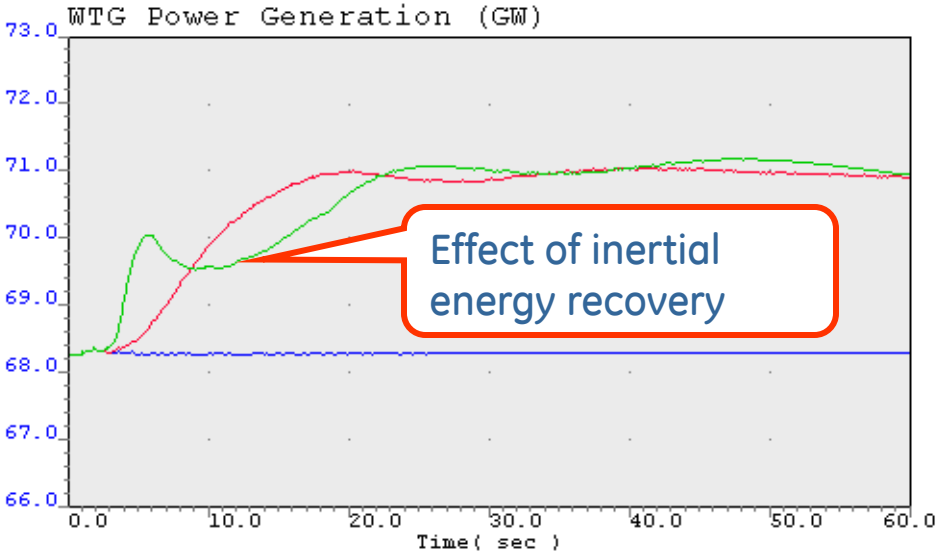
** based on our load flow case and EI FRO = 1002 MW/0.1 Hz from Attachment A BAL-003-1 Frequency Response and Frequency Bias Setting Supporting Document, October 1, 2012

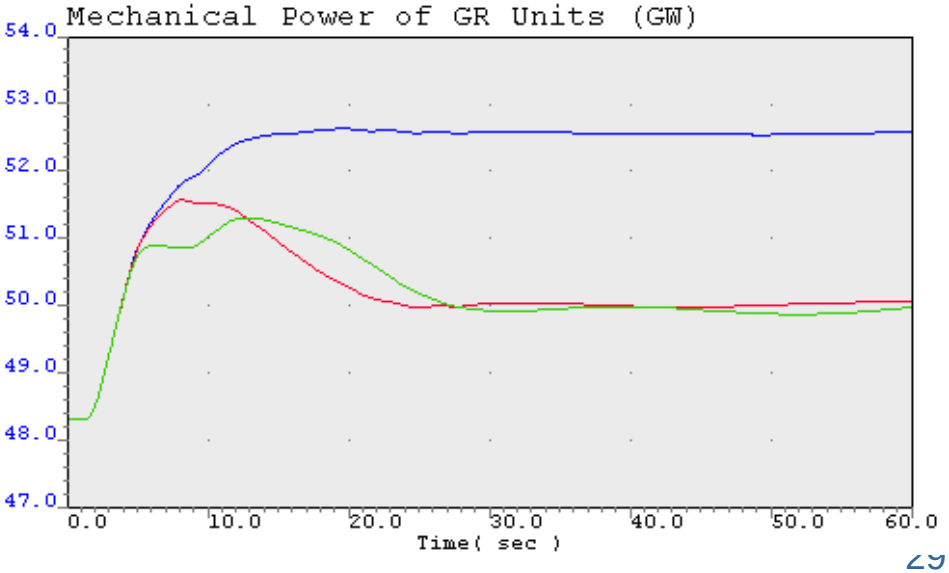


Preliminary Proposal Not for Further Distribution or Citation

# Frequency and Governor Response to Loss of 4455 MW Generation - Governor and Inertial Response from WTGS Case (with High Wind)




Case 1: Clean MMWG

Case 2: MMWG Reduced Kt

onse from WTGs

nor and Inertial
Response from WTGs

From NREL/GE Eastern Frequency Response Study - 2012

imagination at work

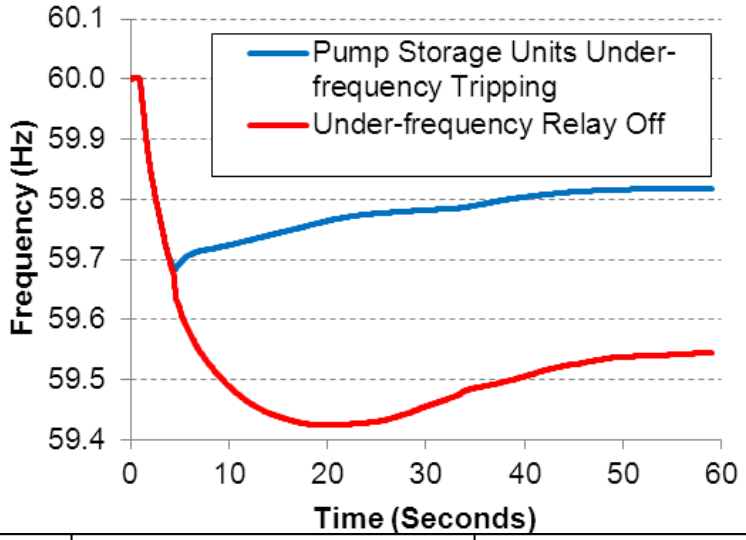


Preliminary Proposal Not for Further Distribution or Citation

# Mitigation Measures – Load Control/Fast Energy Storage

Raised the tripping threshold of pumps and pumped storage hydro plants to 59.7 Hz.

Tripping of 1379 MW of pump motor load immediately arrests the frequency decline.




| | Winter Low Load – High WECC Wind Case – Extreme Minimum Headroom | | | Winter Low Load – High WECC Wind Case – Extreme Minimum Headroom – Pump Storage Units Under-frequency Tripping | | |
|---|---|---|---|---|---|---|
| | WECC | CA | Non-CA | WECC | CA | Non-CA |
| Frequency Nadir (Hz) | 59.42 | 59.42 | 59.43 | 59.68 | 59.68 | 59.68 |
| Frequency Nadir Time (Seconds) | 20.7 | 18.8 | 20.7 | 4.6 | 4.6 | 4.6 |
| LBNL-Nadir Based Frequency Response (MW/0.1Hz) | 467 | 461 | 468 | 847 | 843 | 844 |
| GE-CAISO Nadir Based Frequency 0.1Hz) | 336 | 118 | 213 | 349 | 301 | 46 |
| %) | | 35.1 | 63.3 | | 86.2 | 13.1 |
| (Hz) | 59.54 | 59.55 | 59.56 | 59.82 | 59.82 | 59.82 |
| Response | 590 | 592 | 606 | 1471 | 1475 | 1474 |
| g Based nse (MW/0.1Hz) | 424 | 152 | 275 | 607 | 527 | 81 |
| Percent of total (%) | | 35.8 | 64.9 | | 86.8 | 13.3 |

From GE/CAISO California Frequency Response Study - 2011

# Outline

- Study Objectives and Background
- Task 1 - Define Study Databases and Establish Initial Conditions
- Task 2 - Evaluate WECC Frequency Response
- Task 3 - Evaluate WECC Transient Stability
- Task 4 - Evaluate Factors Affecting Dynamic Performance
- Task 5 - Evaluate Mitigation Measures
- Task 6 - Final Report
- Discussion

# THANK YOU

nicholas.miller@ge.com



Preliminary Results: Not for Further Distribution or Citation