GE
Energy

# Western Wind & Solar Integration Study

## Project Overview & Scenario Description

Dick Piwko

Stakeholder Meeting
February 9, 2010

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# Variability and Uncertainty

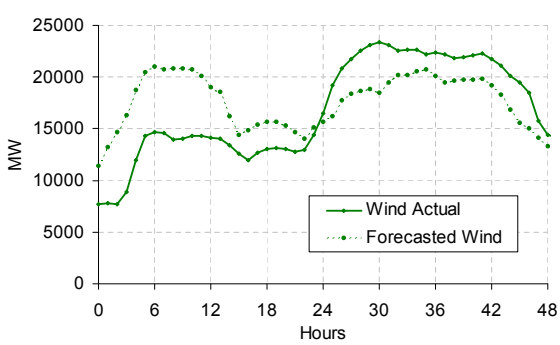
**Variability:** Wind and solar generator outputs vary as the intensity of their energy sources (wind and sun)

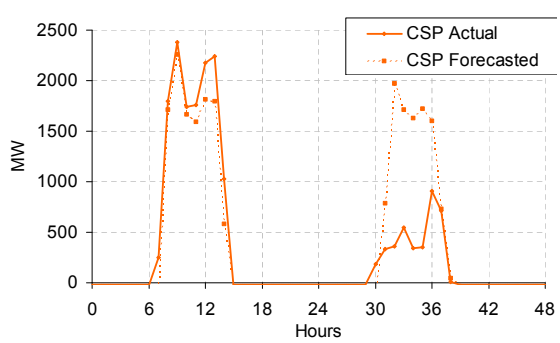
- Several timescales: minute (regulation), hour (ramping), diurnal, seasonal

**Uncertainty:** Wind and solar generation are similar to "load"

- Not dispatchable – output is predicted by a forecast
- Actual power output is different that forecast output

A perfect forecast eliminates **uncertainty**, but there is still **variability**



# Scenario Overview

- 2017 Study Year
- 2004, 2005, 2006 Load Shapes Escalated to 2017
- Wind and Solar Penetration Levels (% Energy)

| In Footprint | | Rest of WECC | |
|---|---|---|---|
| **Wind** | **Solar** | **Wind** | **Solar** |
| 10% | 1% | 10% | 1% |
| 20% | 3% | 10% | 1% |
| 20% | 3% | 20% | 3% |
| 30% | 5% | 20% | 3% |

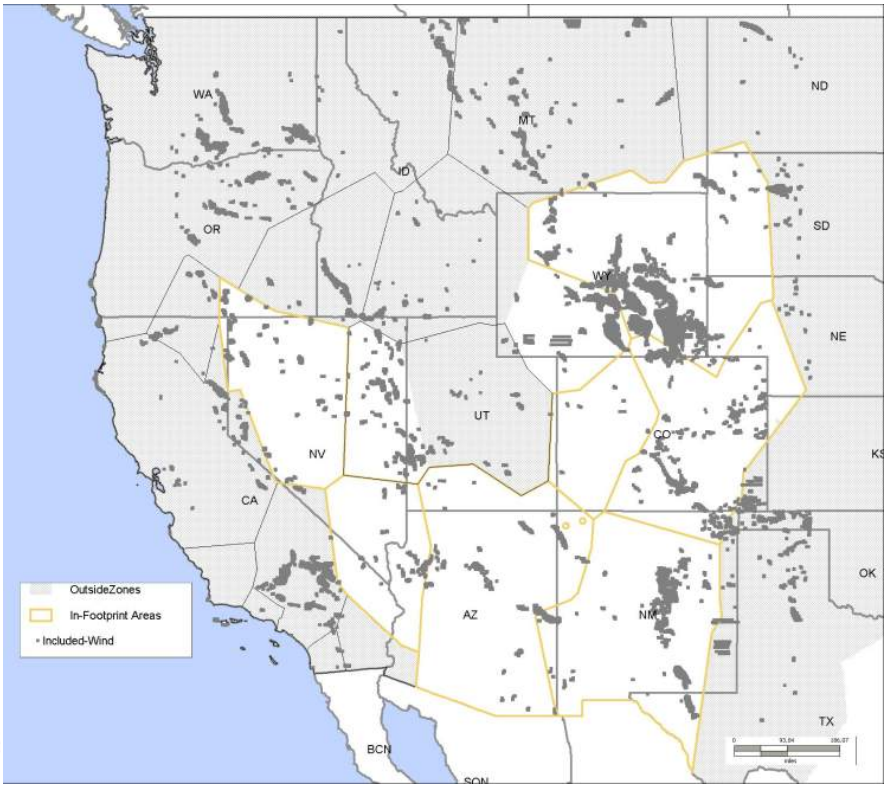
- Solar Mix
  - 70% Concentrating Solar Plant with Storage (CSP w/S)
  - 30% Photo-voltaic (PV)



# Scenarios

- Baseline: No new renewables
- In-Area: Each state meets its wind and solar energy target from sources within that state
- Mega-Project: Concentrate projects in best resource areas for maximum cost benefit
- Local-Priority: Balance of best resource and in-area sites

# Available Wind Sites

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# Available Solar Sites

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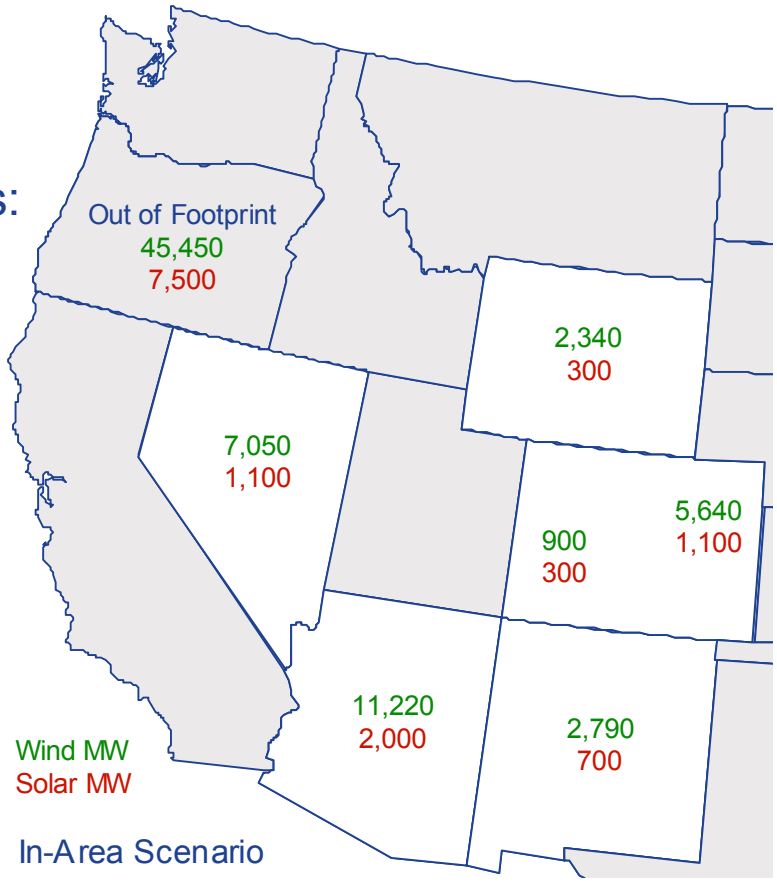
# In-Area Scenario

Footprint has:
30% Wind
5% Solar

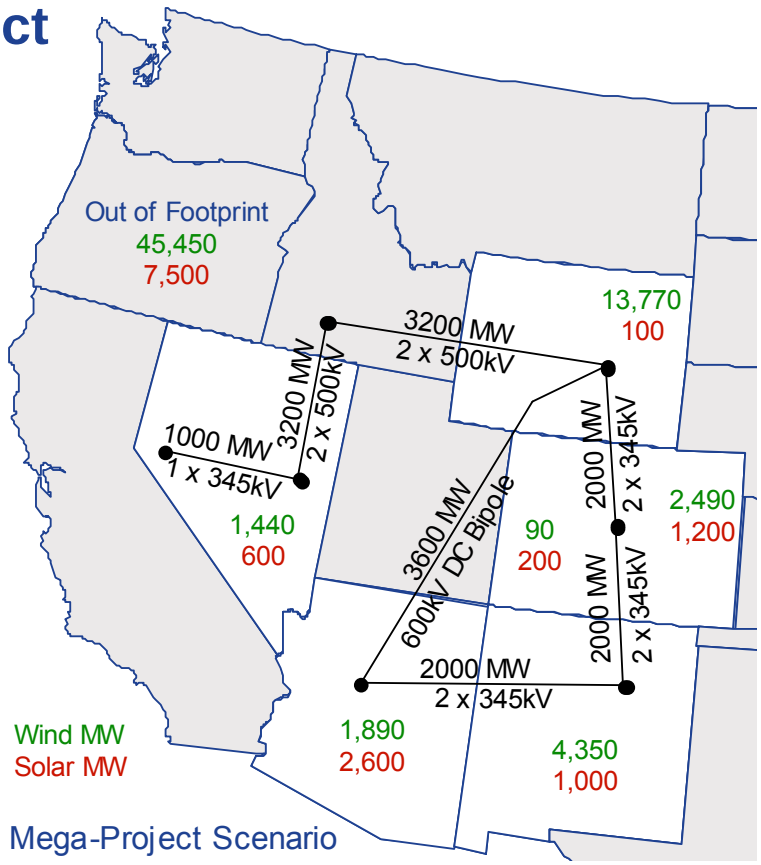



In-Area Scenario



# Mega-Project Scenario

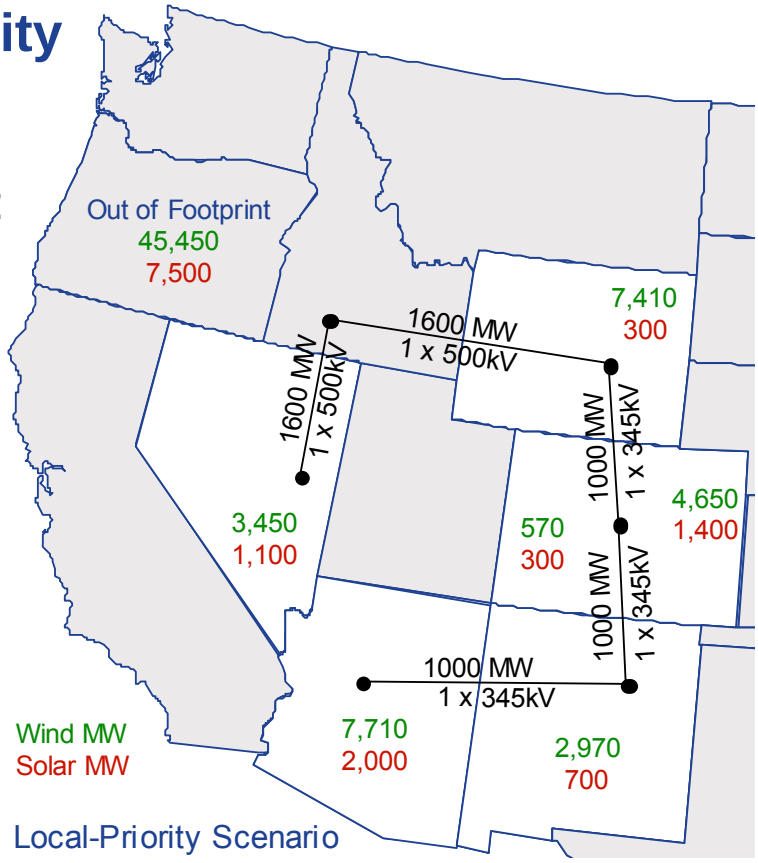
Footprint has:
30% Wind
5% Solar




Mega-Project Scenario

# Local-Priority Scenario

Footprint has:
30% Wind
5% Solar

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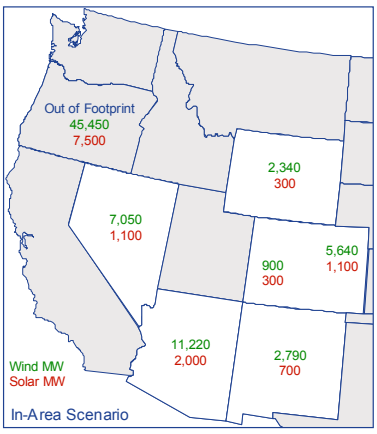
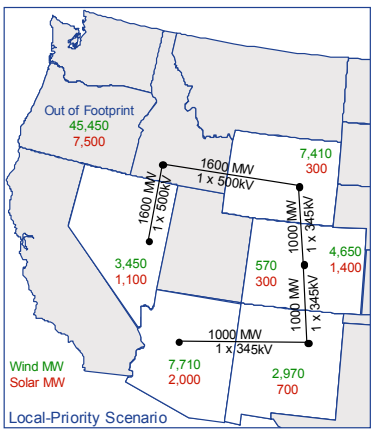
Local-Priority Scenario

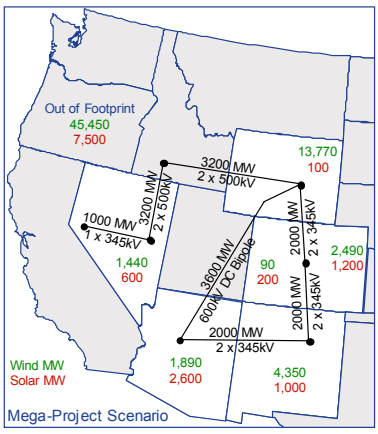


# Capital Costs: Wind, Solar, Transmission

| Scenario | Wind MW | Solar MW | Transmission (GW-mi) | Wind Cost ( $B ) | Solar Cost ( $B ) | Transmission Cost ( $B ) | Total Cost ( $B ) | Delta ( $B ) |
|---|---|---|---|---|---|---|---|---|
| In-Area | 29,940 | 5,800 | 0 | 59.9 | 23.2 | 0.0 | 83.1 | |
| Local-Priority | 26,760 | 5,800 | 2,100 | 53.5 | 23.2 | 3.4 | 80.1 | -3.0 |
| Mega-Project | 24,030 | 5,700 | 6,900 | 48.1 | 22.8 | 11.0 | 81.9 | -1.2 |

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# Scenario Overview

**In Area**

| Area | Load Minimum (MW) | Load Maximum (MW) | 10% Wind Rating (MW) | 1% Solar Rating (MW) | 20% Wind Rating (MW) | 3% Solar Rating (MW) | 30% Wind Rating (MW) | 5% Solar Rating (MW) |
|---|---|---|---|---|---|---|---|---|
| Arizona | 6,995 | 23,051 | 3,600 | 400 | 7,350 | 1,200 | 11,220 | 2,000 |
| Colorado East | 4,493 | 11,589 | 2,040 | 300 | 3,780 | 800 | 5,640 | 1,400 |
| Colorado West | 712 | 1,526 | 300 | 0 | 600 | 200 | 900 | 300 |
| New Mexico | 2,571 | 5,320 | 1,080 | 200 | 1,920 | 400 | 2,790 | 700 |
| Nevada | 3,863 | 12,584 | 2,340 | 200 | 4,680 | 700 | 7,050 | 1,100 |
| Wyoming | 2,369 | 4,016 | 930 | 100 | 1,620 | 100 | 2,340 | 300 |
| **In Footprint** | **21,249** | **58,087** | **10,290** | **1,200** | **19,950** | **3,400** | **29,940** | **5,800** |

**Local Priority**

| Area | Load Minimum (MW) | Load Maximum (MW) | 10% Wind Rating (MW) | 1% Solar Rating (MW) | 20% Wind Rating (MW) | 3% Solar Rating (MW) | 30% Wind Rating (MW) | 5% Solar Rating (MW) |
|---|---|---|---|---|---|---|---|---|
| Arizona | 6,995 | 23,051 | 2,850 | 400 | 5,250 | 1,200 | 7,710 | 2,000 |
| Colorado East | 4,493 | 11,589 | 2,190 | 300 | 3,870 | 800 | 4,650 | 1,400 |
| Colorado West | 712 | 1,526 | 210 | 0 | 450 | 200 | 570 | 300 |
| New Mexico | 2,571 | 5,320 | 1,350 | 200 | 2,100 | 400 | 2,970 | 700 |
| Nevada | 3,863 | 12,584 | 1,350 | 200 | 2,490 | 700 | 3,450 | 1,100 |
| Wyoming | 2,369 | 4,016 | 1,650 | 100 | 4,020 | 100 | 7,410 | 300 |
| **In Footprint** | **21,249** | **58,087** | **9,600** | **1,200** | **18,180** | **3,400** | **26,760** | **5,800** |

**Mega Project**

| Area | Load Minimum (MW) | Load Maximum (MW) | 10% Wind Rating (MW) | 1% Solar Rating (MW) | 20% Wind Rating (MW) | 3% Solar Rating (MW) | 30% Wind Rating (MW) | 5% Solar Rating (MW) |
|---|---|---|---|---|---|---|---|---|
| Arizona | 6,995 | 23,051 | 810 | 400 | 1,260 | 1,800 | 1,890 | 2,600 |
| Colorado East | 4,493 | 11,589 | 2,010 | 300 | 2,400 | 400 | 2,490 | 1,200 |
| Colorado West | 712 | 1,526 | 60 | 0 | 90 | 0 | 90 | 200 |
| New Mexico | 2,571 | 5,320 | 1,860 | 400 | 2,700 | 1,000 | 4,350 | 1,000 |
| Nevada | 3,863 | 12,584 | 570 | 100 | 1,020 | 200 | 1,440 | 600 |
| Wyoming | 2,369 | 4,016 | 3,390 | 0 | 8,790 | 0 | 13,770 | 100 |
| **In Footprint** | **21,249** | **58,087** | **8,700** | **1,200** | **16,260** | **3,400** | **24,030** | **5,700** |

**All Scenarios**

| | | | 10% | 1% | 10% | 1% | 20% | 3% |
|---|---|---|---|---|---|---|---|---|
| **Out of Footprint** | **46,328** | **119,696** | **22,950** | **2,500** | **22,950** | **2,500** | **45,450** | **7,500** |

# The View from 50,000 Feet . . .

Production simulation analysis indicates that 35% energy penetration of wind and solar generation is technically feasible

- Technical details of statistical analysis, production simulation analysis, and sub-hourly quasi-steady-state (QSS) analysis show how system operation is affected
- Operations are dramatically different from what is typical now

This study investigates technical feasibility of high wind and solar penetration

- "Can you do this?" is the focus of this study
- "What do you need to do to get there?" is explored to some extent
- "Should you do this?" is a policy and economic issue, beyond our scope

*Huge volume of technical analysis has been performed on this project*

- *Summarize key findings this morning*
- *Discuss recent results on sub-hourly reserves this afternoon*
- *Followed by moderated discussion . . . . . .*

# GE Project Team

Dick Piwko
Kara Clark
Lavelle Freeman
Gary Jordan
Nick Miller

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GE
Energy

# Western Wind & Solar Integration Study

## Key Findings

Gary Jordan
Lavelle Freeman
Kara Clark
Nick Miller

Stakeholder Meeting
February 9, 2010

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# Key Findings

- Is it Feasible to Accommodate 30% Wind and 5% Solar?
- What Makes This Possible?
- What Are Some of the Benefits?
- Are Increased Reserves or Storage Required?
- What Factors Have Large Economic Impacts?
- Is New Long Distance Transmission Required?



# Is it Feasible to Accommodate 30% Wind and 5% Solar?

# 1. Feasibility & Control Area Cooperation

"The technical analysis performed in this study shows that it is feasible for the West Connect region to accommodate 30% wind and 5% solar energy penetration, but it would require extensive control area cooperation or consolidation. Renewable energy penetration outside the WestConnect footprint is an important factor, as it significantly affects performance and economics of renewable energy operations within WestConnect."

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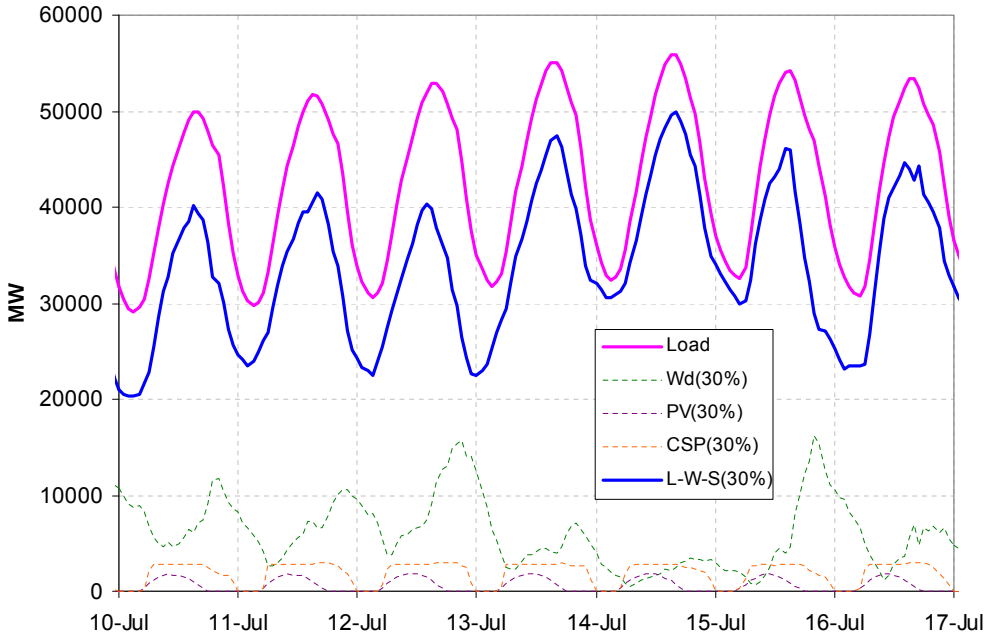
## Study Footprint Total Load, Wind and Solar Variation Week of July 10th

(30% IA Scenario)

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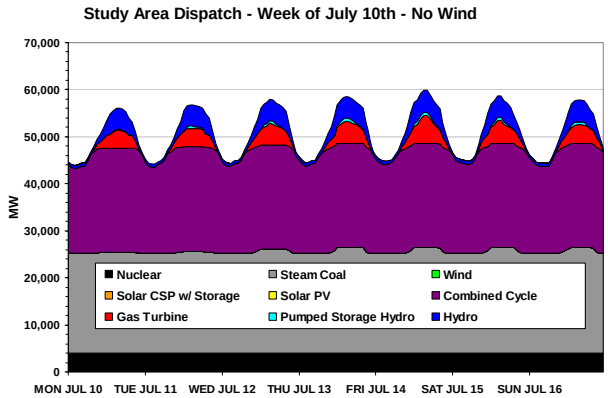
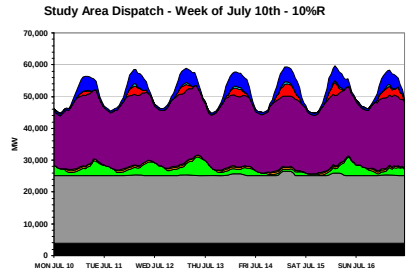
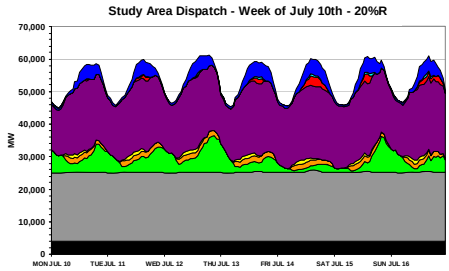
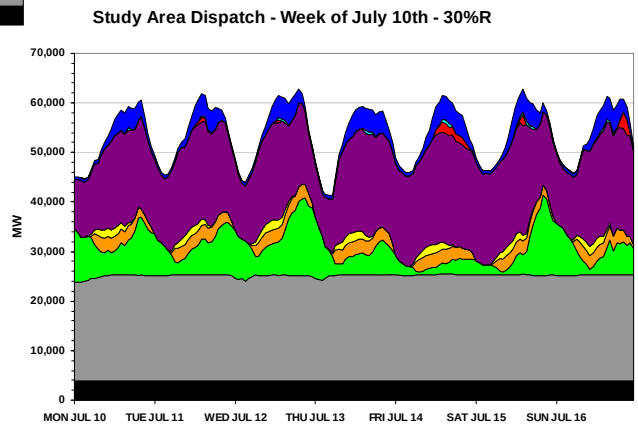
# Study Area Dispatch - Week Of July 10th (30% IA Scenario)

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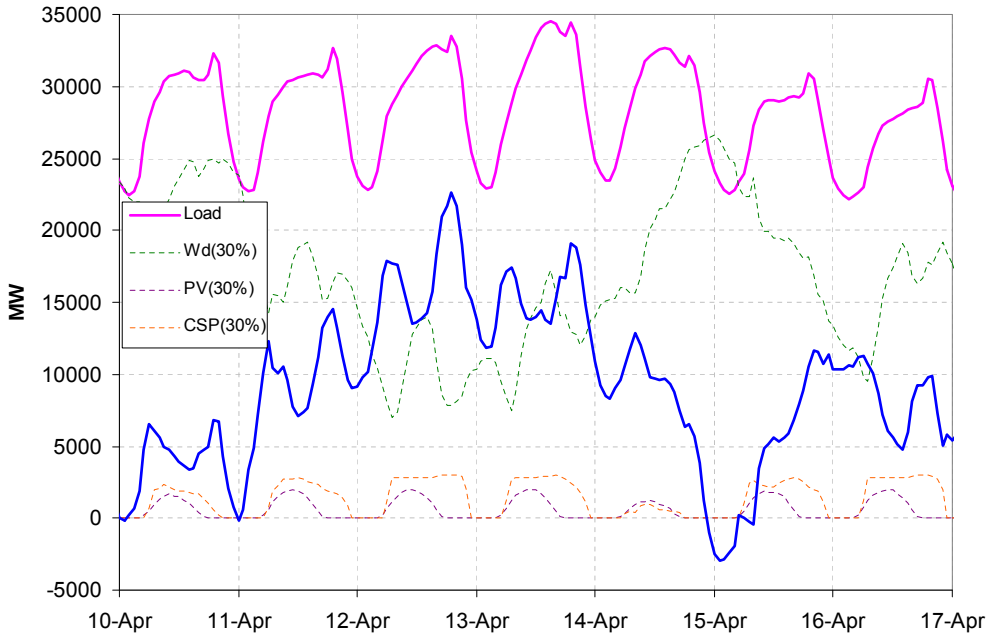
# Study Footprint Total Load, Wind and Solar Variation Week of April 10th

(30% IA Scenario)

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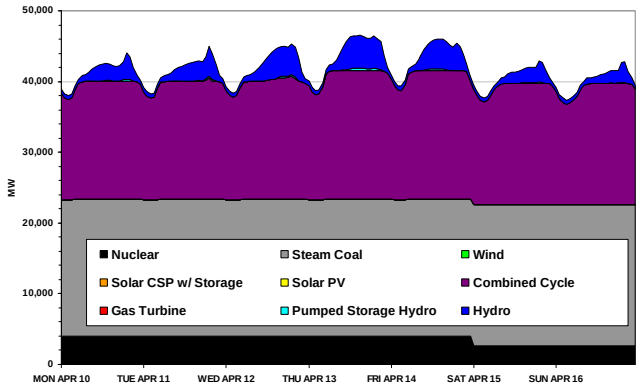
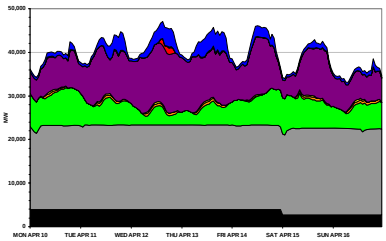
# Study Area Dispatch - Week Of April 10th (30% IA Scenario)

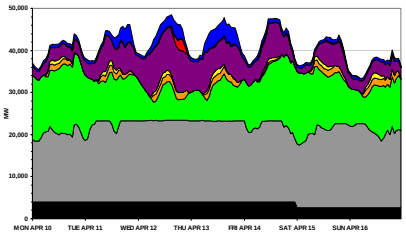
**Study Area Dispatch - Week of April 10th - No Wind**



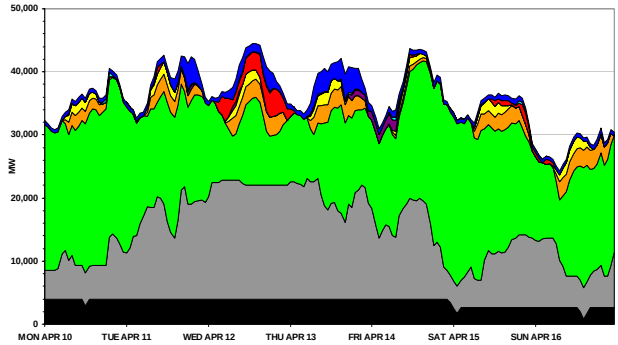

**Study Area Dispatch - Week of April 10th - 10%R**



**Study Area Dispatch - Week of April 10th - 20%R**



**Study Area Dispatch - Week of April 10th - 30%R**

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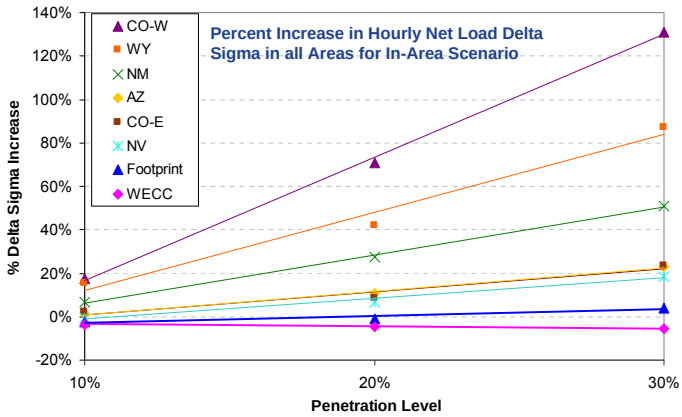
# Summary of Net Load One-Hour Variability by Area for All Scenarios

| Area: | Ariz | | | CO-E | | | CO-W | | | NM | | | NV | | | WY | | | Footprint | | | WECC | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | IA | LP | MP | IA | LP | MP | IA | LP | MP | IA | LP | MP | IA | LP | MP | IA | LP | MP | IA | LP | MP | IA | LP | MP |
| **Sigma (MW)** | | | | | | | | | | | | | | | | | | | | | | | | |
| Load-alone | 584 | 584 | 584 | 367 | 367 | 367 | 37 | 37 | 37 | 152 | 152 | 152 | 312 | 312 | 312 | 87 | 87 | 87 | 1433 | 1433 | 1433 | 4384 | 4384 | 4384 |
| Baseline (Existing) | 583 | 583 | 583 | 374 | 374 | 374 | 37 | 37 | 37 | 158 | 158 | 158 | 311 | 311 | 311 | 101 | 101 | 101 | 1429 | 1429 | 1429 | 4226 | 4392 | 4392 |
| 10% In FP Scenario | 591 | 587 | 573 | 375 | 377 | 376 | 44 | 41 | 38 | 162 | 170 | 192 | 311 | 315 | 311 | 101 | 118 | 188 | 1401 | 1414 | 1426 | 4229 | 4240 | 4248 |
| 20% In FP Scenario | 647 | 613 | 587 | 399 | 401 | 379 | 64 | 57 | 38 | 194 | 203 | 228 | 333 | 331 | 313 | 124 | 212 | 434 | 1417 | 1437 | 1480 | 4187 | 4209 | 4230 |
| 30% In FP Scenario | 719 | 657 | 616 | 453 | 427 | 380 | 86 | 73 | 40 | 230 | 240 | 288 | 370 | 352 | 317 | 164 | 366 | 658 | 1491 | 1523 | 1594 | 4134 | 4153 | 4182 |
| | Ariz | | | CO-E | | | CO-W | | | NM | | | NV | | | WY | | | In Foot Print | | | WECC | | |
| **Max Pos Delta (MW)** | IA | LP | MP | IA | LP | MP | IA | LP | MP | IA | LP | MP | IA | LP | MP | IA | LP | MP | IA | LP | MP | IA | LP | MP |
| Load-alone | 1601 | 1601 | 1601 | 1172 | 1172 | 1172 | 130 | 130 | 130 | 636 | 636 | 636 | 1234 | 1234 | 1234 | 505 | 505 | 505 | 3674 | 3674 | 3674 | 10715 | 10715 | 10715 |
| Baseline (Existing) | 1600 | 1600 | 1600 | 1692 | 1257 | 1257 | 130 | 130 | 130 | 605 | 605 | 605 | 1229 | 1229 | 1229 | 435 | 435 | 435 | 3793 | 3793 | 3793 | 10896 | 10896 | 10896 |
| 10% In FP Scenario | 1858 | 1852 | 1642 | 1479 | 1280 | 1266 | 202 | 157 | 131 | 616 | 626 | 887 | 1185 | 1170 | 1200 | 429 | 539 | 1290 | 4178 | 4178 | 3898 | 11299 | 10959 | 10983 |
| 20% In FP Scenario | 2732 | 2295 | 2165 | 1416 | 1445 | 1281 | 351 | 281 | 131 | 875 | 957 | 1120 | 1492 | 1394 | 1176 | 506 | 1537 | 3085 | 4853 | 4777 | 4499 | 11661 | 11366 | 12202 |
| 30% In FP Scenario | 3483 | 2771 | 2564 | 2097 | 1834 | 1364 | 512 | 373 | 152 | 1047 | 1129 | 1355 | 1711 | 1573 | 1383 | 809 | 2646 | 4487 | 5820 | 5644 | 5864 | 15259 | 14383 | 14318 |

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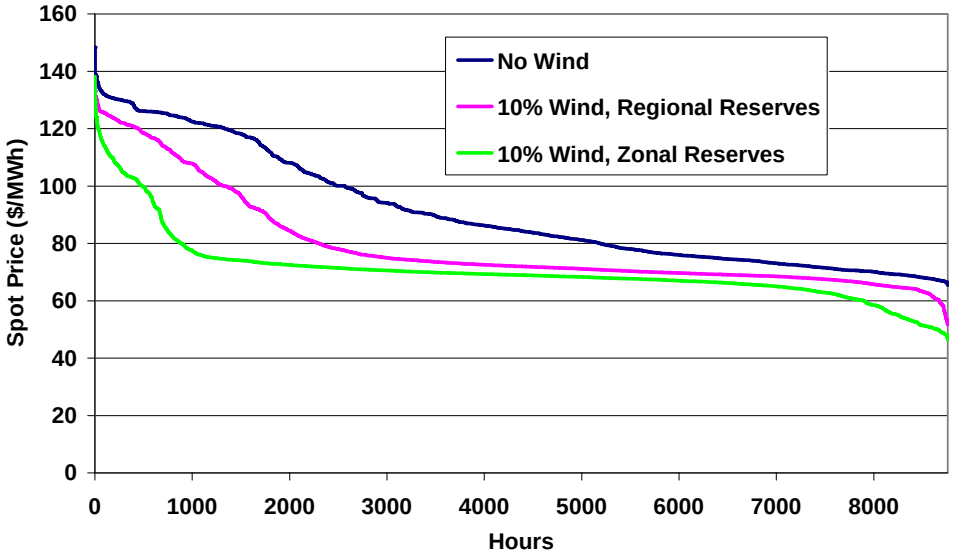
# Spot Price Impact of Balancing Area Consolidation
(10% IA Scenario)




Spinning reserve on a zonal basis ⇒ more generation commitment, lower spot prices, increased operating costs, and decreased value of renewable generation.

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# What Else Makes This Possible?

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# 2. Wind and Solar Forecasts

"Integrating day-ahead wind and solar forecasts into the unit commitment process is essential. Using state-of-the-art wind and solar forecasts would reduce annual WECC production costs by $5 billion, compared to ignoring renewables in the day-ahead forecast. Perfect wind and solar day-ahead forecasts would reduce WECC operating costs by another $500 million per year."

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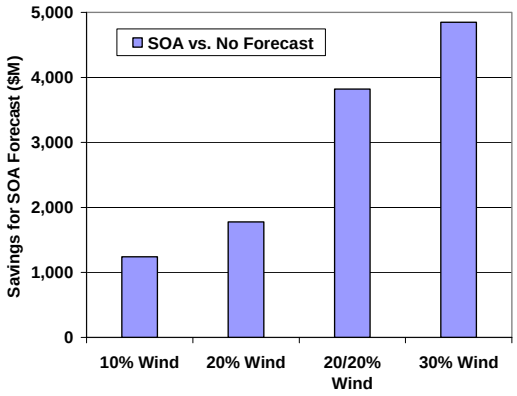
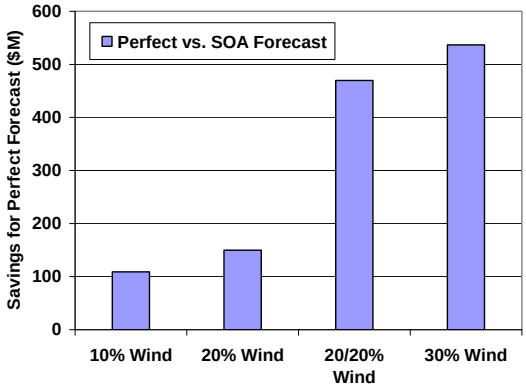
## WECC Incremental Operating Cost Savings for SOA Forecast vs. No Forecast ($M, Left) and for Perfect Forecast vs. SOA Forecast ($M, Right)

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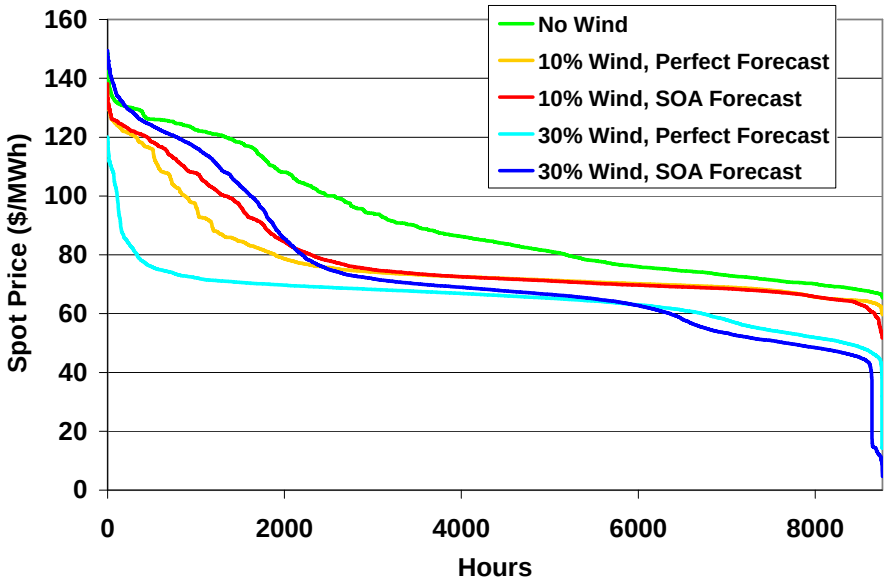
## Annual Spot Price Duration Curve, Perfect Forecast, In-Area Scenarios

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# 3. Effect of Penetration

"Higher levels of penetration require more changes to current practice to successfully operate the system. No significant adverse impacts were observed up to 20% wind penetration in the study footprint, given control area cooperation. Increased renewable generation in the rest of WECC (20/20% case) and in the footprint (30% case) had an increased impact on operation within the study footprint."

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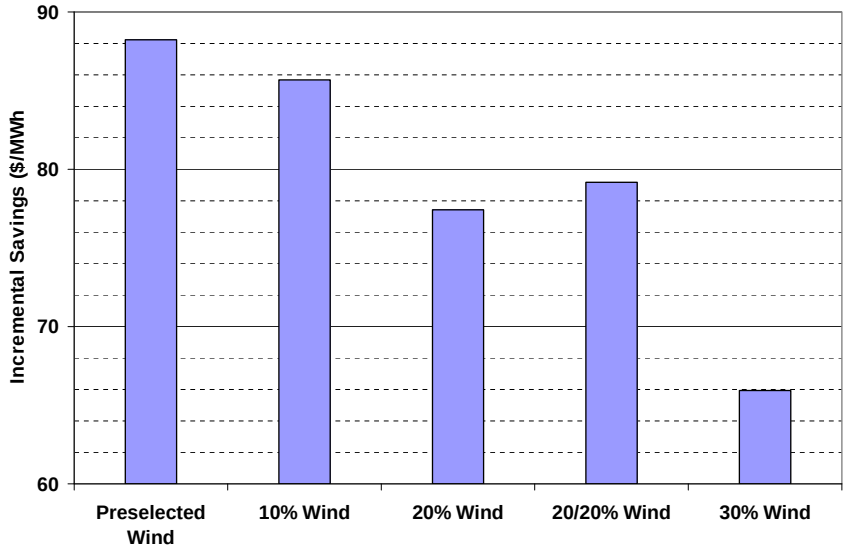
## Incremental Savings Per Incremental Renewable Energy ($/MWh) - WECC - 2006

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# 4. Sub-hourly Schedule

"The current practice of implementing changes to both the generation and inter-area exchange schedules only around the hour have a significant impact on the regulation duty. At high penetration levels, such hourly schedule changes can use most, if not all, of the available regulation capability. This leaves no regulation capability for the sub-hourly variability and results in potential CSP2 violations. Therefore, a sub-hourly schedule procedure will be required to successfully operate the system at high penetration levels"

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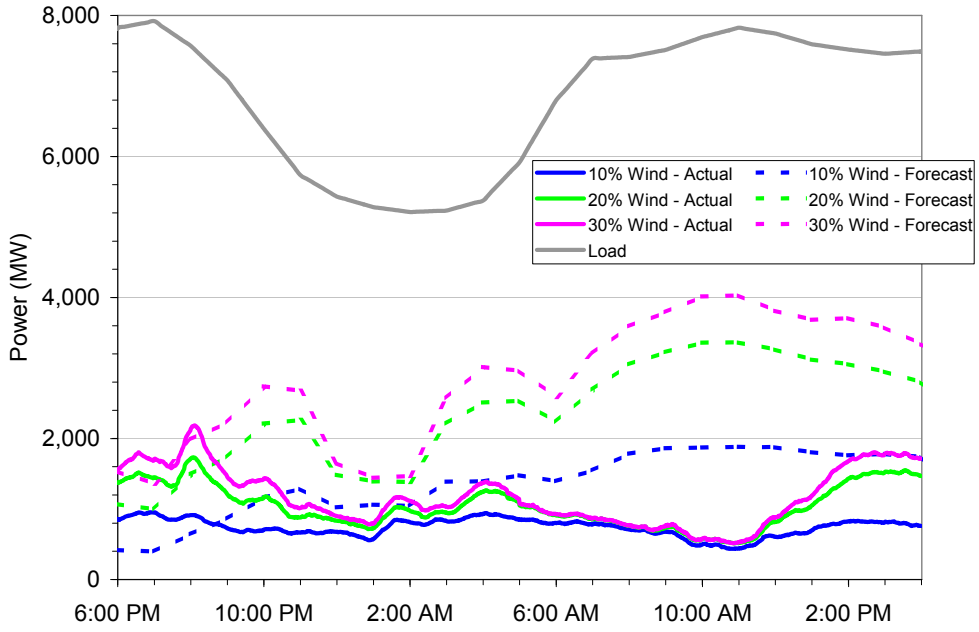
# Colorado East QSS Example for October 26 Input Profiles

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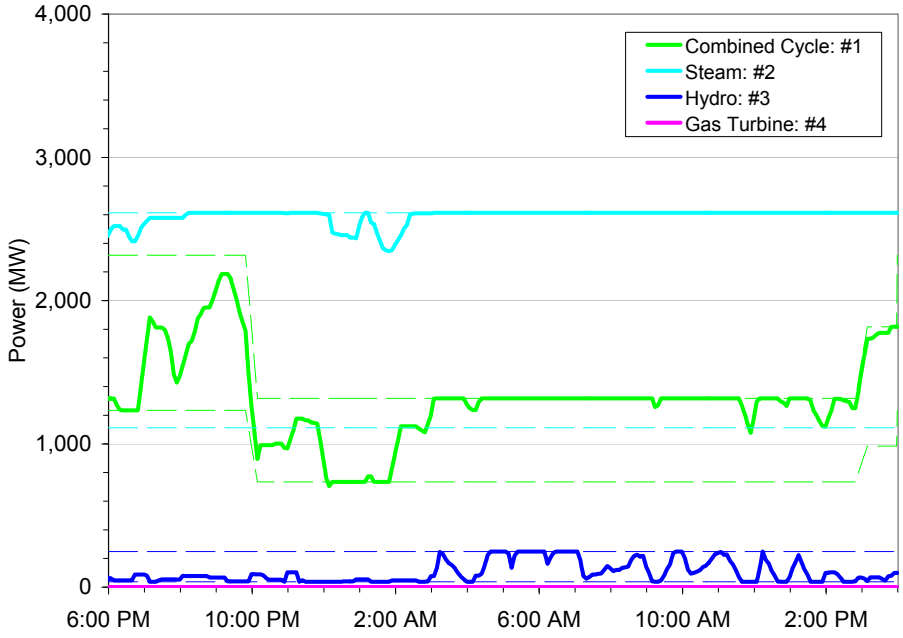
Local Priority, 30% Wind



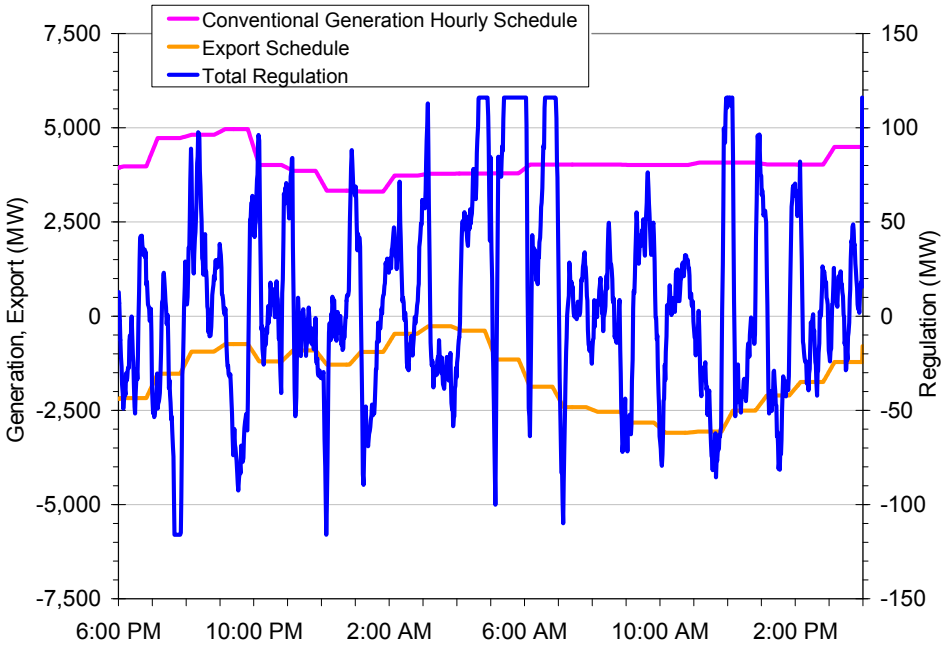
# Colorado East QSS Example for October 26 Generation Dispatch by Type




imagination at work

Local Priority, 30% Wind

# Colorado East QSS Example for October 26 Without Sub-hourly Scheduling

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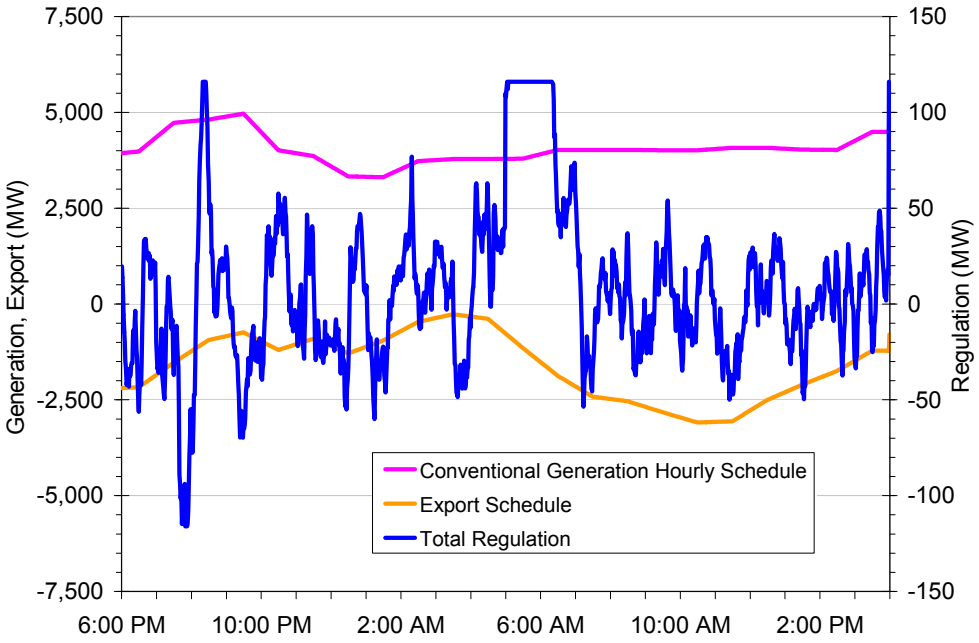
Local Priority, 30% Wind



# Colorado East QSS Example for October 26 With Sub-hourly Scheduling

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Local Priority, 30% Wind

# What Are Some of the Benefits?

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# 5. Value of Renewables

"The 30% wind penetration scenarios show WECC operating cost savings of $20 billion per year due to the wind and solar generation resources. This equates to $80/MWh of wind and solar energy produced. Lower penetrations of renewables showed values up to $88/MWh."

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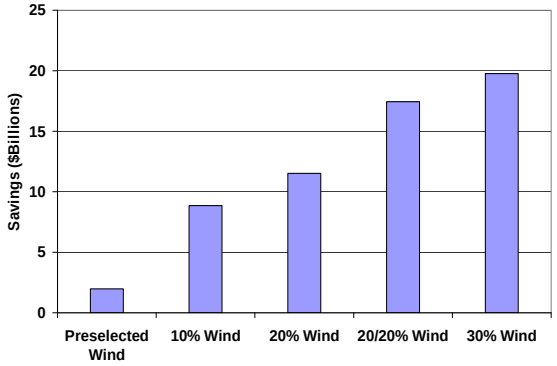
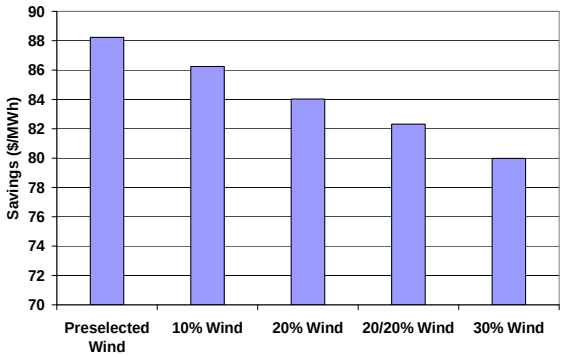
## Operating Cost Savings ($B, Left) and ($/MWh of Renewable Energy, Right), WECC – 2006




imagination at work

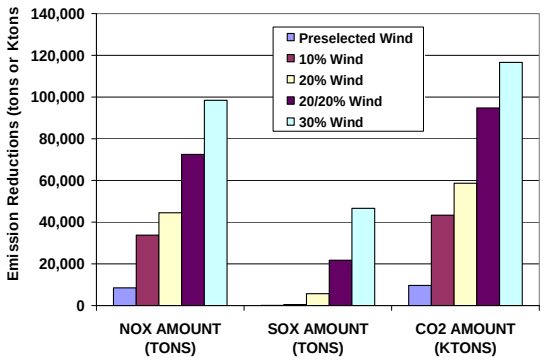


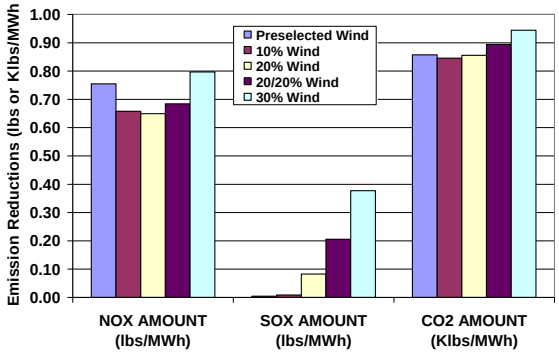
# 6. Emission Reductions

"CO2 emissions would be reduced by nearly 120 million tons per year for the 30% wind penetration scenarios. SOx emissions would be reduced by approximately 45,000 tons and NOx would be reduced nearly 100,000 tons per year."

imagination at work

# Total Emission Reductions (Left) and Reductions/MWh of Renewable Generation (Right), WECC - 2006

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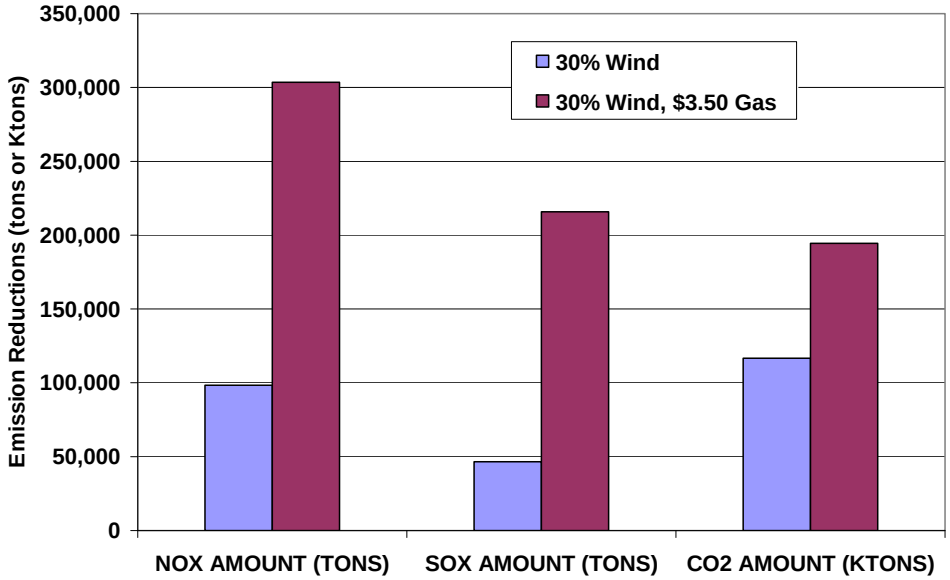
# Emission Reductions With Gas Price Reductions

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# 7. Capacity Value

"Wind generation resources selected for this study were found to have capacity values in the range of 10% to 15%. PV solar plants have capacity values in the range of 25% to 30%. Concentrating solar plants with thermal energy storage have capacity values in the range of 90% to 95%, similar to thermal generating plants."

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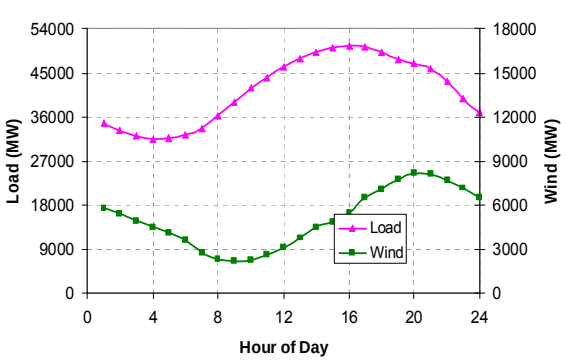
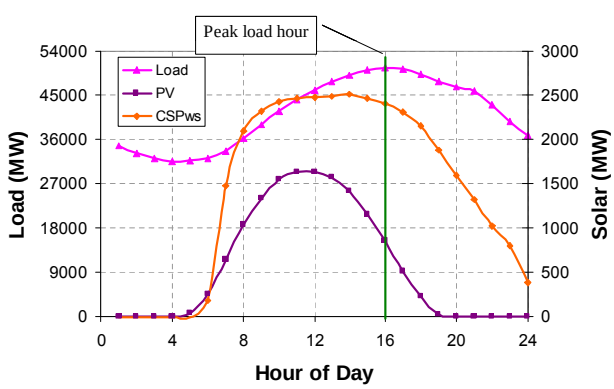
## Capacity Value by Penetration

| Penetration | Wind | CSP | PV |
|---|---|---|---|
| 10% Wind, 1% Solar | 13.5% | 94.5% | 35.0% |
| 20% Wind, 3% Solar | 12.8% | 94.8% | 29.3% |
| 30% Wind, 5% Solar | 12.3% | 95.3% | 27.7% |

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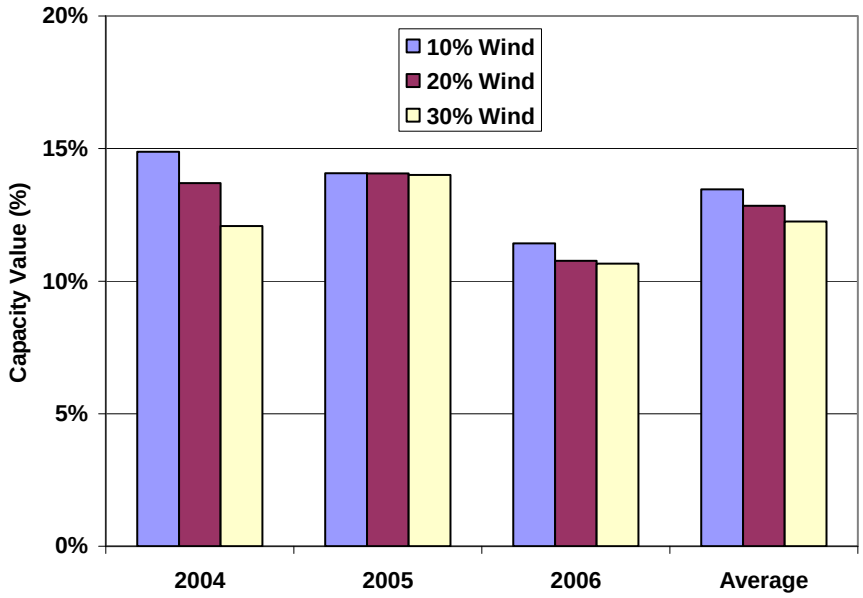
## Capacity Value For Wind, Perfect Capacity, Daily LOLE, All Years




imagination at work



# Are Increased Reserves or Storage Required?

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# 8. Energy Storage

"Increased penetrations of renewables did increase the utilization of the existing energy storage facilities slightly, but there were no indications that construction of additional storage was justified."

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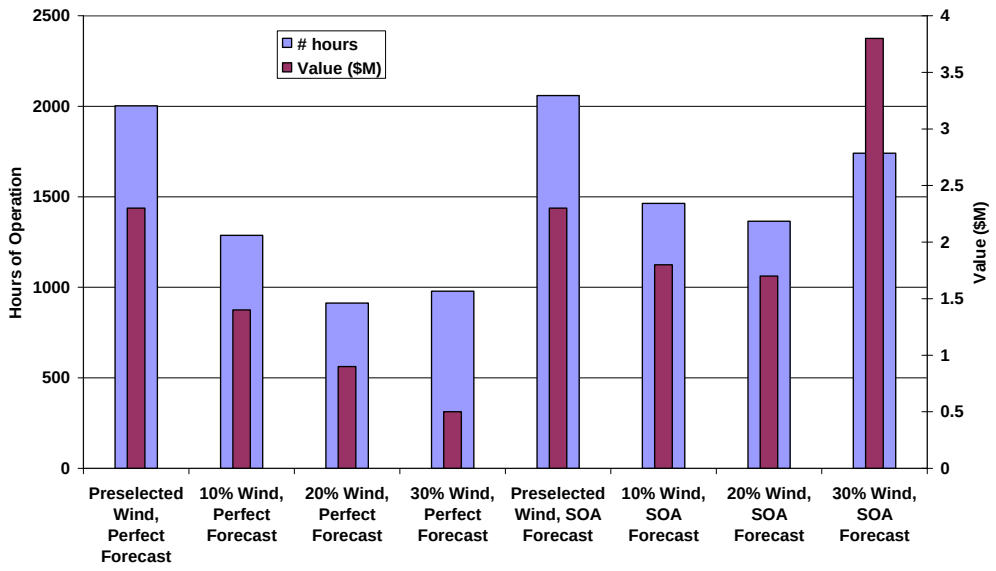
## Incremental Value of a 100 MW PSH Plant




imagination at work

# 9. Operating Reserve Requirements

"Sub-hourly operating reserves are expected to increase by 1% to 5% of total wind plant MW production during each hour (not total MW rating of wind plants on line), depending on the degree of cooperation between neighboring control areas. Economic operation of the system tends to provide for incremental variability due to wind and solar without imposing additional commitment rules. With 35% wind and solar penetration, the additional sub-hourly reserves would increase operating costs by less than $1 per MWh of wind energy."

imagination at work



# Reserve Requirements

- System must carry reserves to cover contingencies *and* most net load variations
- Relationship between load and wind levels and net load variability is complex
- Statistical expectation of variability can be distilled to some simple approximate rules:

| | Load Only | 30% LP Scenario | | |
|---|---|---|---|---|
| | (% of load) | Load Term (% of load) | Wind Term (% of wind production) | up to (% of wind nameplate) |
| Footprint | 1.3 | 1.1 | 5 | 47 |
| Arizona | 2.2 | 2.2 | 5.6 | 36 |
| Nevada | 2.1 | 1 | 10.7 | 54 |
| Colorado East | 2.4 | 2 | 5.7 | 68 |
| New Mexico | 2 | 3.1 | 3.5 | 70 |
| Wyoming | 1.3 | 2.7 | 8.7 | 33 |
| Colorado West | 1.8 | 3.1 | 7.3 | 100 |

- Contingency reserves are 3% of load; no change
- Average requirement to cover *variability* is roughly double:
  - ~425 MW vs ~850 at footprint
  - Requirements roughly double for reserves by area (vs. footprint)

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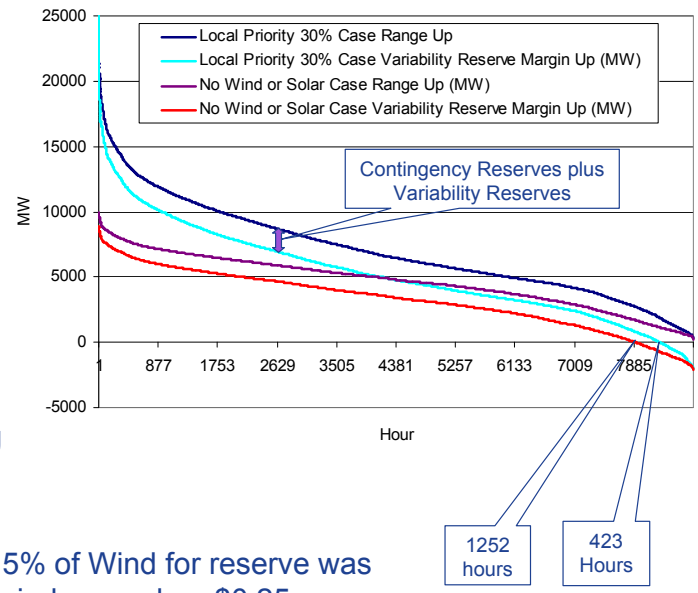
# Reserve Performance

- Variability requirements increase with wind and solar
- Displacement of other resources tends to release up reserves
- Without explicitly requiring additional reserves for variability, the system economics provide sufficient reserves about 95% of the time, at the footprint level
- This is consistent with WECC guidelines for handling variability and with CPS2 targets




- Committing Units to Provide 5% of Wind for reserve was shown to reduce the value of wind power by ~$0.25 per MWhr. The above results suggest this is not necessary.

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# 10. Down Reserves from Wind Plants

"A wind plant can reduce its output very quickly in response to a command signal. This capability enables wind plants to provide down reserves (i.e., curtailment) in response to commands from system operators. Such a function could be implemented via the system ACE signal, as demonstrated by simulations performed in this study."

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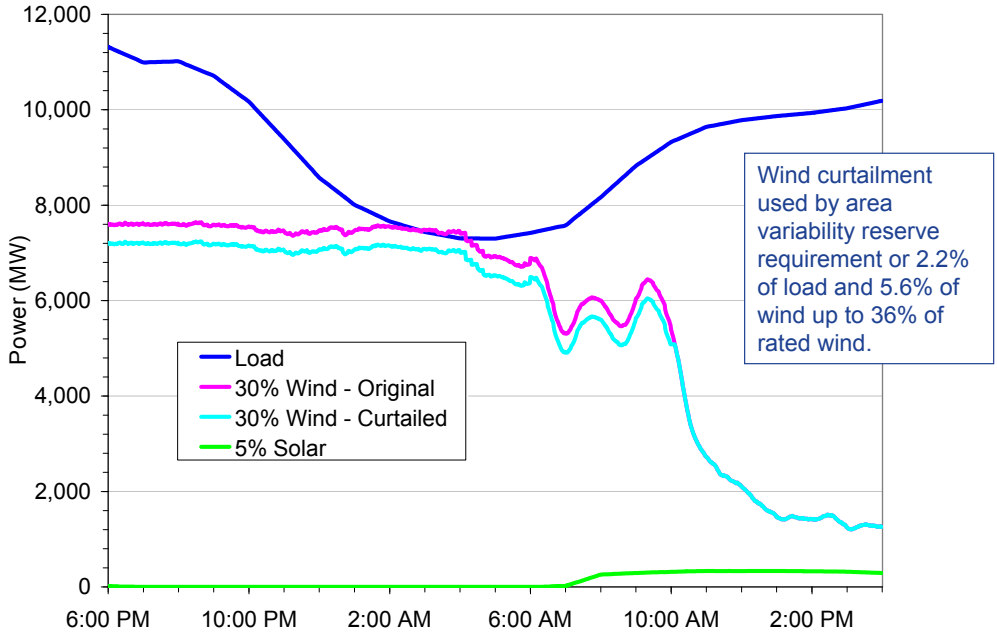
# Arizona QSS Example for April 15
# Input Profiles

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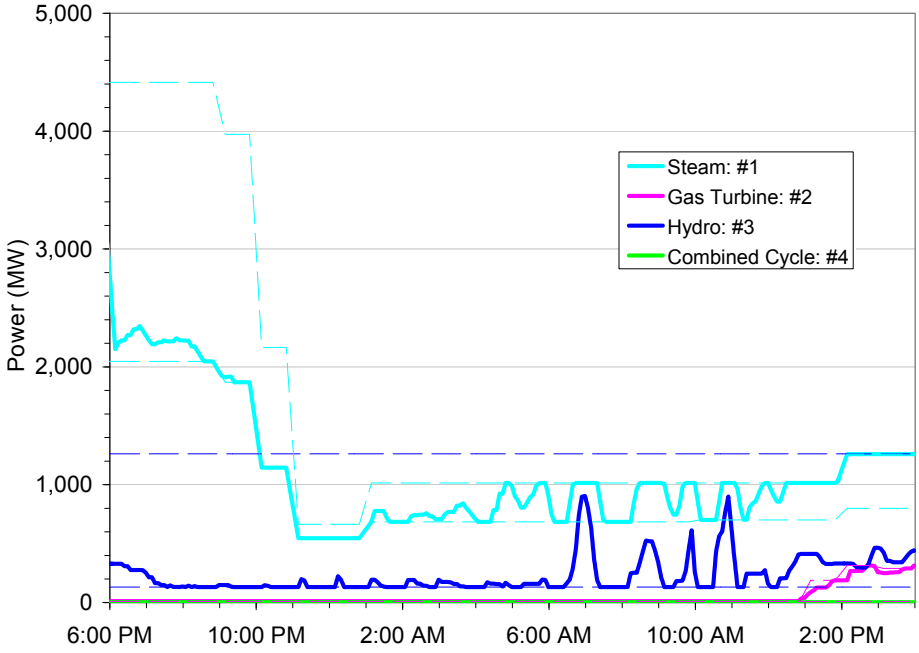
Local Priority, 30% Wind



# Arizona QSS Example for April 15
# Generation Dispatch by Type

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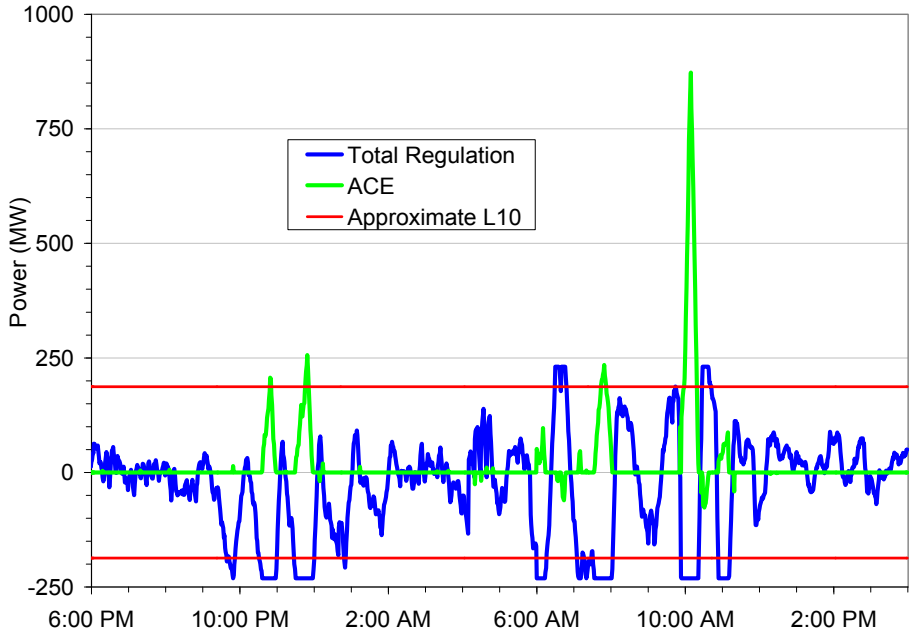
## Arizona QSS Example for April 15 Regulation, ACE

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# 11. Wind Curtailment

"The production simulation analysis showed that wind curtailment was generally not needed on an hourly basis. However, the QSS analysis showed wind curtailment would be required under some rare combinations of low load and high wind with sub-hourly variability."

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# What Factors Have Large Economic Impacts?

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# 12. Different Scenarios Behave Similarly

"The In-Area, Local Priority and Mega Project scenarios showed similar overall performance and economics for a given penetration level. This indicates that the specific locations of the wind and solar resources within WestConnect are not critical, provided there is adequate transmission infrastructure and control area cooperation."

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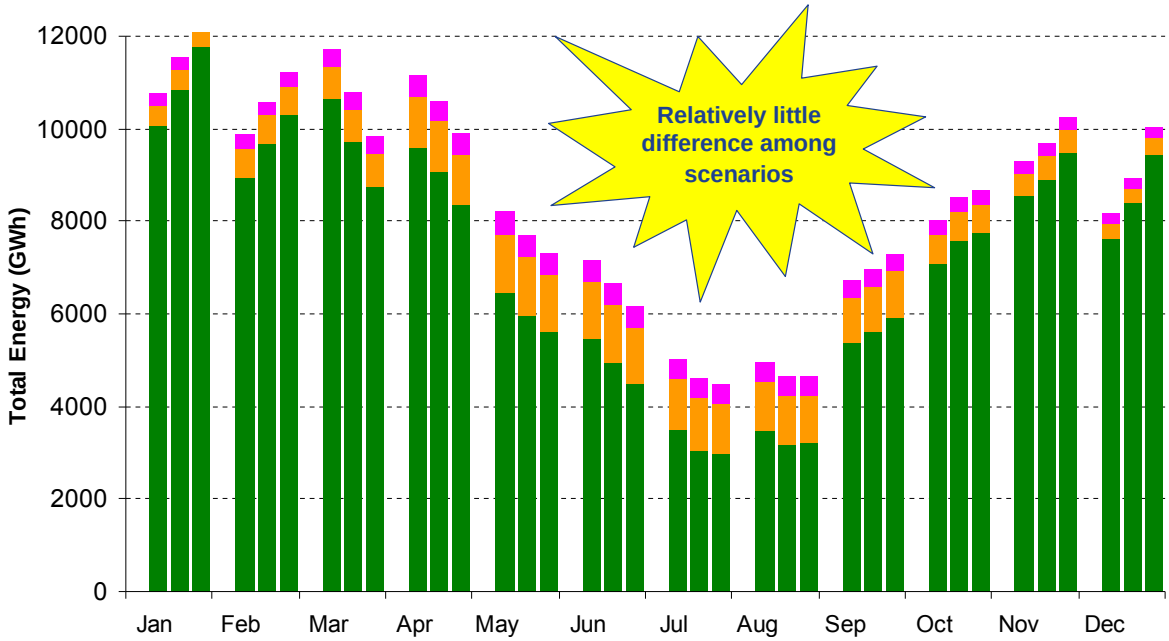
# Footprint Monthly Energy from Wind and Solar for all Scenarios (30% Penetration Level)

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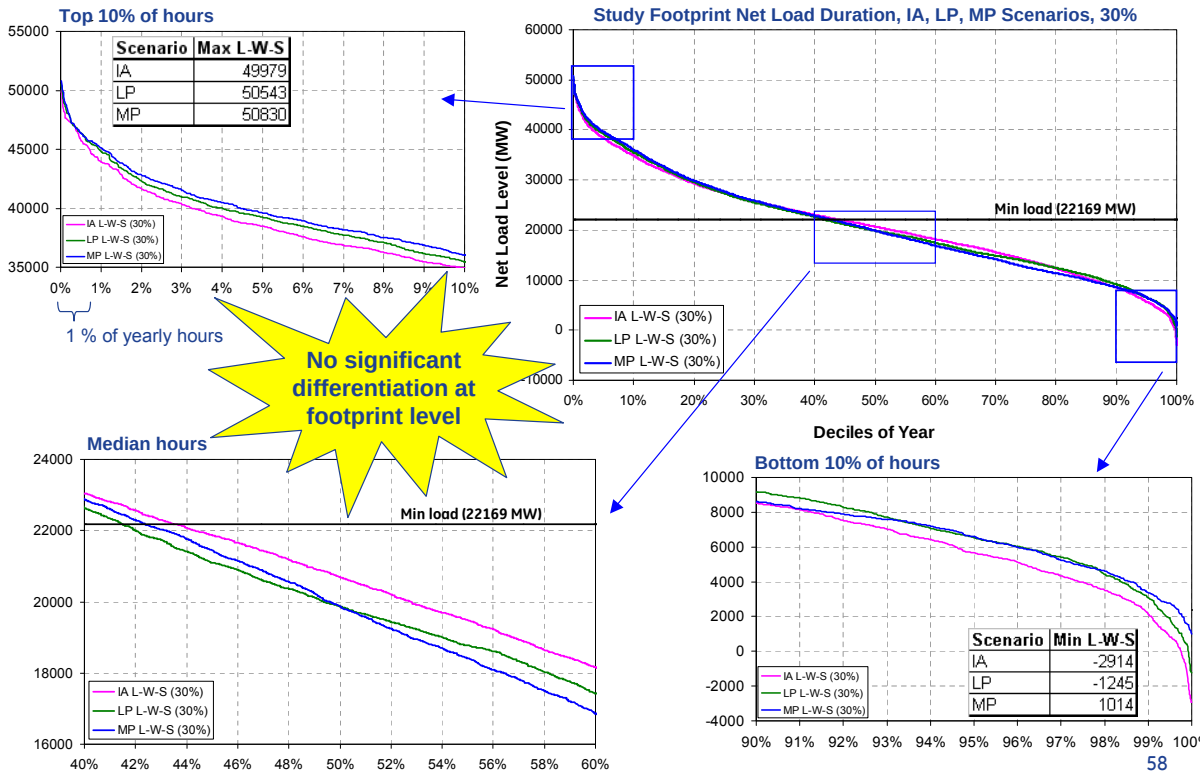
Much less difference in wind and solar energy between the scenarios than across months

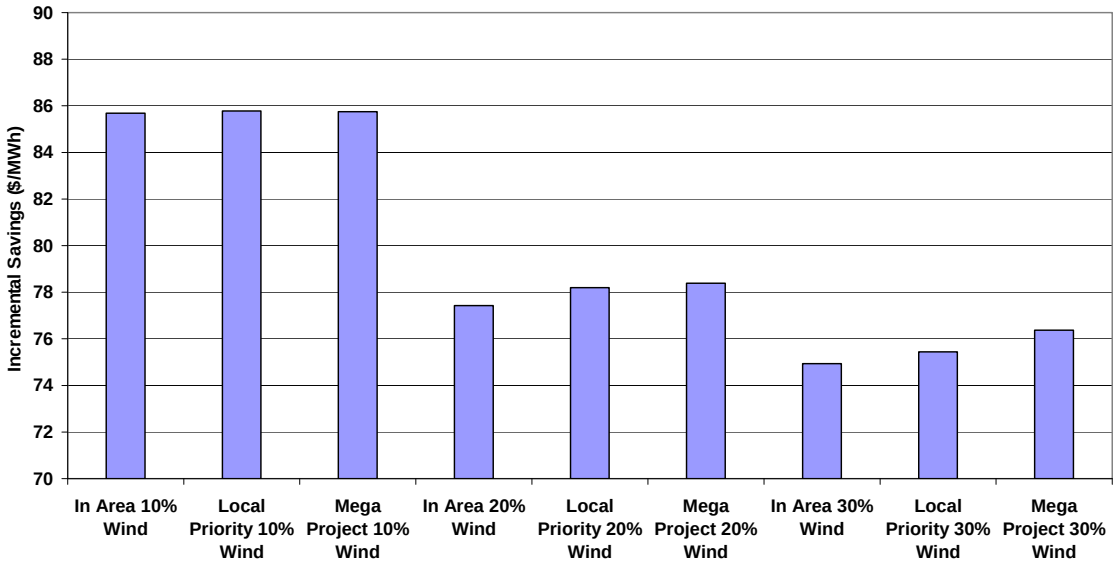


# Footprint Net Load Duration Plots for all Scenarios

(30% Penetration Level)



## Operating Cost Savings Per MWh of Renewable Energy for all of WECC




Overall, difference in savings between the scenarios is quite small

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# 13. Hydro Plant Operation

"Hydro generation is capable of quick start/stop cycling and fast ramping, which makes it very well matched with variable wind and solar generation. If hydro energy dispatch is adjusted to account for day-ahead wind and solar forecasts, WECC operating costs would be reduced by $200 million per year, increasing the value of wind and solar energy by about $1/MWh. On the other hand, if hydro operation were severely constrained (such as a requirement to maintain constant river flow), WECC operating costs would increase by up to $1 billion per year."

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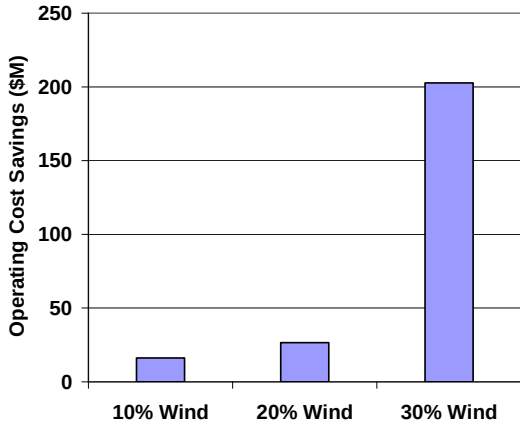
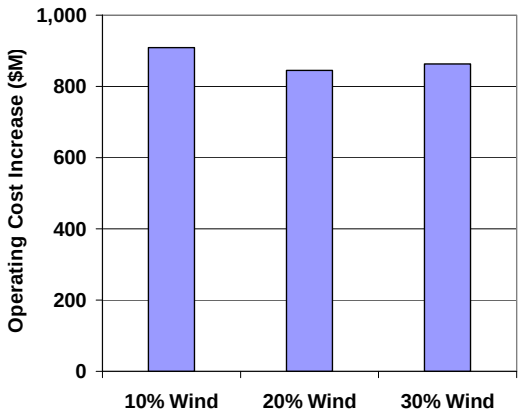
## Savings for Hydro Dispatch to Net Load (Left), and Cost Increase for Flat Hydro Operation (Right), WECC

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# 14. Coal Plant Operation

"Coal plants are normally expected to have minimum operating load in the range of 40% to 50% of full rating. If coal plants are unable or unwilling to operate down to that level, operating costs will increase. For example, limiting coal plant operation to above 70% load increase WECC operating costs by $160 million per year."

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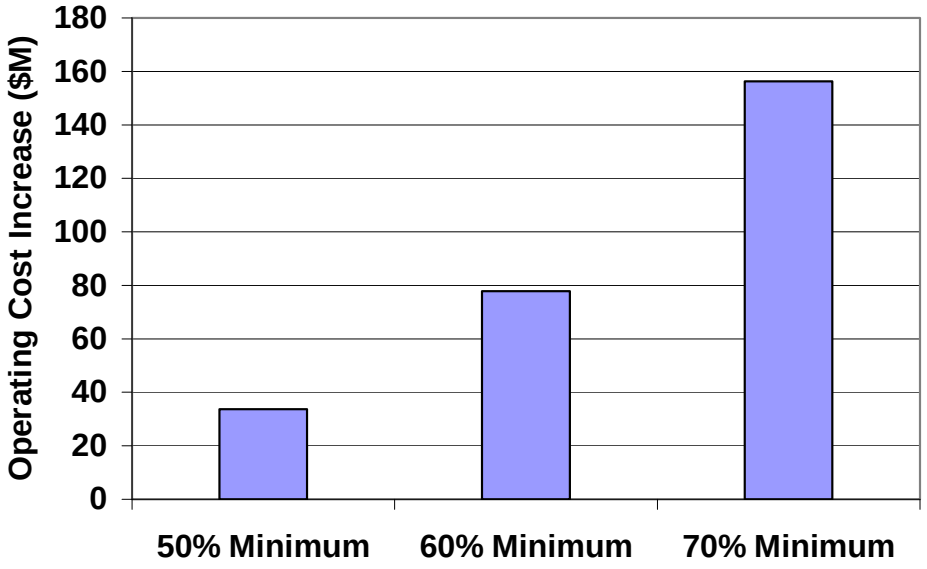
## Increased WECC Operating Costs over Coal at 40% Minimum Rating

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# 15. Load Participation

"Load participation is an attractive alternative for providing some additional sub-hourly operating reserves. Using load participation instead of committing additional generation for operating reserves would save up to $600 million in operating costs per year. The value of load participation resources would be in the range of $3,000 to $100,000 per MWh reduction in the reserve shortfall."

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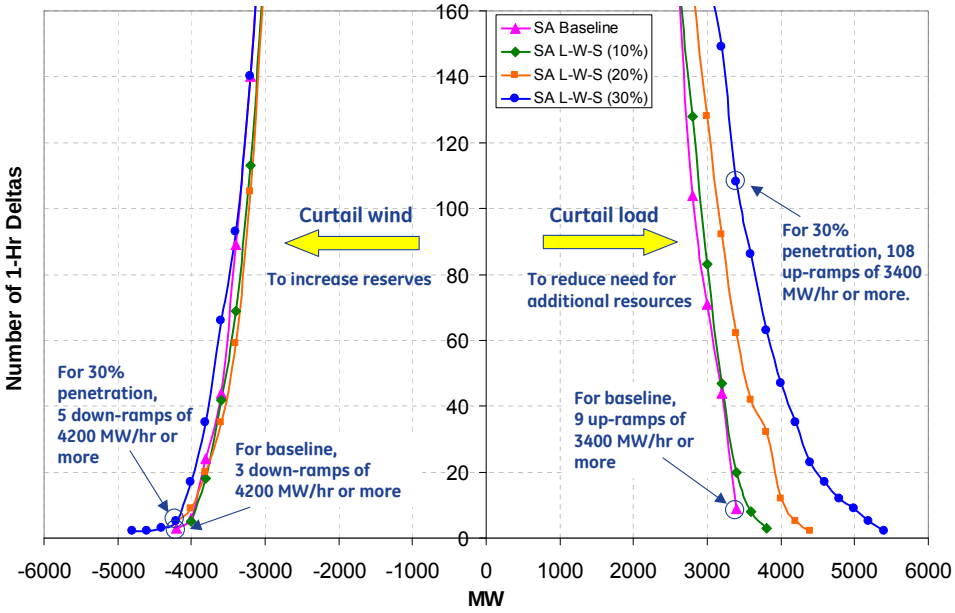
# Study Footprint Distribution of Extreme Hourly Net Load Deltas 2006 Local Priority Scenario

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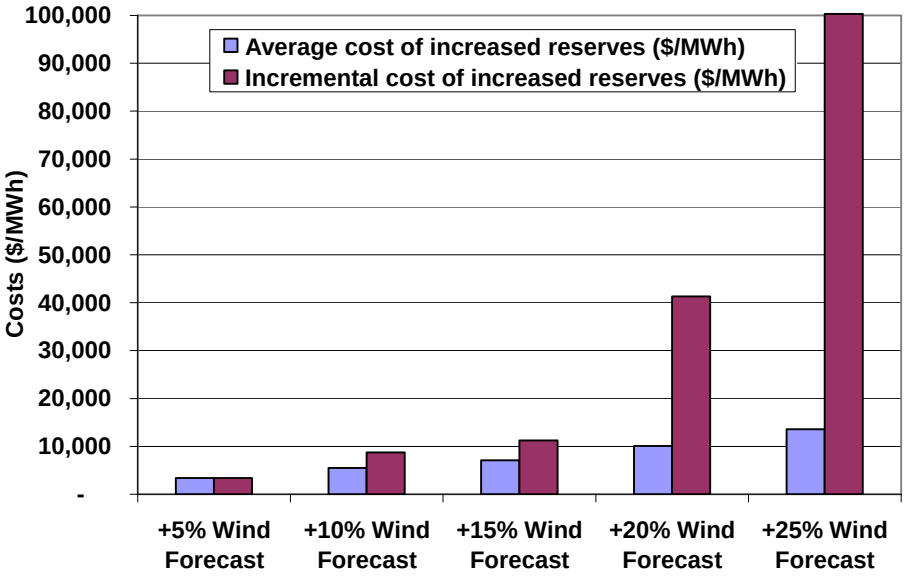
# Cost of Increasing Reserve Commitment For Renewables

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# 16. Fuel Displacement

"Given the fuel prices and carbon tax assumed for this study ($2 Mbtu coal, $9.5Mbtu gas, $30/ton carbon), wind and solar generation primarily displace gas resources nearly all hours of the year. Since gas-fired generation is typically more flexible than coal generation, the natural economic displacement of gas generation by wind and solar generation makes the balance of dispatchable generation on-line less flexible (fewer gas units, more coal units)."

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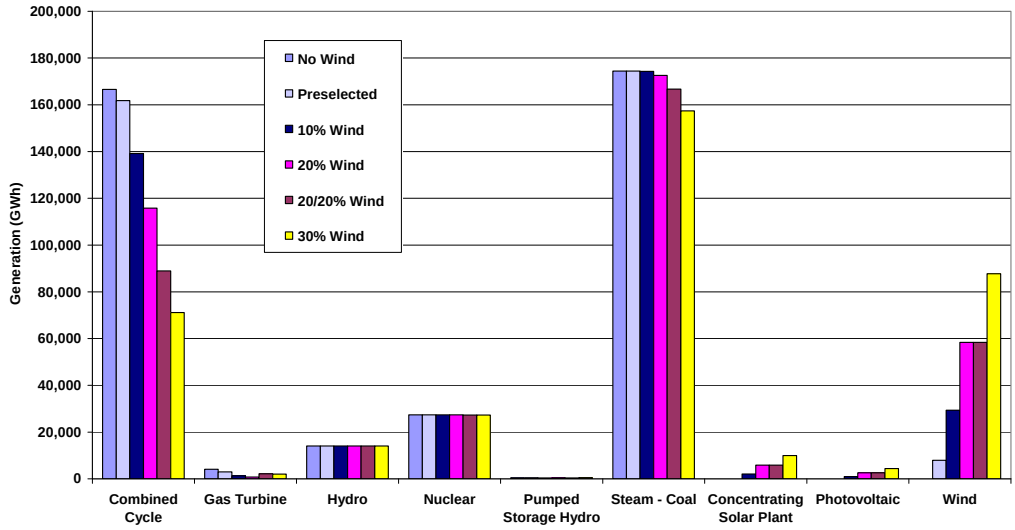
## Generation by Type - Study Area – 2006

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# Is New Long Distance Transmission Required?

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# 17. Need for Transmission

"Up to 20% renewable penetration could be achieved with little or no new inter-area transmission additions, assuming open access to existing transmission."

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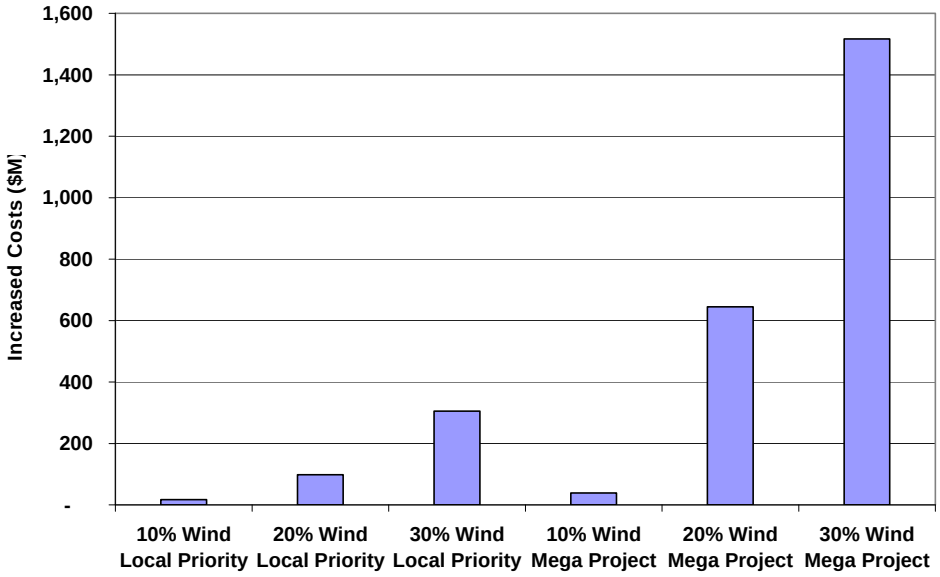
## Increased Costs with No Transmission Expansion




imagination at work



# Conclusions

The technical analysis performed in this study shows that it is feasible for the WestConnect region to accommodate 30% wind and 5% solar energy penetration. To do so successfully requires changes to current practice, including the following:

- Control area cooperation or consolidation
- Open access to all transmission resources
- Economically rational commitment and dispatch process
- Use of state of the art wind and solar forecasts
- Flexible fleet generation (e.g., lower turn down, faster ramp rates, reduced start/stop costs or minimum down time)
- Additional operating reserves
- Sufficient intra-state transmission
- Inter-state transmission expansion
- Sub-hourly scheduling of both generation and inter-area exchange
- Load participation
- Implementation of down reserve in wind plants

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# Further Investigation

The GE project team regards the following as valuable topics for further investigation:

- Changes in non-renewable generation portfolio (e.g., impact of retirements, characteristics and value of possible fleet additions or upgrades)
- Reserve requirements and strategies (e.g., strategies and requirements for off-line reserves, reserves from non-generation resources)
- Load participation (e.g., functionality, market structures, PHEV)
- Fuel sensitivities (e.g., price, carbon taxes, gas contracts and storage, hydro constraints and strategies)
- Forecasting (e.g., calibration of forecasting using field experience, strategies for use of short-term forecasting)
- Transmission (e.g., intra-area constraints and challenges)

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GE
Energy

# Western Wind & Solar Integration Study

## Operating Reserve Requirements

Nick Miller

Stakeholder Meeting
February 9, 2010

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# Outline

- Intra-hour Variability
- Implications for Reserves
- Concepts for Simple Reserve Rules
- Performance



# Introduction to Intra-hour Variability

Variability vs. Uncertainty

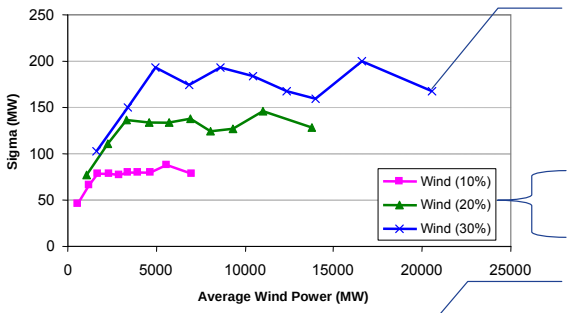
- Day-ahead forecast error is the major contributor to uncertainty
- Sub-hourly changes in net load are the main source of variability

- Sub-hourly variability drives dynamic reserve requirements
- Handling of DAH uncertainty dominates dynamic reserve capability

- In this section, 10-min variability is focus
  - 10 minutes is a good divider between running reserves and cold/standby reserves
  - 10-minute data available

# 10-minute Variability: Wind and Net Load (Local Priority Case)

## Wind LP 2006

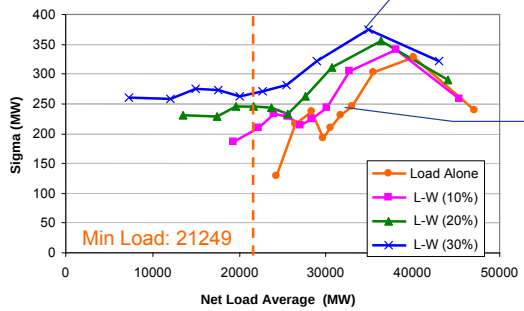



e.g. Average wind power of top 10% of hours is 20,583 MW. σ 10-minute Δ for these 876 hours is 168MW

| | |
|---|---|
| 10% Nameplate | 9600 |
| 20% Nameplate | 18180 |
| 30% Nameplate | 26760 |

- Wind variability not simply proportional to wind power level

## Net Load* LP 2006




e.g. Average net load power of 2nd to top 10% of hours is 34,821 MW. Sigma 10-minute delta for these 876 hours is 374MW

This curve is load only variability

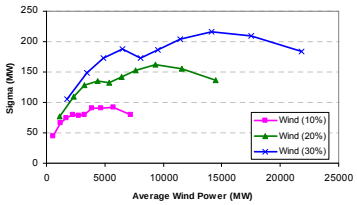
- Variability increases with increased penetration
- Periods of low net load tend to have considerably more variability

* For Balance of this portion of the presentation Solar is disregarded: Net Load = Load - Wind

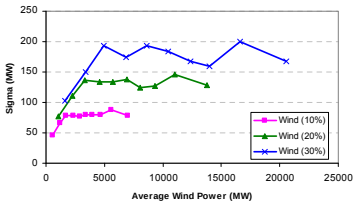


# 10-minute Variability: Wind and Net Load - 3 Scenarios

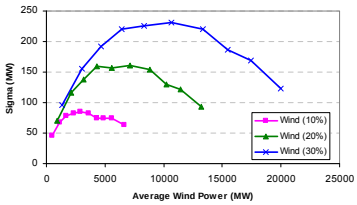
## In Area 2006

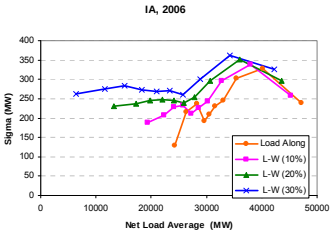


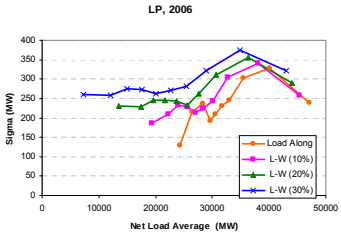

## Local Priority 2006

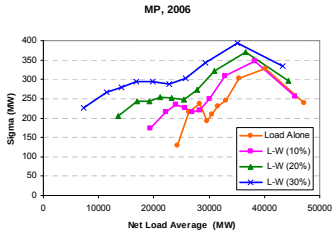



## Mega Project 2006



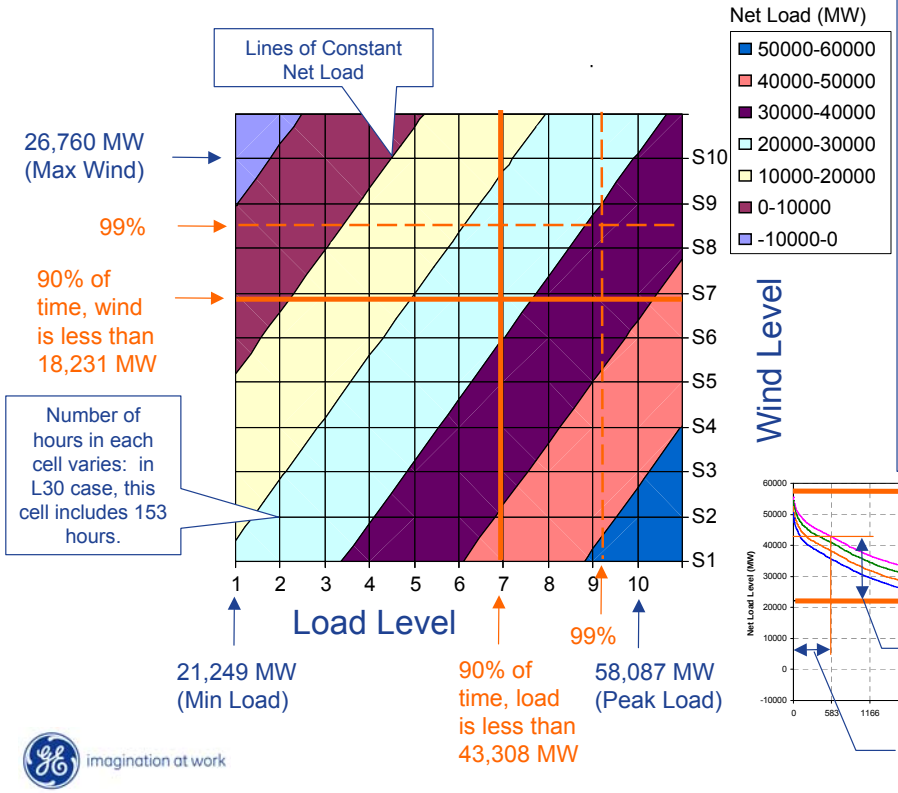




- Wind shapes vary with spatial diversity
  - Mega project more concentrated: looks more like a single plant
- Net load trends similar at study footprint level

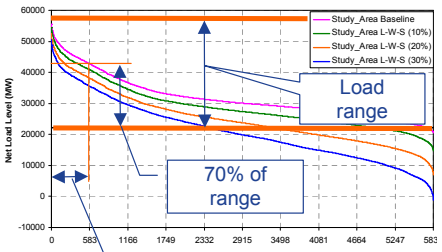
imagination at work

# L30 Load - Wind - Net Load Relationship




What is this plot ???

a. Each year has 8,760 hours.
b. Load varies between a minimum and maximum
c. Wind power varies between zero and a maximum
d. The range of load and wind are each divided into 10 equal sized buckets
e. So, there are 100 combinations of load & wind
f. The value (color) at each intersection is the Net Load for that combination

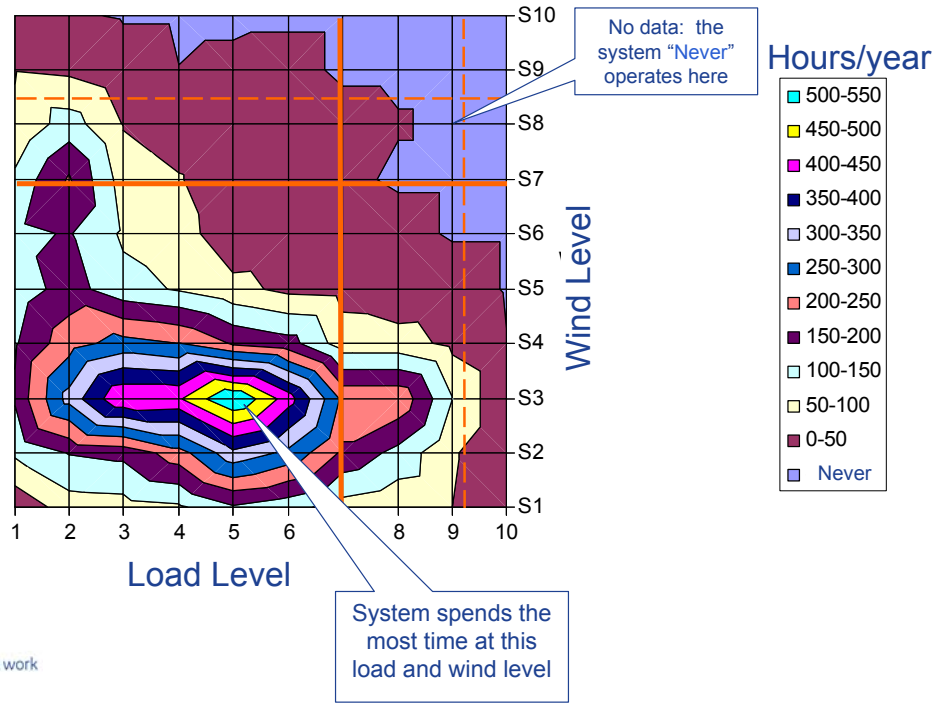



imagination at work



# Operations L30: Hours of Load & Wind Combinations

L30 Hours of Operation (per year)

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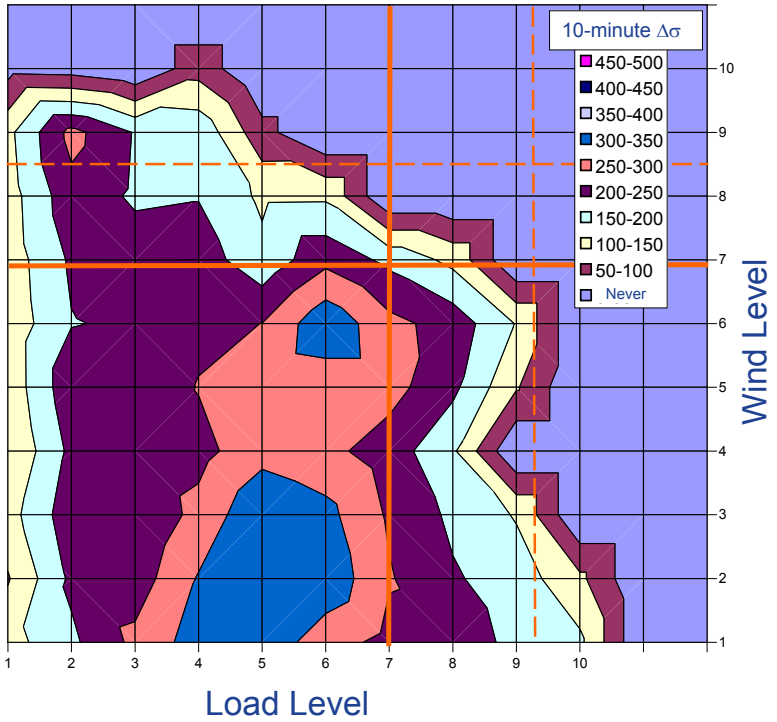
## Load Only Variability L30



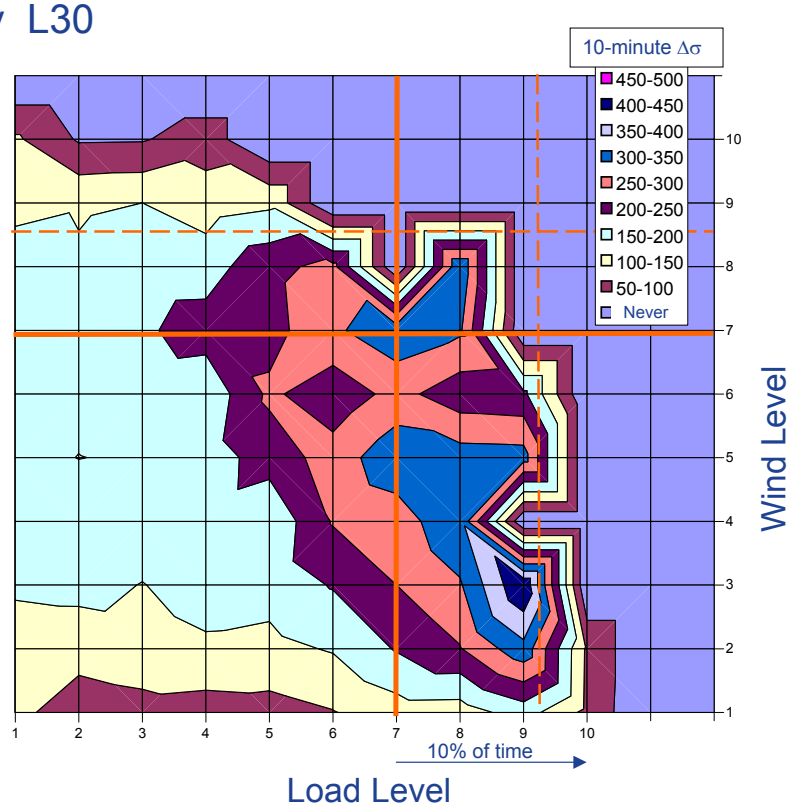

- Load variability highest at moderate loads
- Dominated by diurnal load cycle

imagination at work



## Wind Only Variability L30

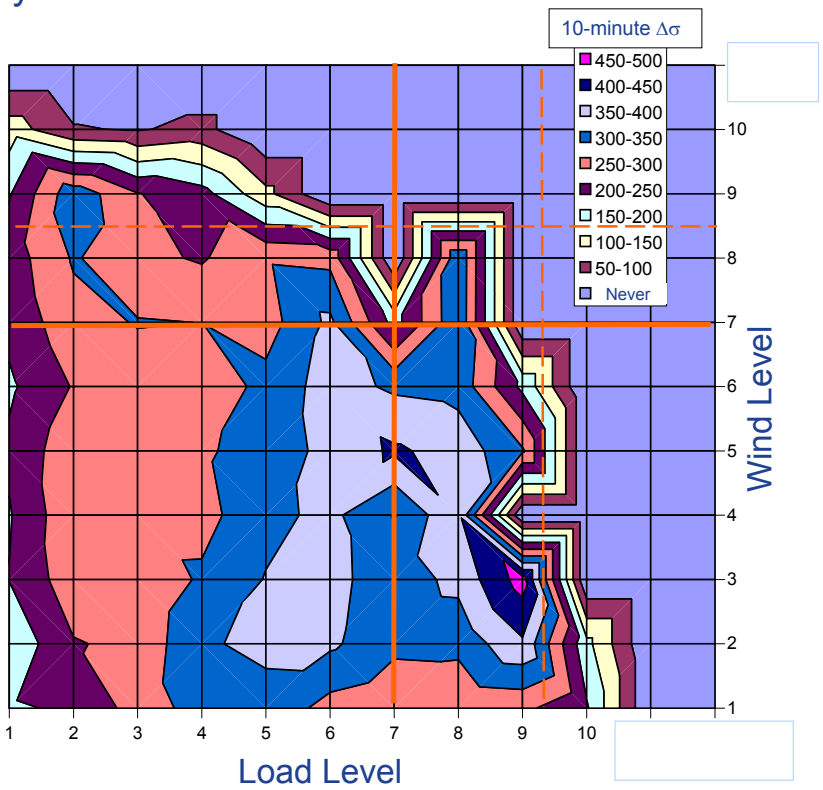
- Wind variability appears to be affected by load level
- Not Intuitive
- But maybe it makes sense…
- Diurnal patterns suggest wind is more variable during periods of high load: i.e. during the day




imagination at work

# Net Load Variability L30

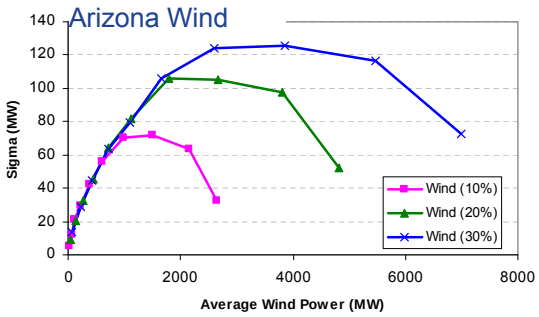
- Net load variability increases with wind
- Implied reserve requirement is 3 x $\Delta\sigma$
- Requirement is a function of both load level and wind level

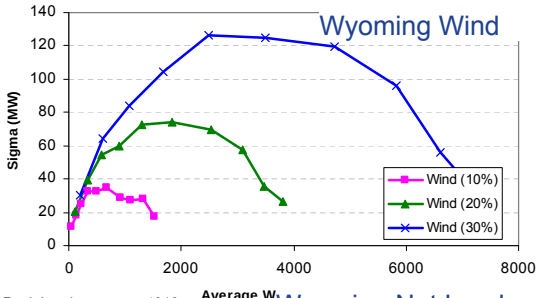


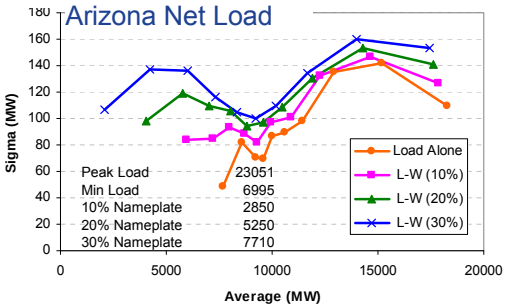

imagination at work

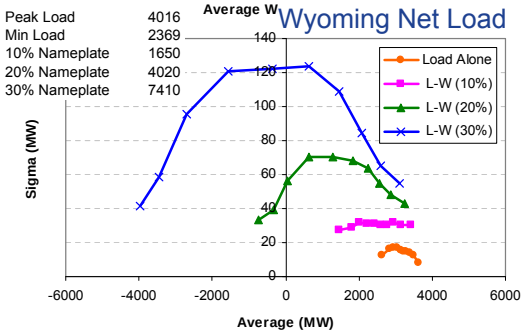


# Arizona & Wyoming: Average (MW) vs Sigma of 10-min Delta (MW)



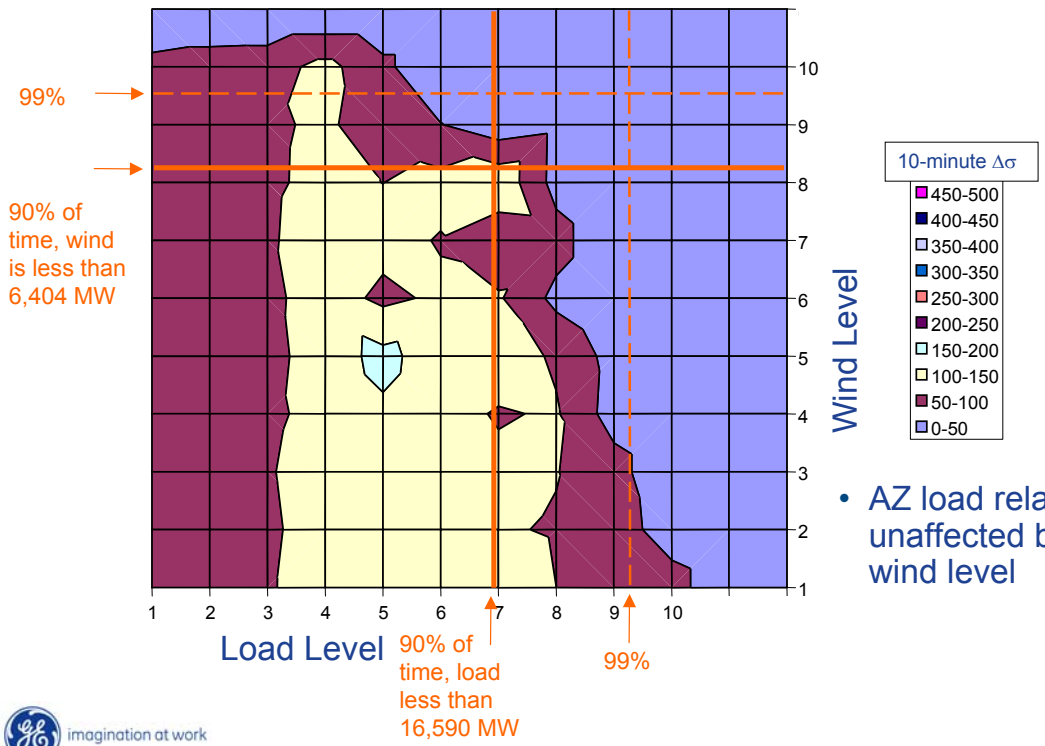




- At area level wind impact is more observable
- By the time that we get to a very high wind system like Wyoming, wind dominates

imag

# Arizona L30R Load Variability




- AZ load relatively unaffected by wind level

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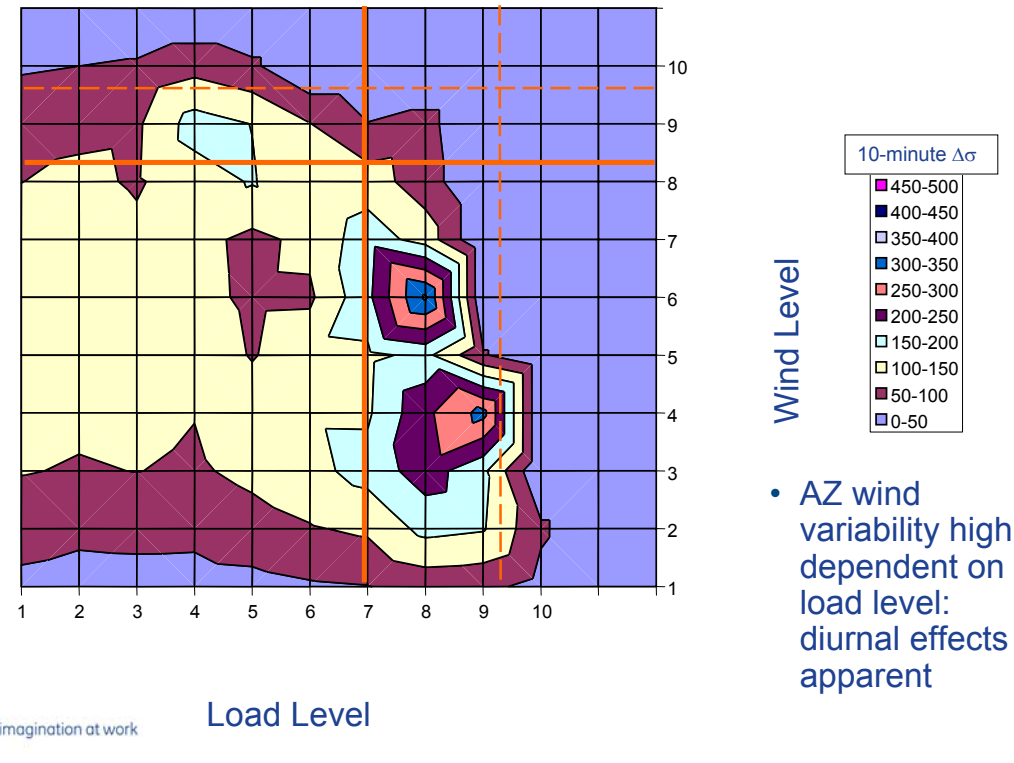
# Arizona L30R Wind Variability




- AZ wind variability highly dependent on load level: diurnal effects apparent

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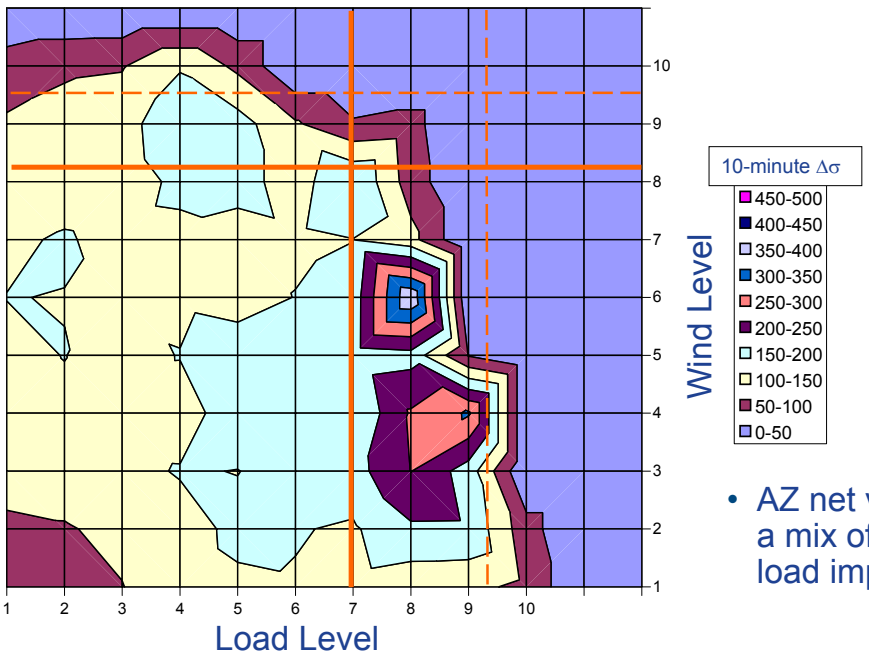
# Arizona L30R Net Load Variability




- AZ net variability a mix of wind and load impacts

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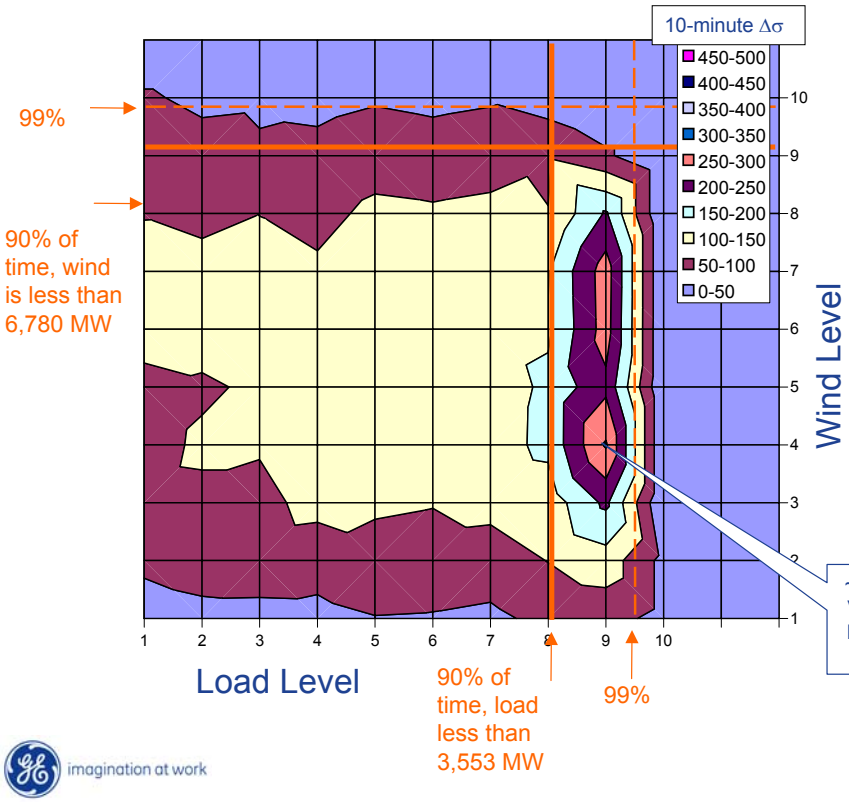
# Wyoming L30R Wind Variability




- Wind variability slightly dependent on load level – except at very high loads (small sample?)
- High variability at middle of wind power range is an expected characteristic

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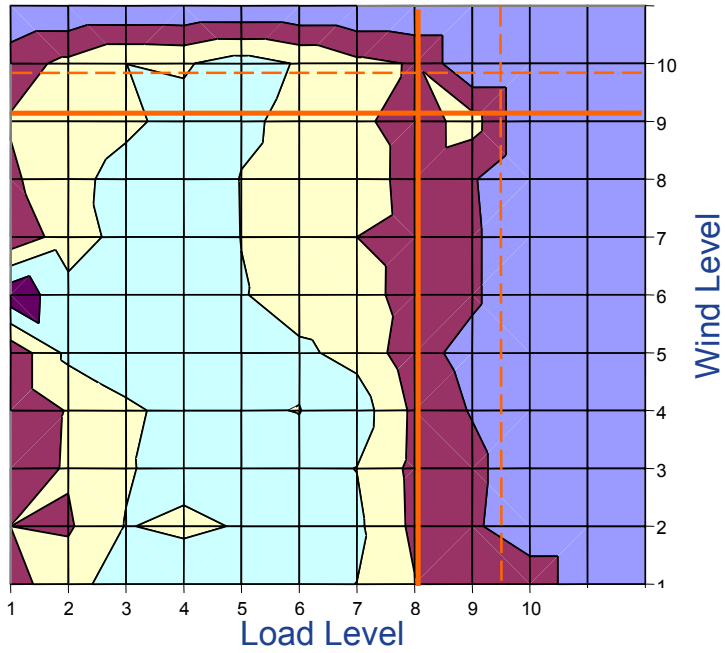
# Wyoming L30R Load Variability




Note scale

- 20.0-25.0
- 15.0-20.0
- 10.0-15.0
- 5.0-10.0
- 0.0-5.0

- Load variability basically insignificant compared to wind variability

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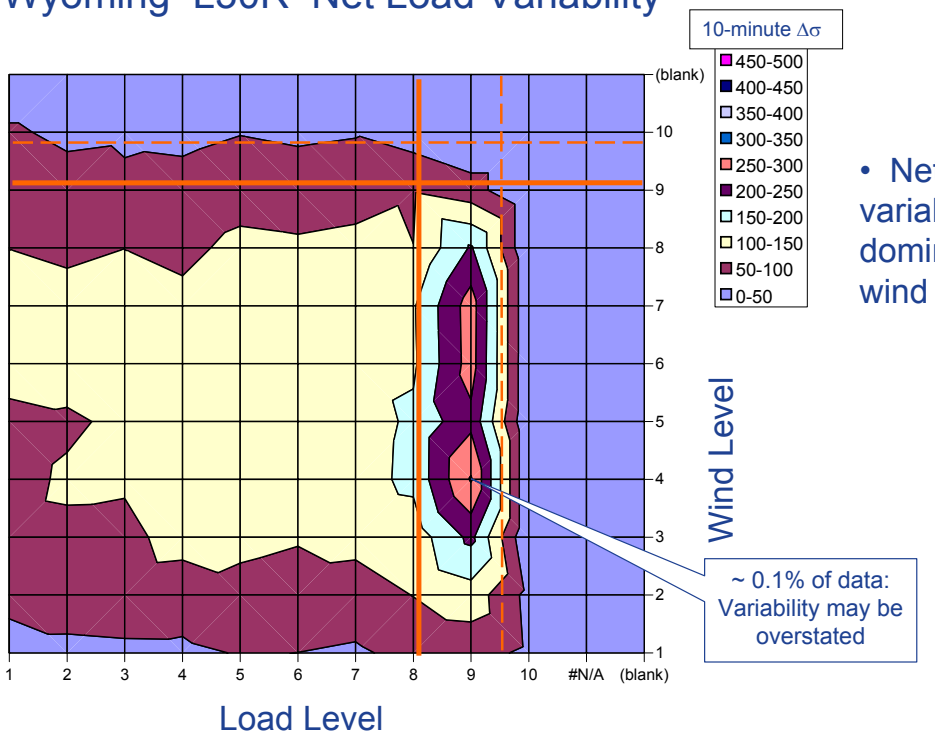
# Wyoming L30R Net Load Variability




- Net Load variability totally dominated by wind variability

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# Implications for Reserves

- Spinning reserves for contingencies are 3% of load; no change
- System must carry reserves to cover contingencies and *most* net load variations (per WECC guidelines and NERC CPS2 rules)
- Since the system must rebalance within 10 minutes most of the time, a target of carrying reserves sufficient to meet 3σ of 10-min load variability most of the time is consistent with operating guidelines, i.e.

For all operating conditions there is an implied reserve requirement of : 3 x σΔ 10-min Net Load

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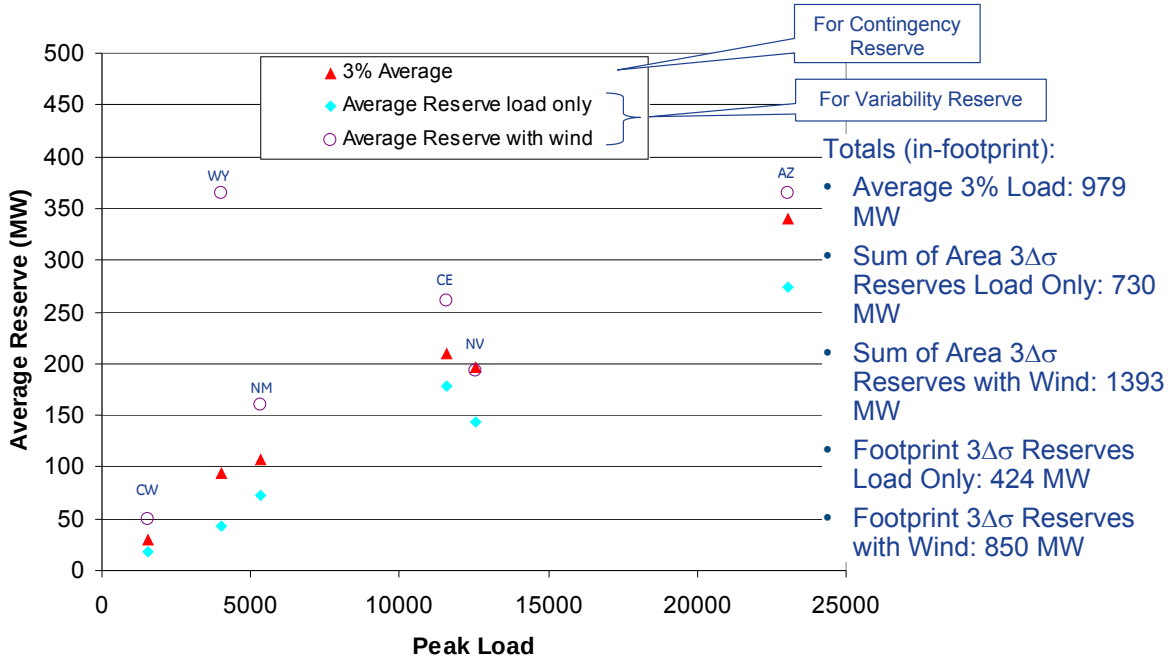
# Average Reserve Requirements




Totals (in-footprint):

- Average 3% Load: 979 MW
- Sum of Area 3Δσ Reserves Load Only: 730 MW
- Sum of Area 3Δσ Reserves with Wind: 1393 MW
- Footprint 3Δσ Reserves Load Only: 424 MW
- Footprint 3Δσ Reserves with Wind: 850 MW

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# Distillation of 3Δσ to Simple Rules

- Complex load and wind variability relationships provide insight, but taken alone are not likely to be usable for system operations
- We explored several ways to map the variability into some simple metrics
- Some of those results are presented here
- We start with something really simple:

  3% of Load plus 5% of Wind *Production*

  A "3+5 Rule"

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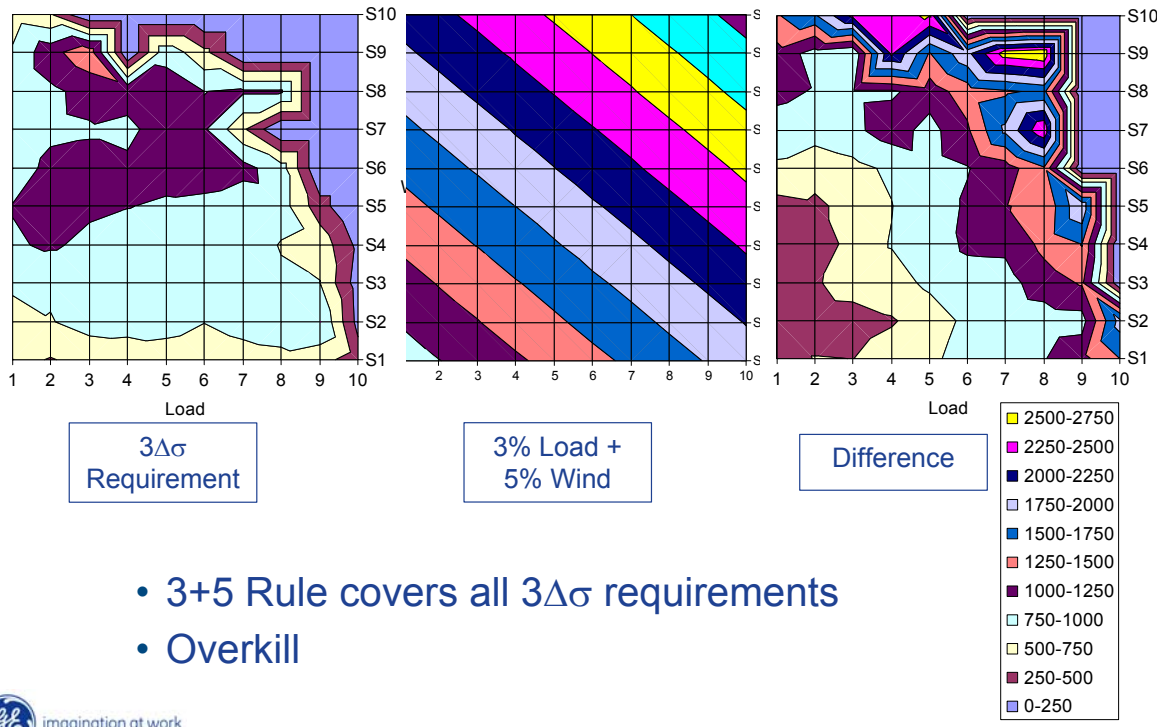
## In Footprint L30R 3% Load plus 5% Wind Rule




3Δσ Requirement

3% Load + 5% Wind

Difference

- 3+5 Rule covers all 3Δσ requirements
- Overkill

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# Best Fit

The idea of a fit is relatively simple: we determine single scalar value of X (a "load coefficient") and Y (a "wind coefficient"), such that the error, given by:

$$\text{error} = \iint \beta(\lambda,\omega) * (3\Delta\sigma(\lambda,\omega) - (X\lambda + Y\omega))2 \; d\lambda \, d\omega$$

is minimized, where

- $\lambda$ is a particular load level
- $\omega$ is a particular wind level
- $\beta(\lambda,\omega)$ is the probability of being at a particular load l and wind power w
- $\Delta\sigma(\lambda,\omega)$ is the 10-minute delta sigma

The equation is integrated over the entire load and wind space: net result is an "RMS" best fit: an "X+Y rule"

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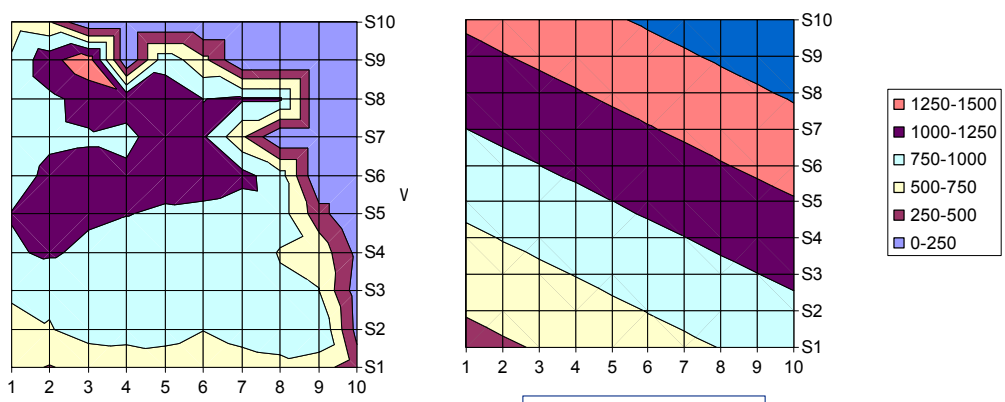
# In Footprint L30R Net Load Variability X+Y rule




3Δσ Requirement

X+Y rule:
RMS best fit:
1.3% Load
3.6% Wind

- Promising
- Less at low wind; extra at high wind

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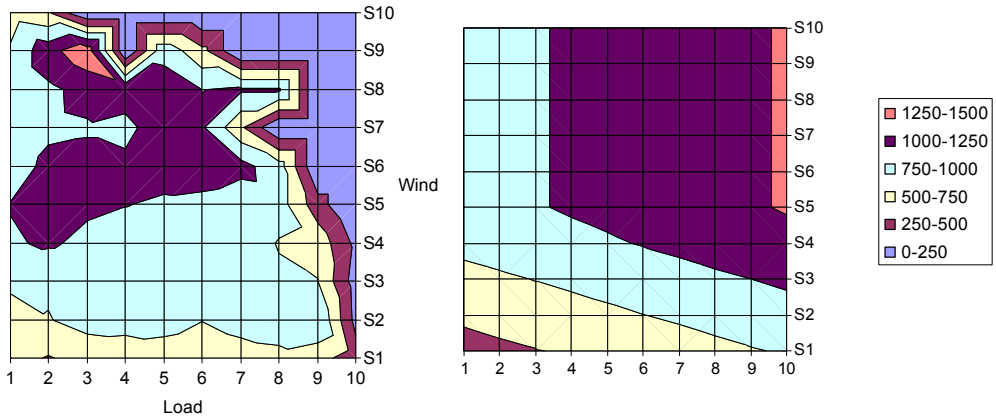
## In Foot print L30R Net Load Variability X+Y Conditional rule




3Δσ Requirement

X+Y conditional rule:
1.1% Load
5.0% Wind < 47% Wind Nameplate



# Variability Reserve Requirement Rules

| | Load Only | 30% LP Scenario | | |
|---|---|---|---|---|
| | (% of load) | Load Term (% of load) | Wind Term (% of wind production) | up to (% of wind nameplate) |
| Footprint | 1.3 | 1.1 | 5 | 47 |
| Arizona | 2.2 | 2.2 | 5.6 | 36 |
| Nevada | 2.1 | 1 | 10.7 | 54 |
| Colorado East | 2.4 | 2 | 5.7 | 68 |
| New Mexico | 2 | 3.1 | 3.5 | 70 |
| Wyoming | 1.3 | 2.7 | 8.7 | 33 |
| Colorado West | 1.8 | 3.1 | 7.3 | 100 |

- Average requirement to cover *variability* is roughly double:
  - ~425 MW vs ~850 MW at footprint
  - Requirements roughly double for reserves by area (vs. footprint)

# Intra-hour Variability Performance

- How did the system 'naturally' in MAPS perform?
- We show how L30R MAPS case results compare to implied reserve requirements.

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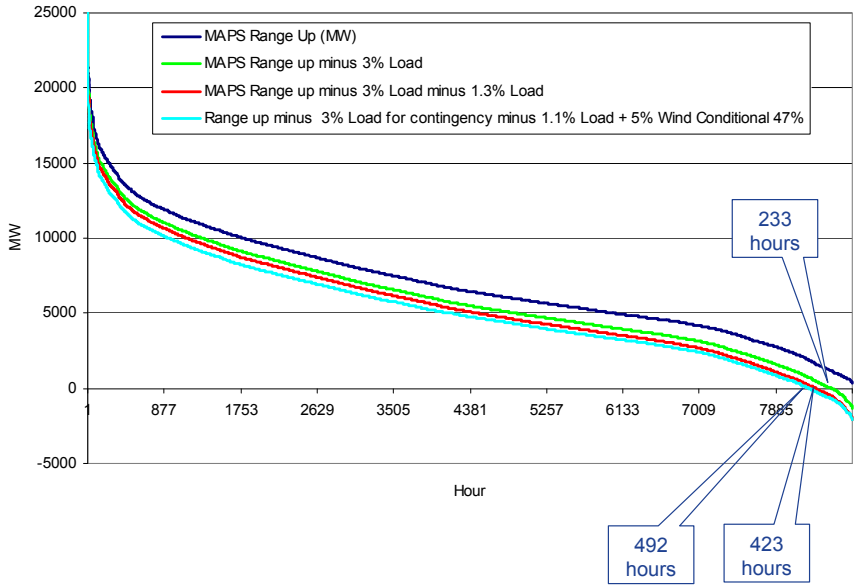
# Reserve Duration - Best Fit (X+Y Conditional) Rules

- 233 hours <3%
- 89 hours actual contingency reserve short fall
- 492 hours of variability reserve short fall:
- ~5%

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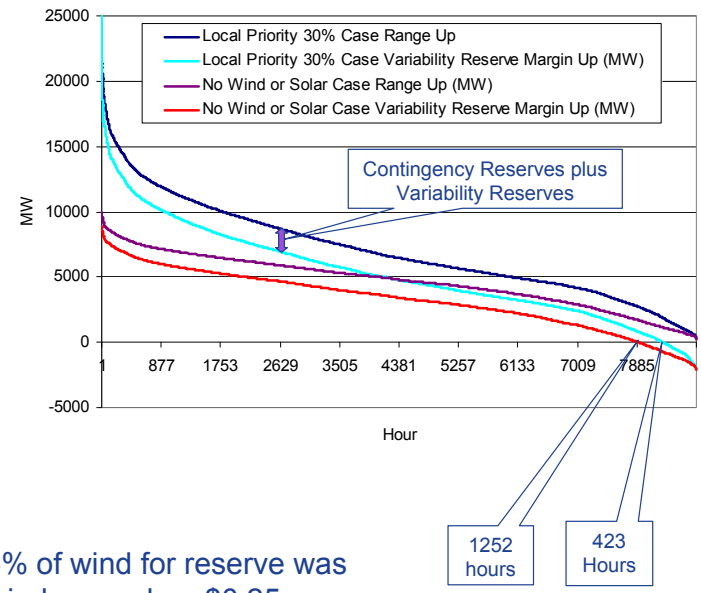
# Comparison to No Wind and Solar

- Variability requirements increase with wind and solar
- Displacement of other resources tends to release up reserves
- Without explicitly requiring additional reserves for variability, the system economics provide sufficient reserves about 95% of the time, at the footprint level
- This is consistent with WECC guidelines for handling variability and with CPS2 targets




- Committing units to provide 5% of wind for reserve was shown to reduce the value of wind power by ~$0.25 per MWhr. The above results suggest this is not necessary.

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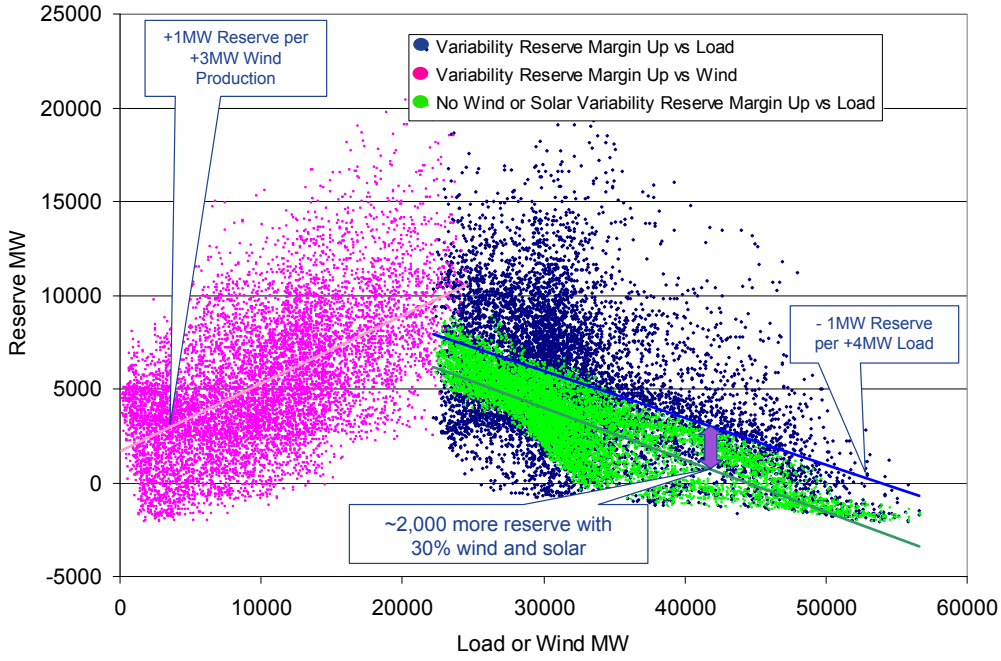
# Variability Reserve Margins

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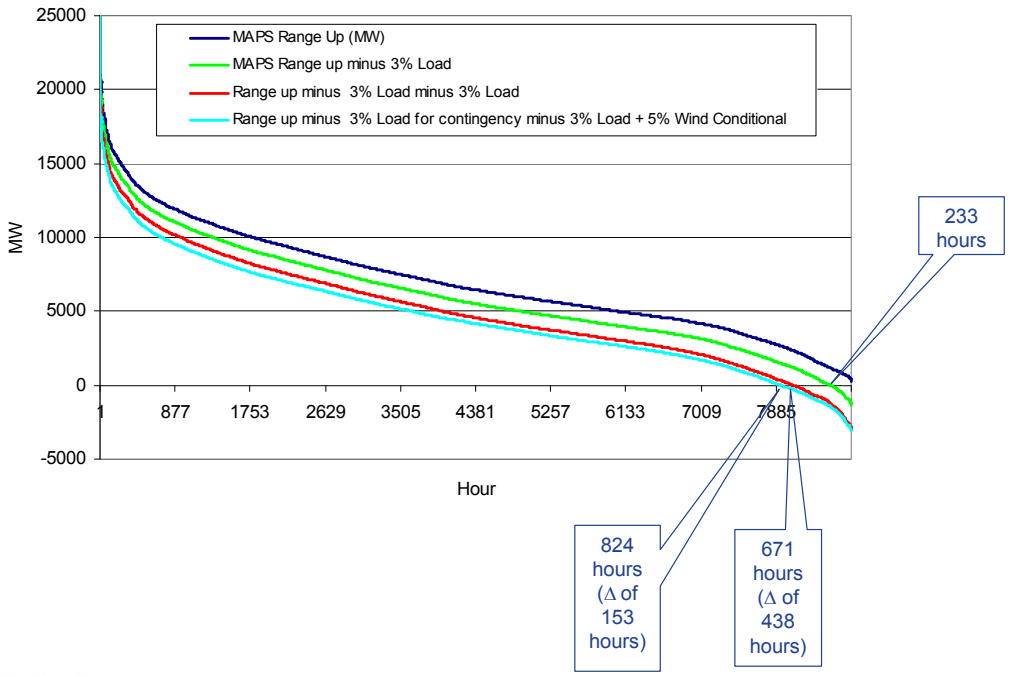
# Reserve Duration - 3+5 Rules

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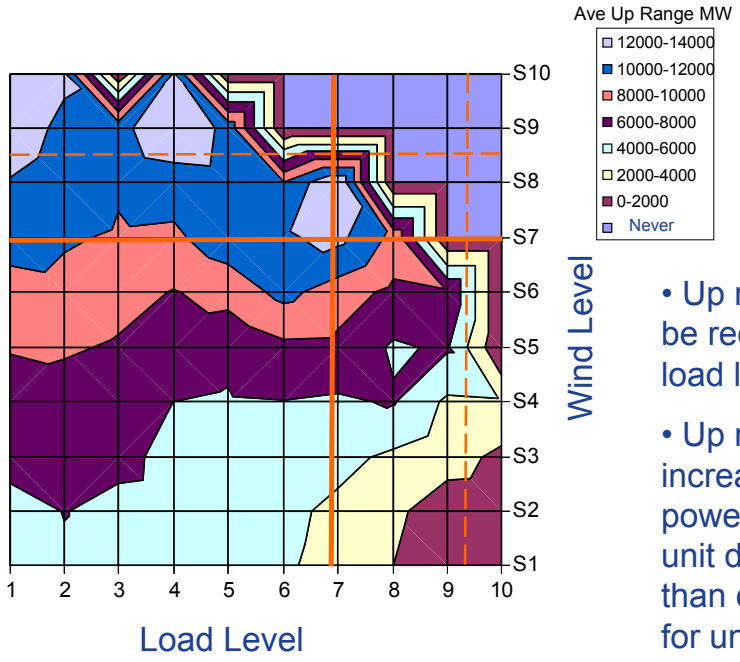
# Average Up Range L30R case




- Up reserves tend to be reduced at high load levels
- Up reserves tend to increase with wind power: reduction in unit dispatch more than compensates for unit de-commitments

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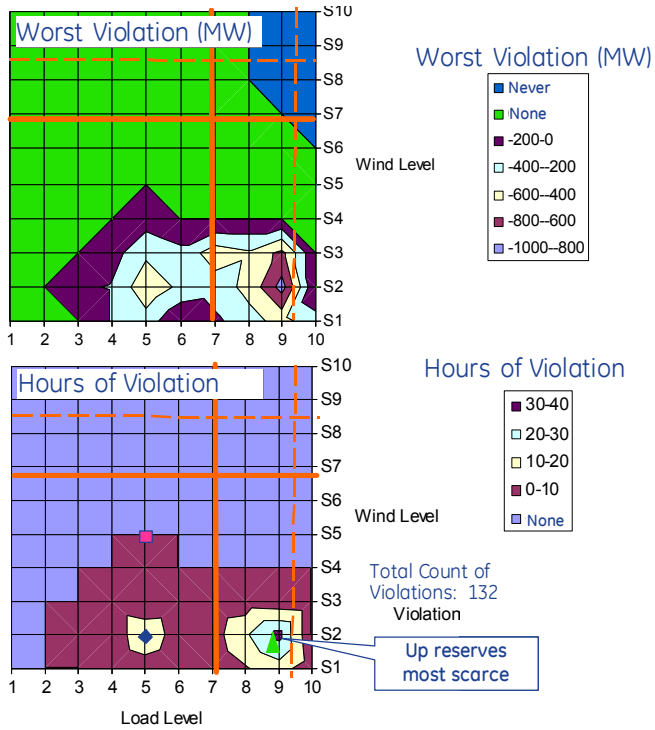
# L30R Case Up Reserve Violations

- Implied reserve requirement is 3 x σ 10-min Δ Net Load
- Violation if **Up Range** (from MAPS case) < 3σ
- Violation means hour has insufficient reserves to meet implied requirement. Load is still served.

Scarcity of reserves at very high load aggravated by increased reserve requirement due to wind variability

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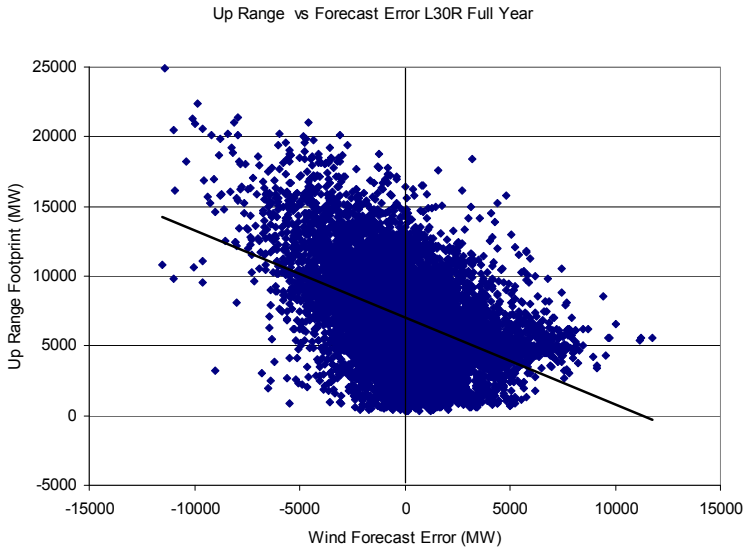
# Up Reserves vs. Forecast Error (Full Year)

Available Reserves are impacted by forecast error, but not dominated by them

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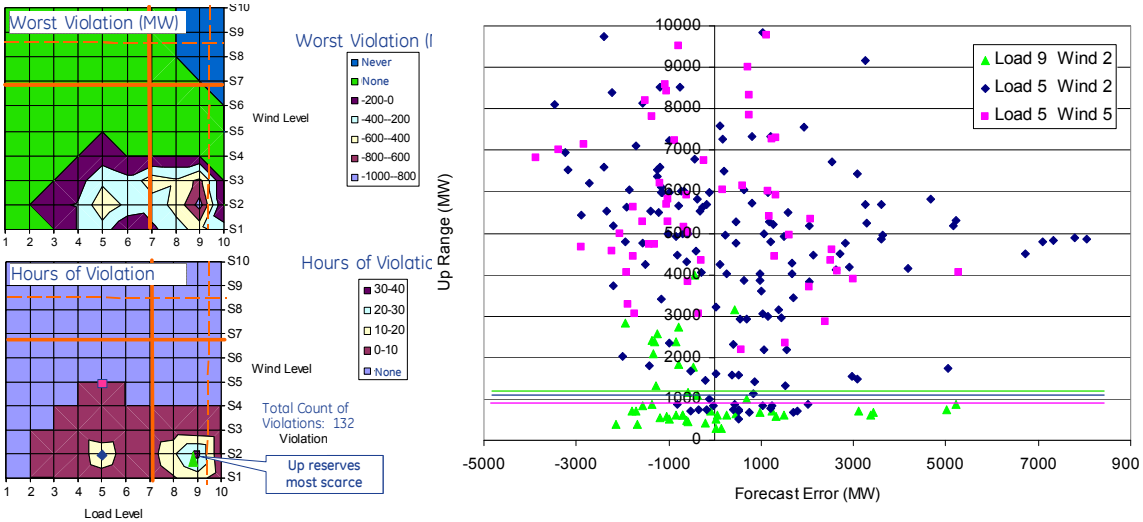
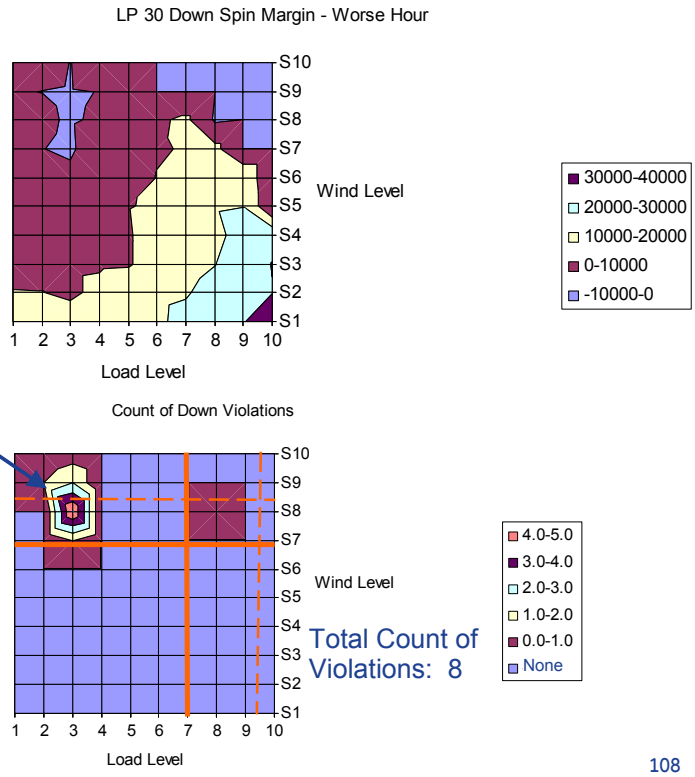
# Up Reserves vs. Wind Forecast Error (Selected Load – Wind Pairs)



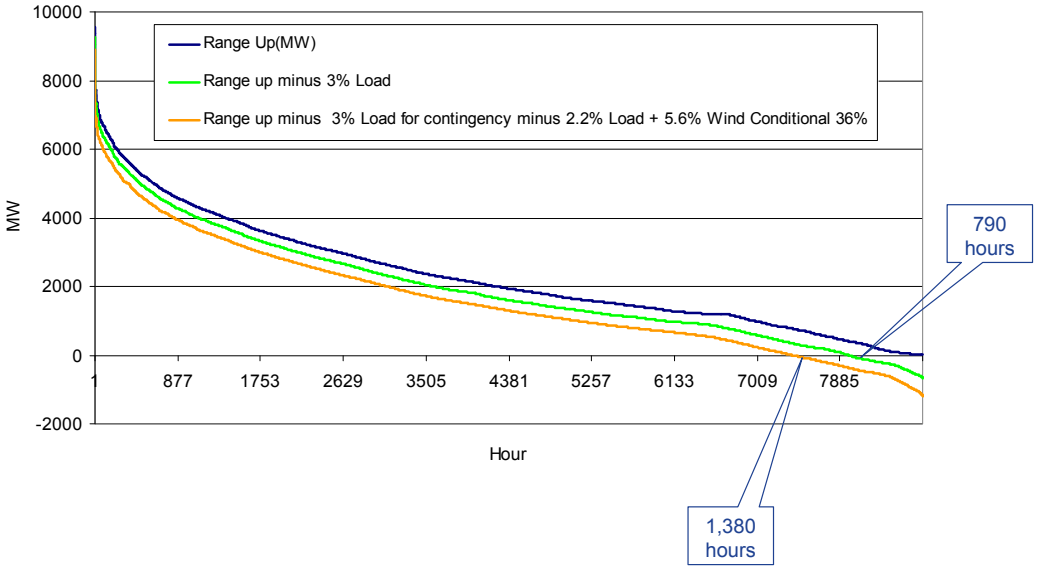



# L30R Case Down Reserve Violations

- Scarcity of down reserves at very high wind and relatively light load is consistent with other results



# Az Reserve Duration - X+Y Rules

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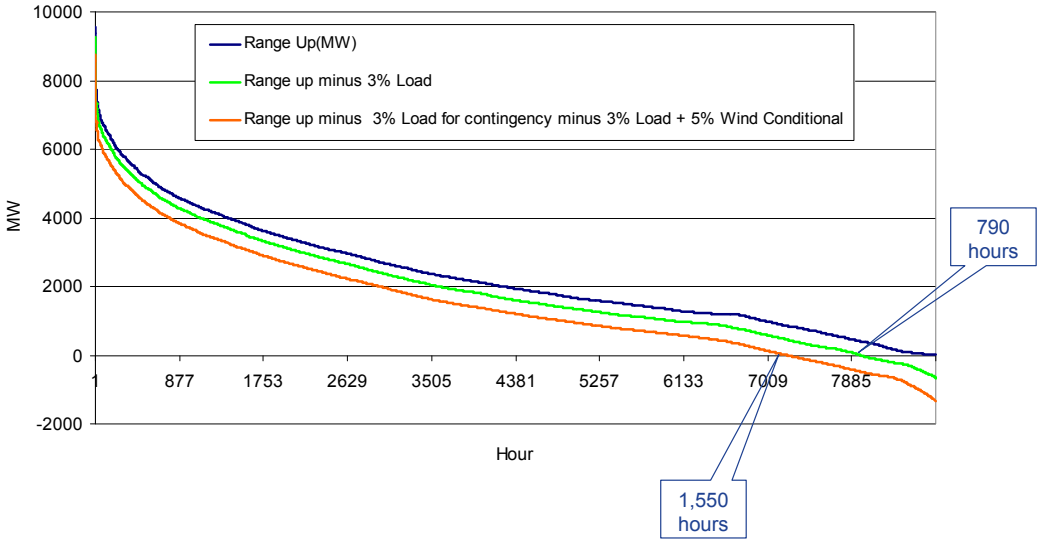
# Az Reserve Duration - 3+5 Rules

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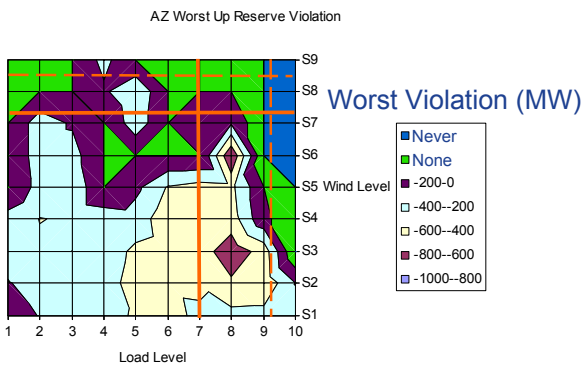
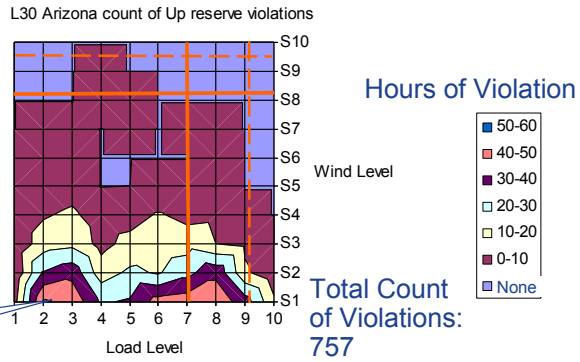
# Arizona L30R Case up Reserve Violations

- Worst violations at high load and moderate wind
- Frequent violations at low wind moderate load: due to Forecast error (?)




Up reserves short due to over-forecast of wind power ?

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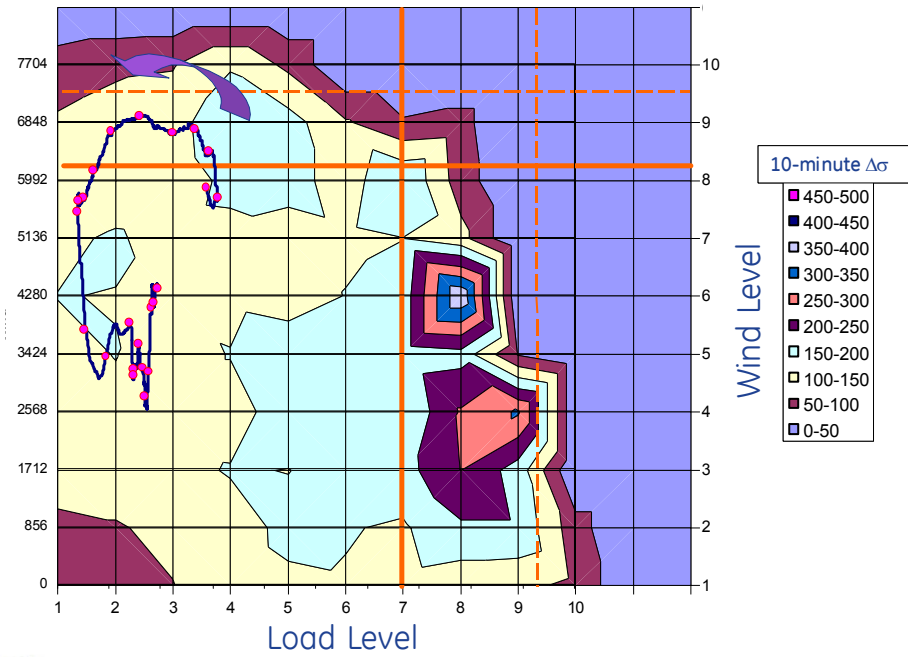
# Arizona L30R Scenario October 26 2006 Trajectory

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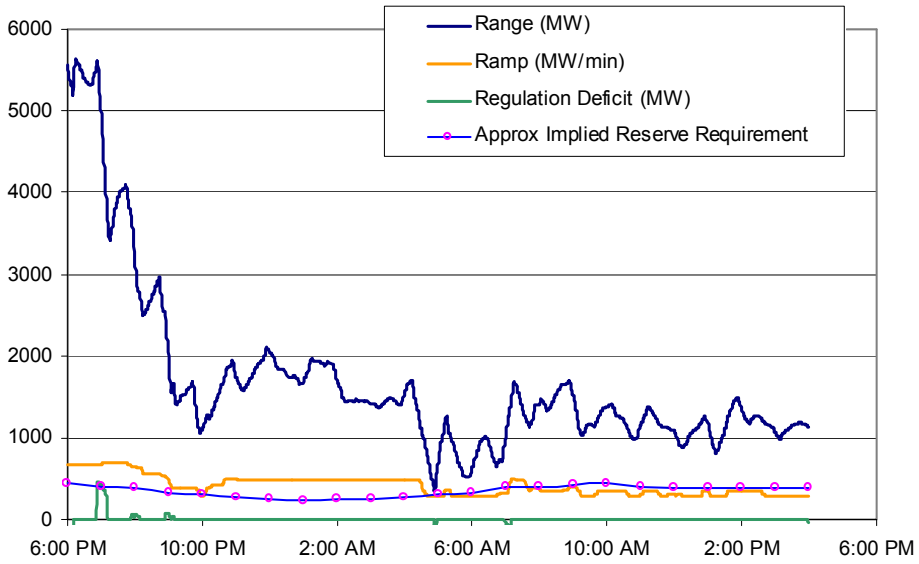
# Arizona L30R Scenario Results October 26 2006

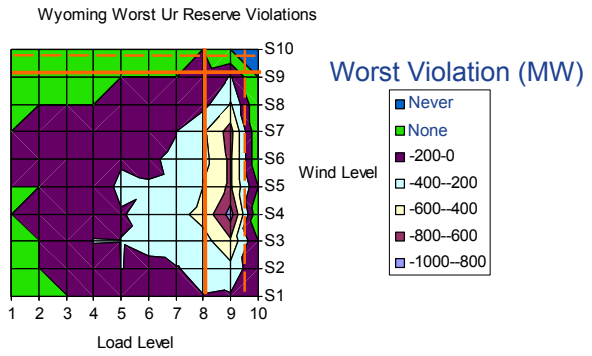


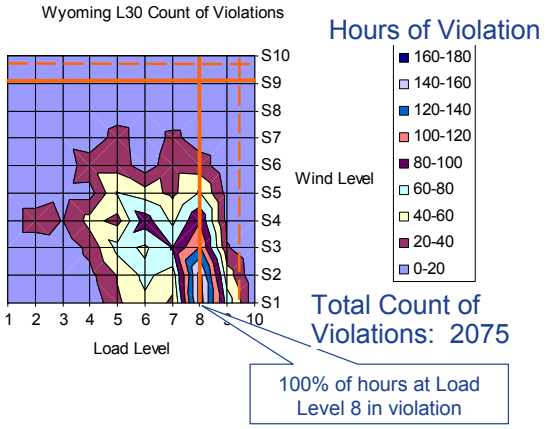

imagination at work



# Wyoming L30R Case up Reserve Violations

- Wyoming, with about twice as much wind as load, doesn't come close to meeting implied reserve requirement with in-state resources in this case

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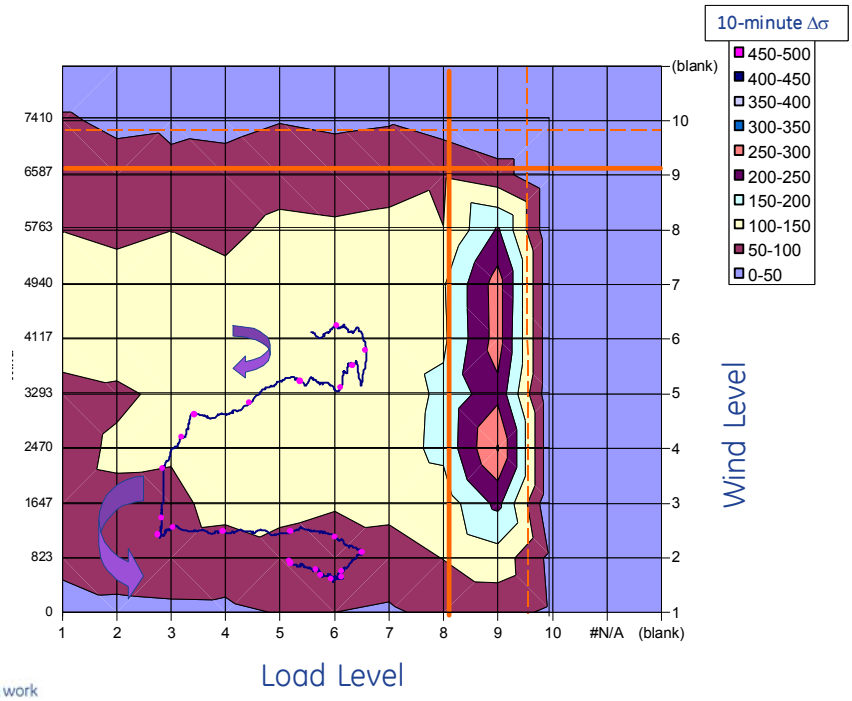
# Wyoming L30R Net Load Variability October 26 2006 Trajectory

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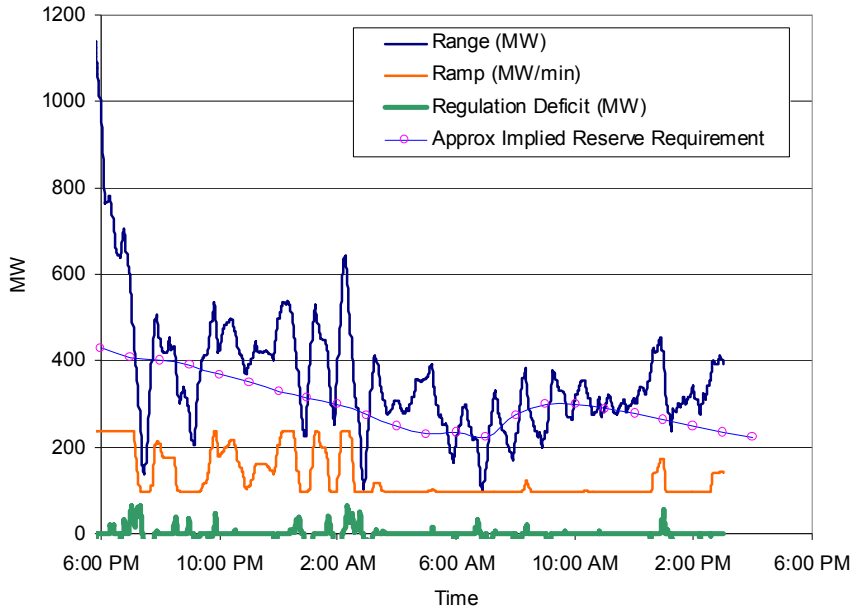
# Wyoming L30R Scenario October 26, 2006 Results

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# Conclusions

- Variability increases with wind and solar
- Incremental reserves are needed to cover most of this variability without impacting contingency reserves
- Relatively simple variability reserves rules, based on load and wind production, can be devised
- Displacement of other resources tends to release up reserves
- Without explicitly requiring additional reserves for variability, the system economics provide sufficient reserves about 95% of the time, at the footprint level
- This is consistent with WECC guidelines for handling variability
- Reserve requirements, if carried by individual areas, are greater
- Committing Units to Provide 5% of Wind for reserve was shown to reduce the value of wind power by ~$0.25 per MWhr. These results suggest that it is not necessary.
- Further industry investigation of reserve requirements and strategies is needed

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