Outline

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2. Statistical Analysis
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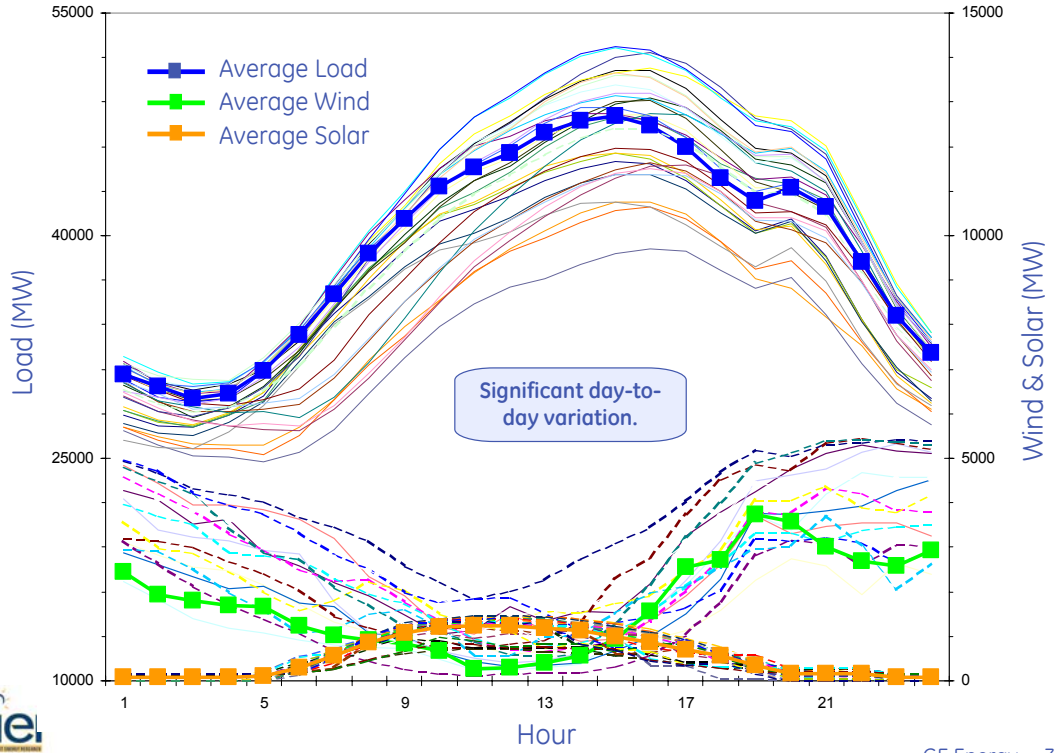
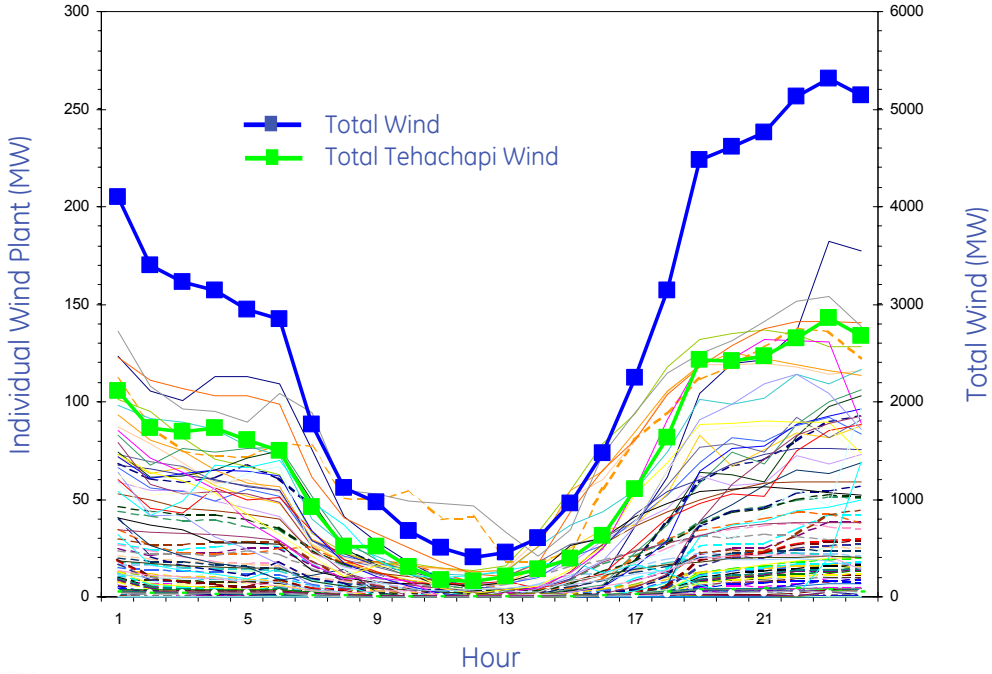
4. Quasi-Steady-State Analysis, QSS
5. Operational Implications and Mitigation Methods
6. Conclusions and Recommendations

Temporal/Seasonal/Spatial Patterns

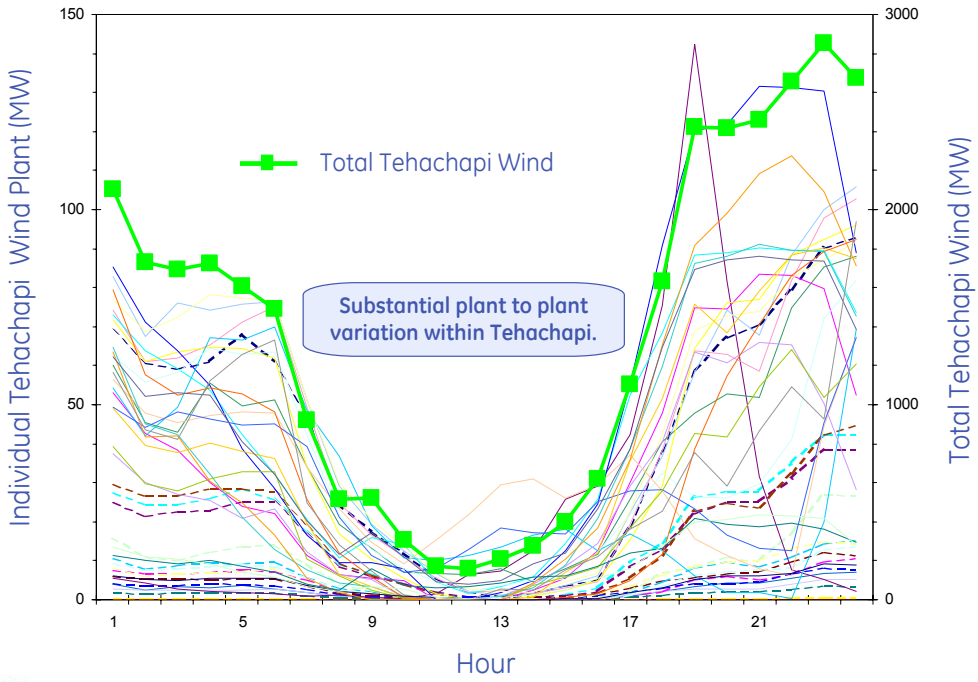
Temporal Pattern: All Days of July 2003



Spatial Pattern: July 21, 2003

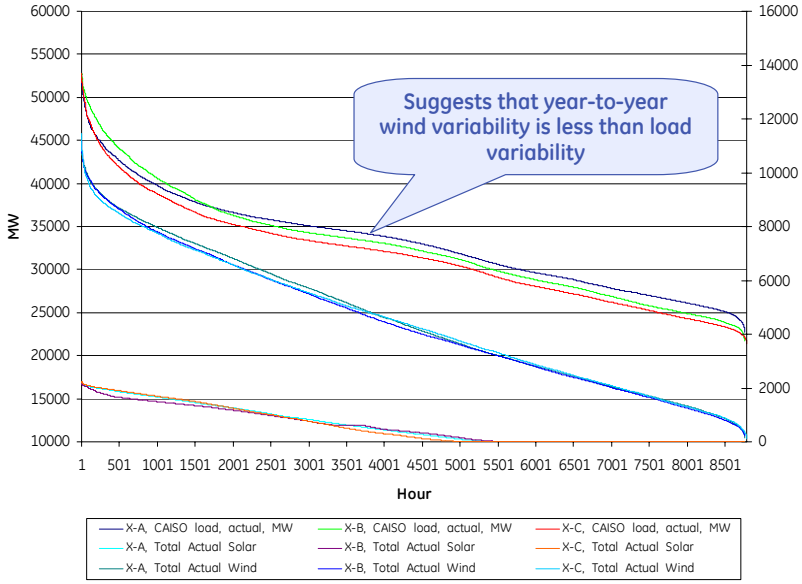


Spatial Pattern: July 21, 2003



2010X-ABC Duration Curves

A = 2002 load shape
B = 2003 load shape
C = 2004 load shape



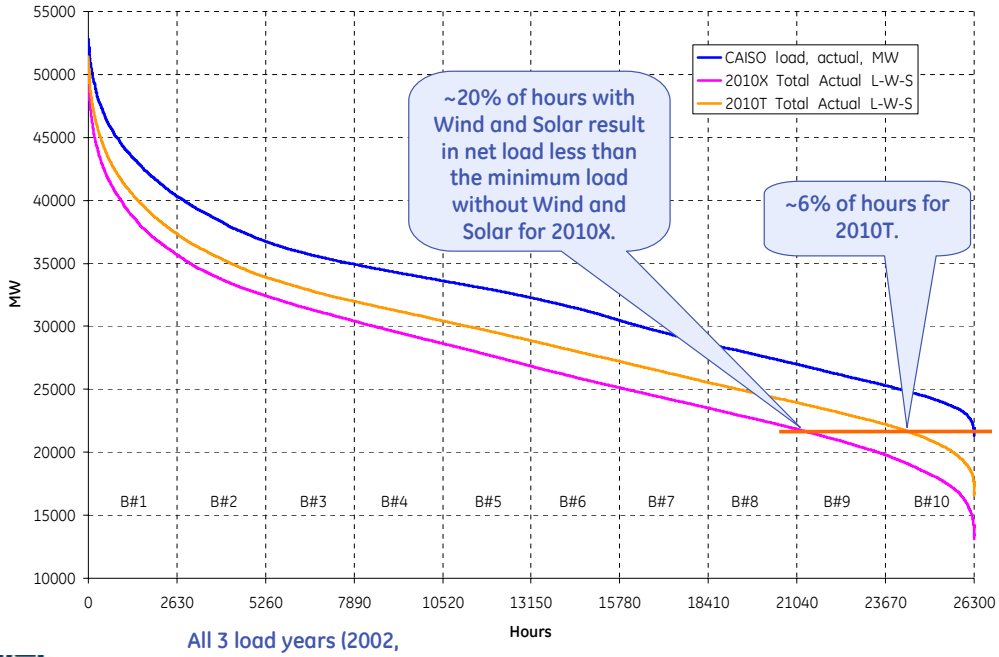
Hourly Statistical Analysis:

2010: Accelerated (X) and Tehachapi (T) Cases

Penetration Overview

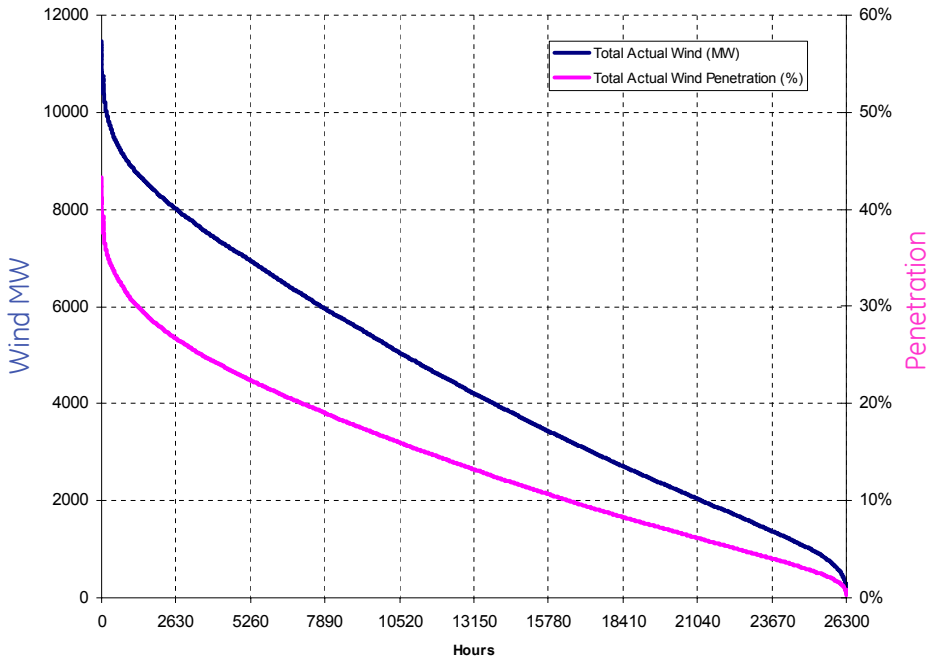
(Results by Load Level, Divided into Ten Groups or Deciles)

2010 Hourly Load Duration Curves
Load Alone vs. Load – Wind - Solar

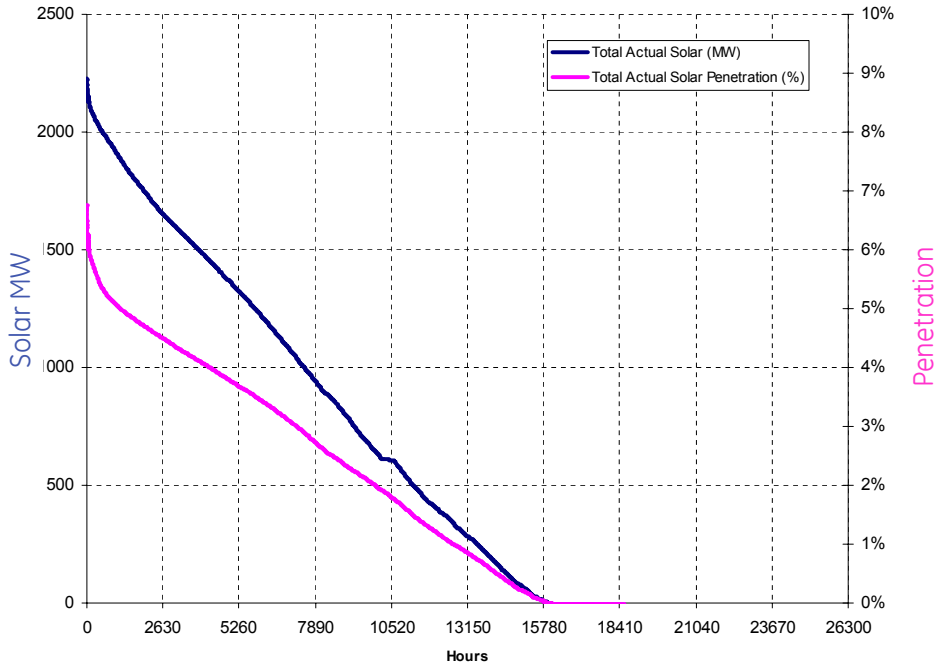


All 3 load years (2002, 2003, 2004) included

Wind Generation and Penetration Duration Curves – 2010X



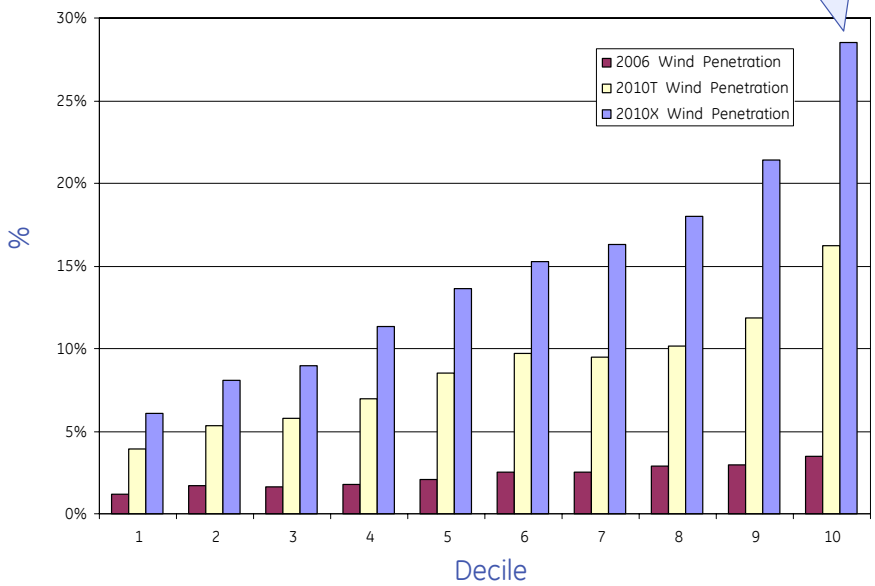
Solar Generation and Penetration Duration Curves – 2010X



Hourly Wind Penetration – 2006 & 2010

Wind Penetration = Average Wind MW / Average Load MW

Wind penetration for light load decile approaches 28%.



Hourly Delta Statistical Analysis:

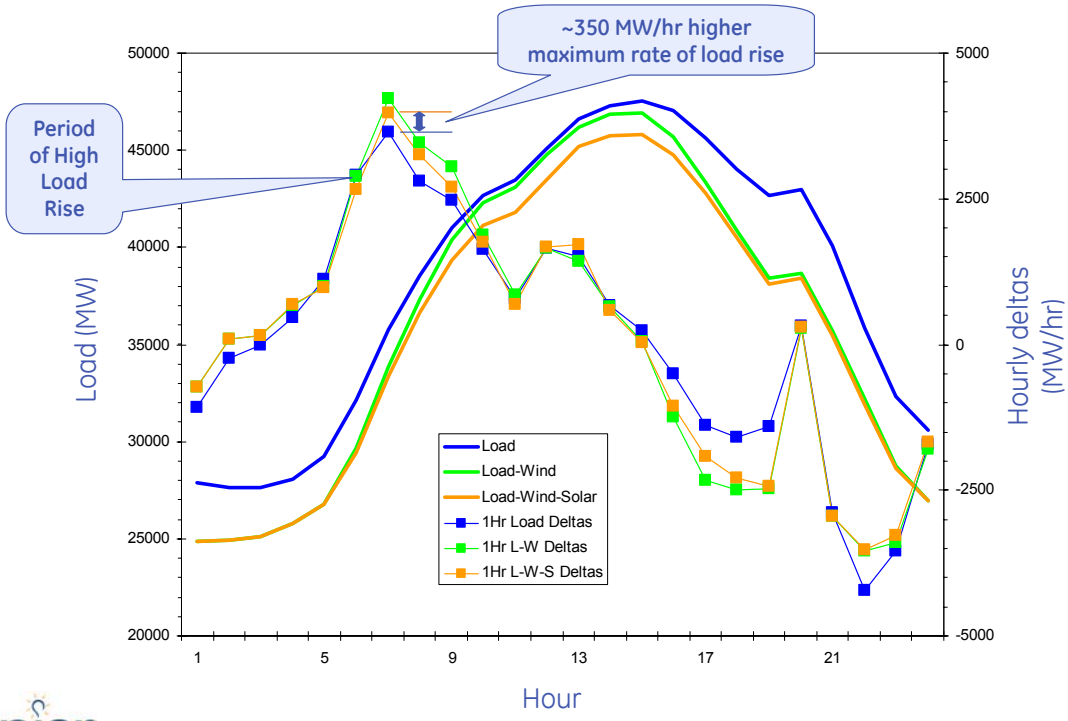
2010: Accelerated (X) and Tehachapi (T) Cases

(Results by Load Level)

- 1 hour and 3 hour variability

- Details for selected months

1-Hour Delta (Hour-to-hour Change) Example: July 1, 2002



Statistics Terminology

Statistical analysis provides maneuverability/flexibility requirements.

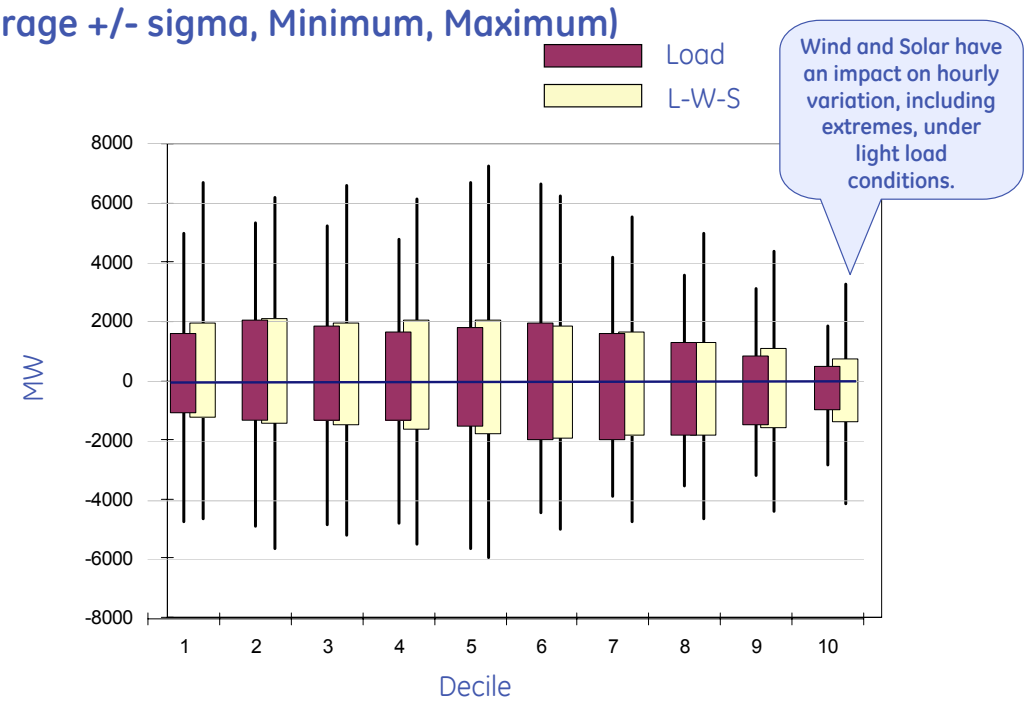
Changes in load and net load (load minus wind minus solar) relate to three types of operating requirements:

1-hr Delta	Schedule flexibility
5-min Delta	Load Following capability/Economic Dispatch
1-min Delta	Regulation

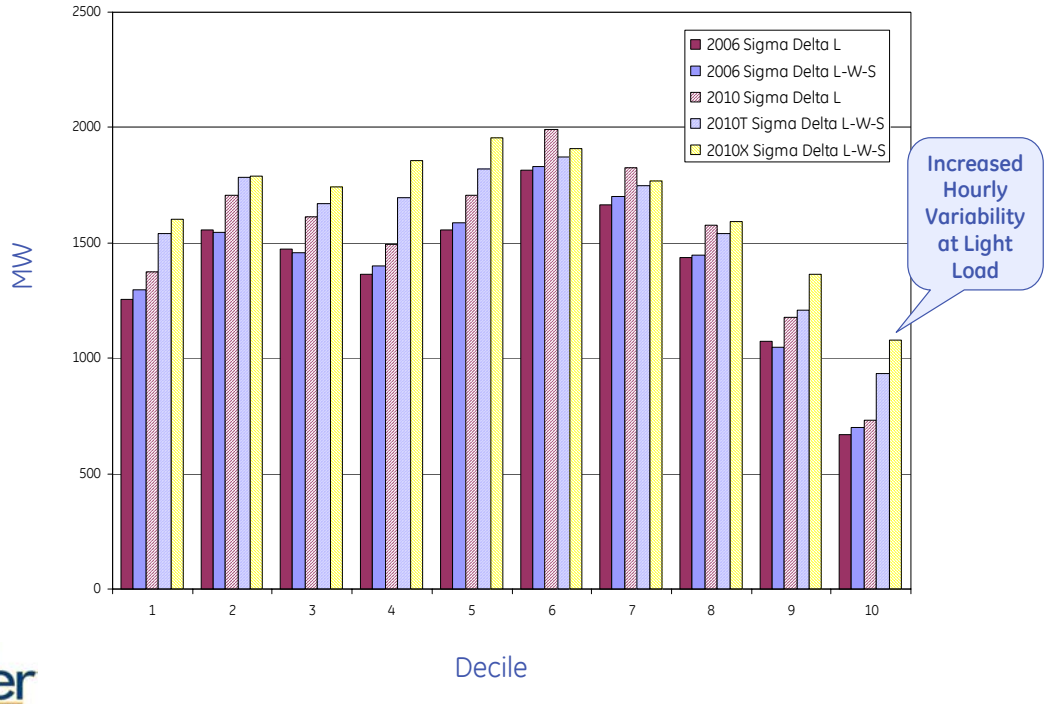
3 times standard deviation (σ) is a proxy for maneuverability/flexibility requirements - the vast majority (99.7%) of events fall within +/-3 σ (in a normal population)

Increase in 3σ is one measure of requirement for additional maneuverability/flexibility due to increased variability

2010X 1-Hour Load and Load-Wind-Solar Deltas (Average +/- sigma, Minimum, Maximum)



2010 & 2006 Standard Deviation of 1-Hour Deltas



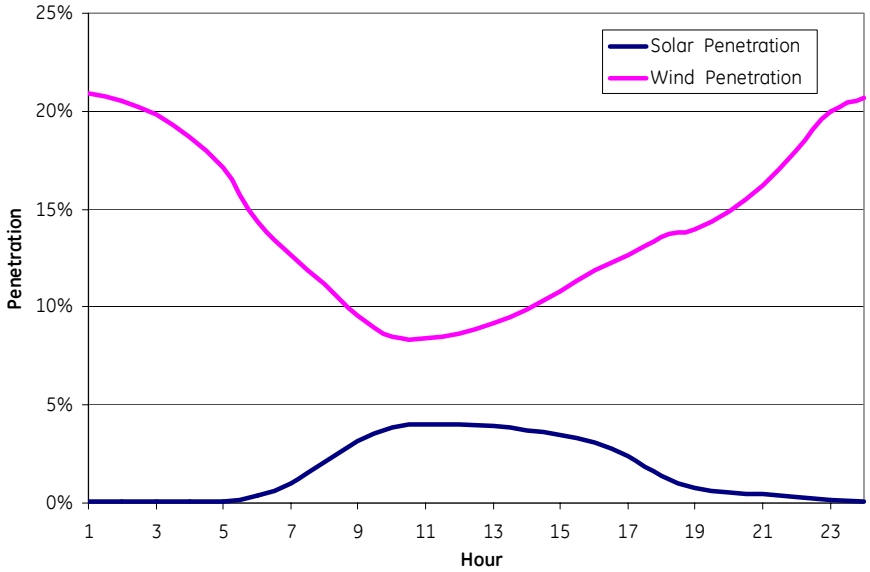
Hourly Statistical Analysis:

2010: Accelerated (X) and Tehachapi (T) Cases

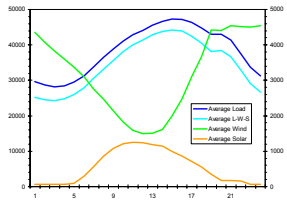
(Results by Time-of-Day)

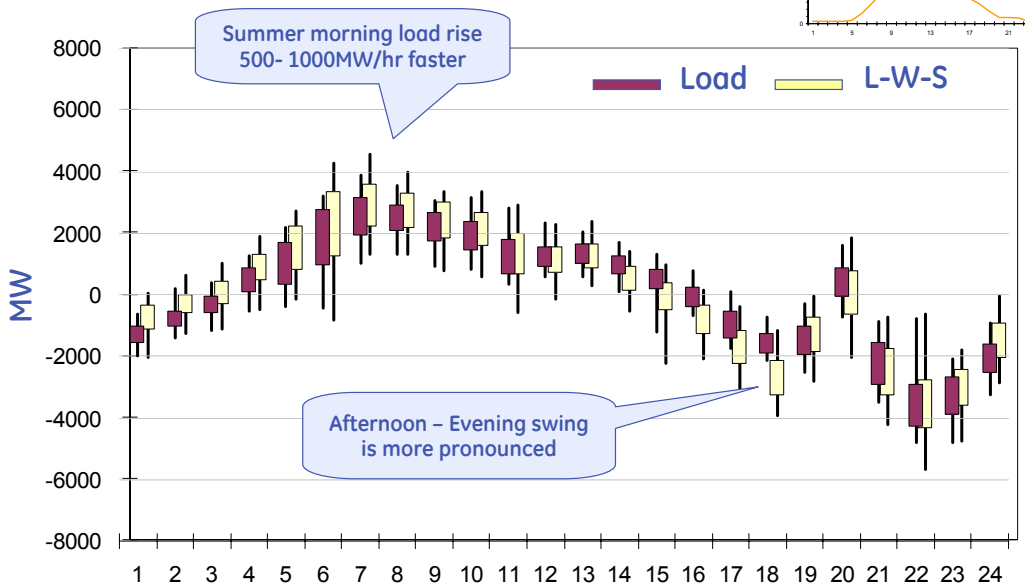
Hourly Wind and Solar Penetration – 2010X

Wind Penetration = Average Wind MW / Average Load MW
Solar Penetration = Average Solar MW / Average Load MW



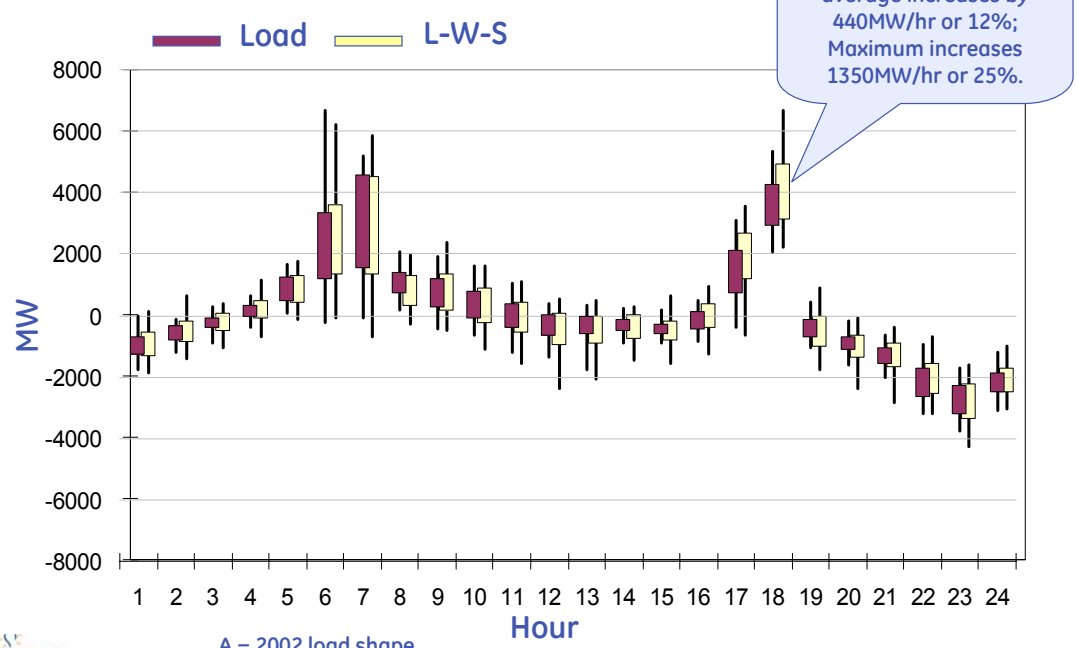
2010X-ABC July, 1-Hour Load and L-W-S Deltas (Avg. +/- sigma, Minimum, Maximum)





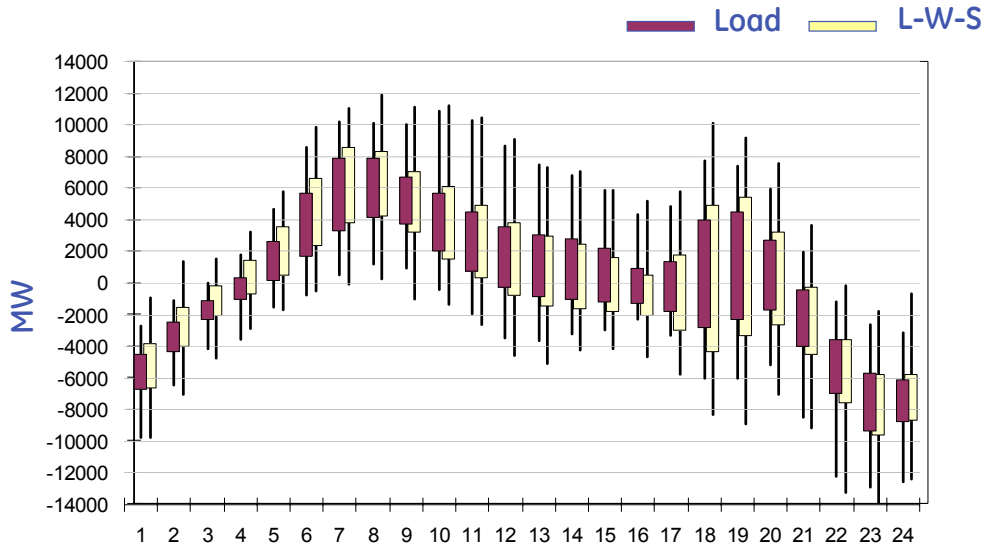
A = 2002 load shape
B = 2003 load shape
C = 2004 load shape

2010X-ABC January, 1-Hour Load and L-W-S Deltas (Avg. +/- sigma, Minimum, Maximum)



A = 2002 load shape
B = 2003 load shape
C = 2004 load shape

2010X-ABC, 3-Hour Load and L-W-S Deltas (Avg. +/- sigma, Minimum, Maximum)



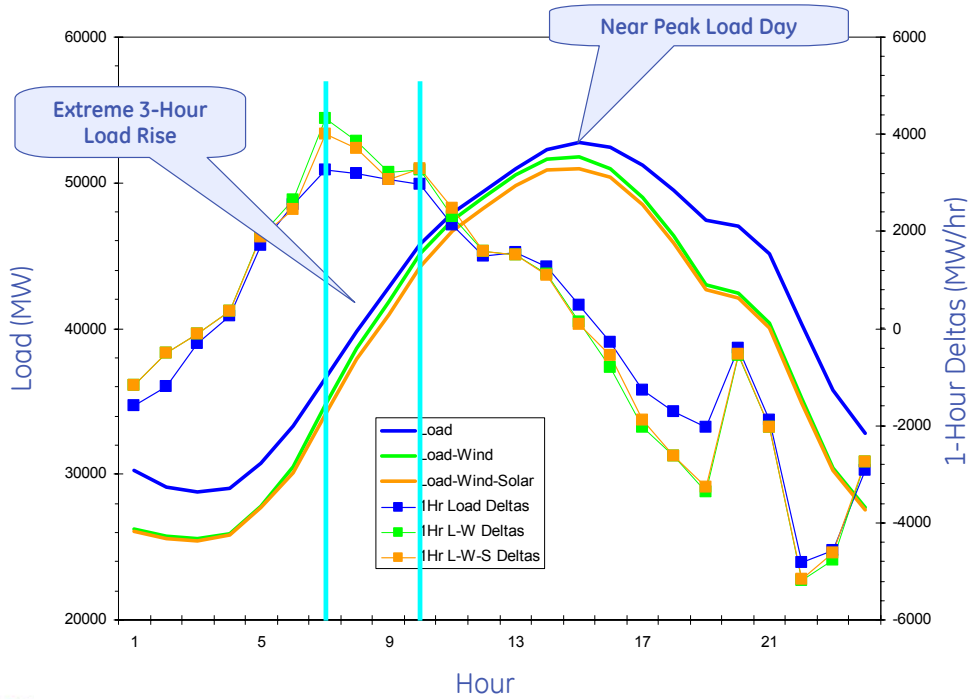
A = 2002 load shape
B = 2003 load shape
C = 2004 load shape

Hourly Statistical Analysis:

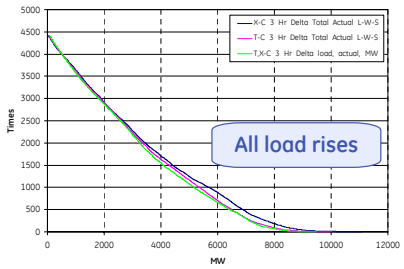
2010: Accelerated (X) and Tehachapi (T) Cases

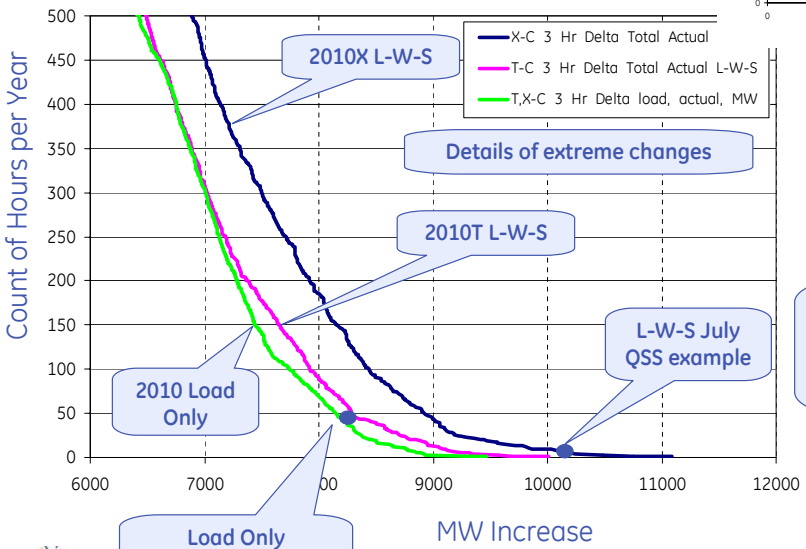
Extremes of 1 hour and 3 hour variability

Example Summer Day: July 21, 2003



2010 (C) 3-Hour Positive Delta Duration Curves

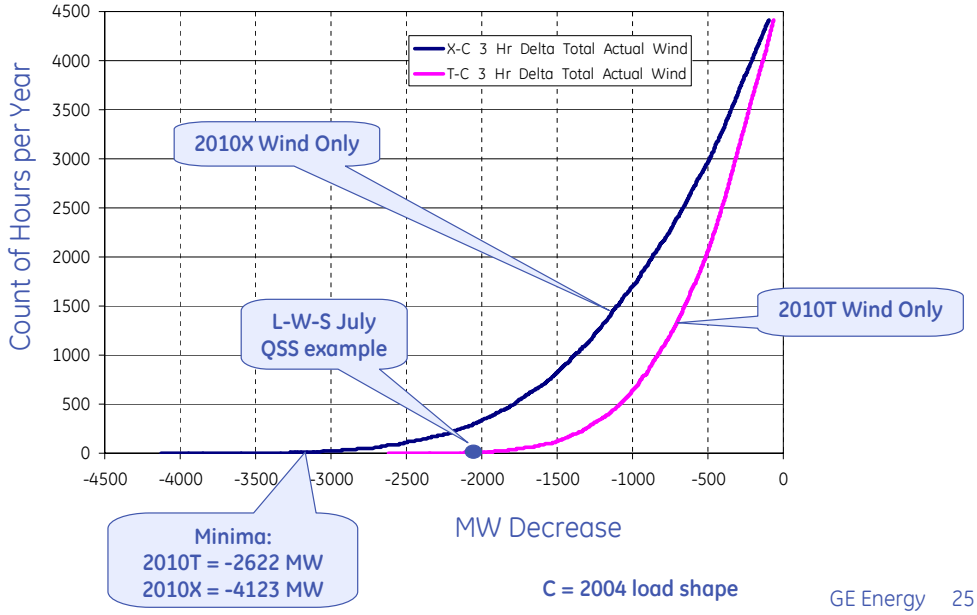




Maxima:
2010 Load = 9464 MW
2010T L-W-S = 10012 MW
2010X L-W-S = 11085 MW

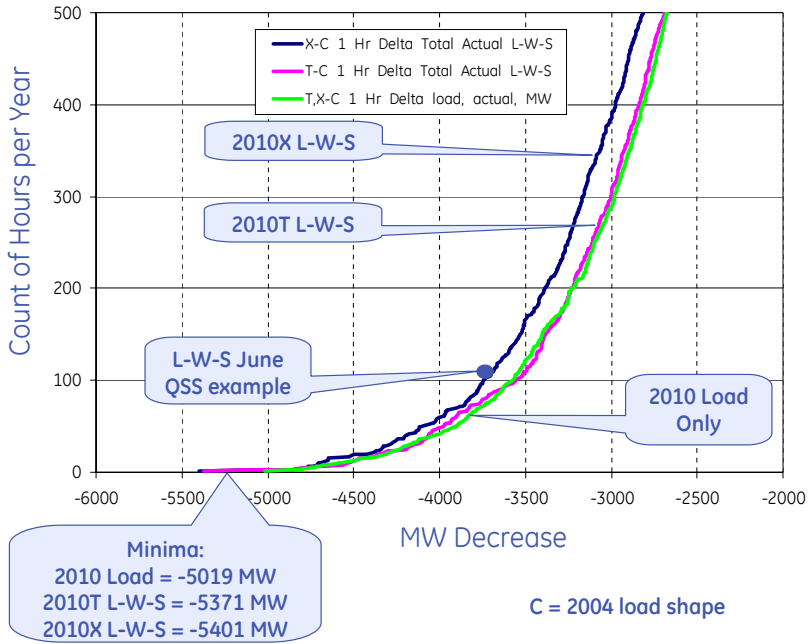
C = 2004 load shape

2010 (C) 3-Hour Negative Delta Wind Duration Curves



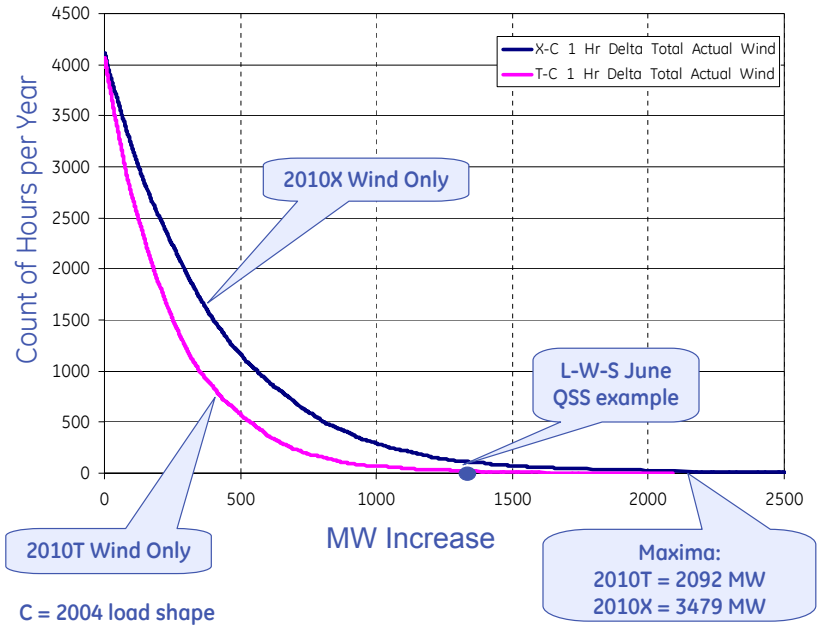
C = 2004 load shape

2010 (C) 1-Hour Negative Delta Duration Curves



C = 2004 load shape

2010 (C) 1-Hour Positive Wind Delta Duration Curves

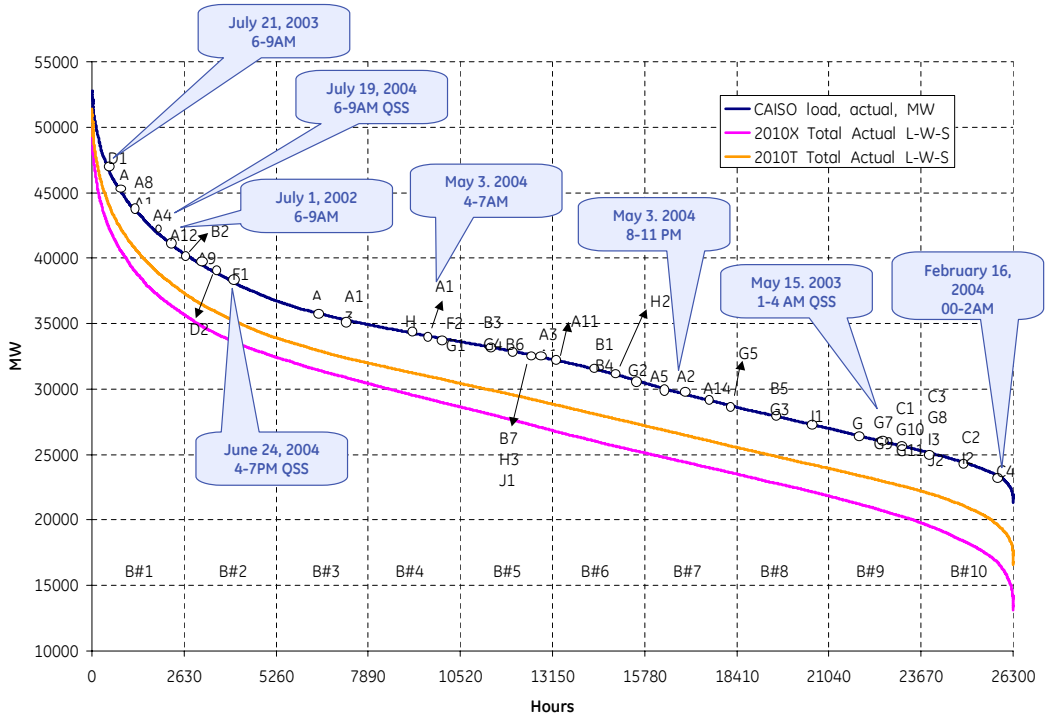


C = 2004 load shape

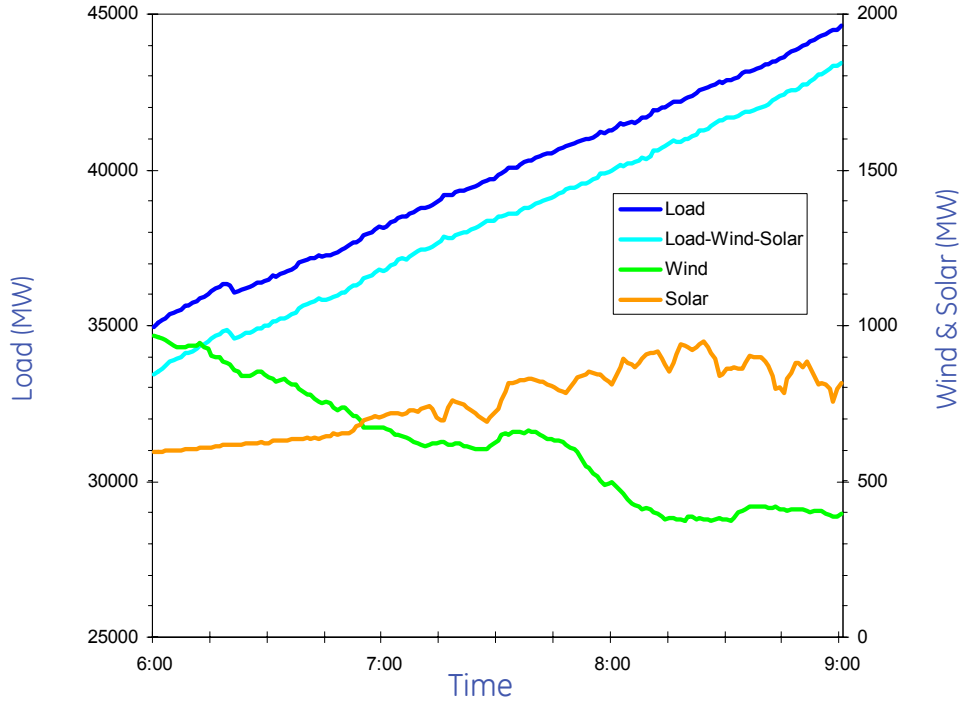
Statistical Analysis: Search for Extremes

- Detailed analysis of selected 3-hour periods exhibiting intermittent behavior
- Search for interesting behavior included:
  - Large changes in load over 1 and 3 hour periods
  - Periods of high wind and solar output
  - Periods of high penetration of wind and solar
  - Low load periods
  - Large changes in wind and solar over 1 and 3 hour periods
  - Periods of high wind with low wind variability
- Specific 3-hour periods were selected from the top 20 of each category for variety in:
  - Year
  - Time of year
  - Time of day
  - Big changes driven by load, wind or solar
  - Direction of changes (up and down)

2010 Load Duration Curve

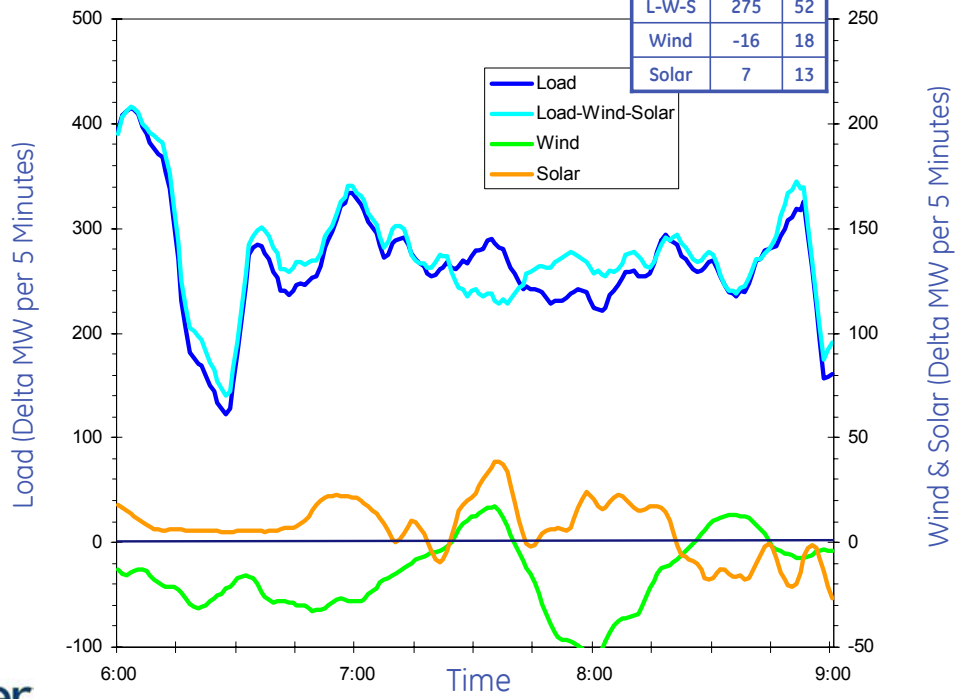


Morning Load Rise Detail: July 21, 2003



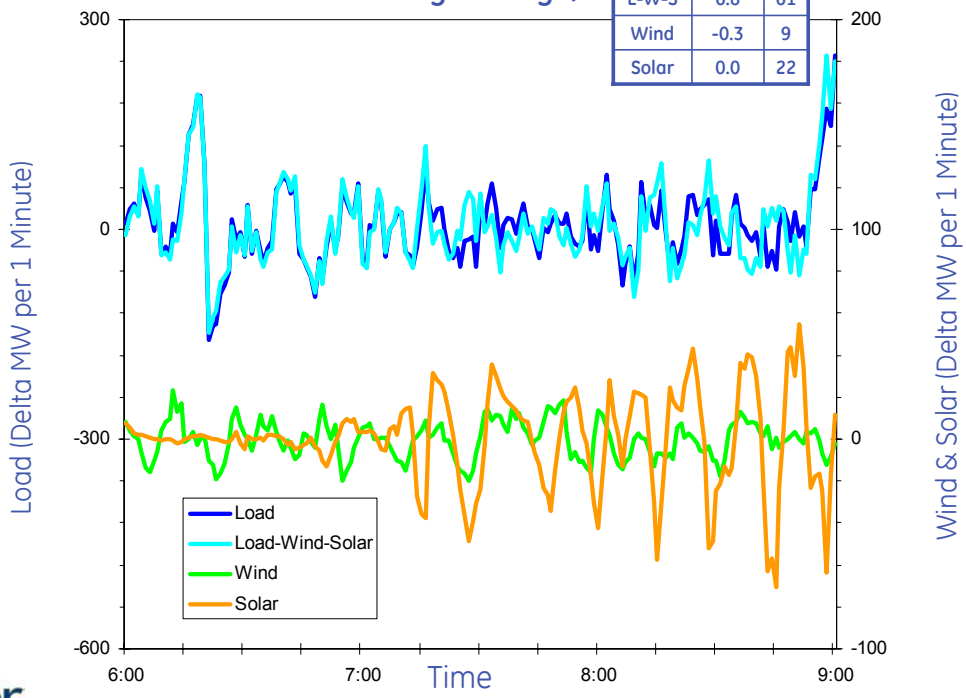
Load Following Requirement: July 21, 2003
(5 Minute Deltas on 15 Minute Rolling Average)

	Mean	σ
Load	265	54
L-W-S	275	52
Wind	-16	18
Solar	7	13



Regulation Requirement : July 21, 2003
(1 Minute Deltas from 15 Min Rolling Average)

	Mean	σ
Load	6.5	56
L-W-S	6.8	61
Wind	-0.3	9
Solar	0.0	22



2006 - 2010 Statistical Analysis: Total Variability

	σ 1-Hour Δs (MW)	σ 5-Min Δs (MW on 15-Min RA)	σ 1-Min Δs (MW from 15-Min RA)	Max, Min 1-Hour Δs (MW)	Max, Min 5-Min Δs (MW on 15-Min RA)	Max, Min 1-Min Δs (MW from 15-Min RA)
2006 Load	1436	189.3	44.8	6123, -5122	526, -480	803, -305
2006 L-W-S	1451	189.9	44.9	6091, -5155	550,-481	803, -306
Change	15	0.3	0.1	-32, -33	24, -1	0, -1
2010 Load	1575	207.6	49.1	6714, -5617	577,-527	881,-334
2010T L-W-S	1623	214.5	50.7	6312, -5713	699, -522	887,-323
Change	48	6.9	1.6	-402, -96	122, 5	6,11
2010X L-W-S	1704	221.8	52.4	7219, -5986	722, -530	884, -335
Change	129	14.2	3.3	505, -37	145, -3	3, -1

Wind and Solar reduce the extreme 1-hour load rise.

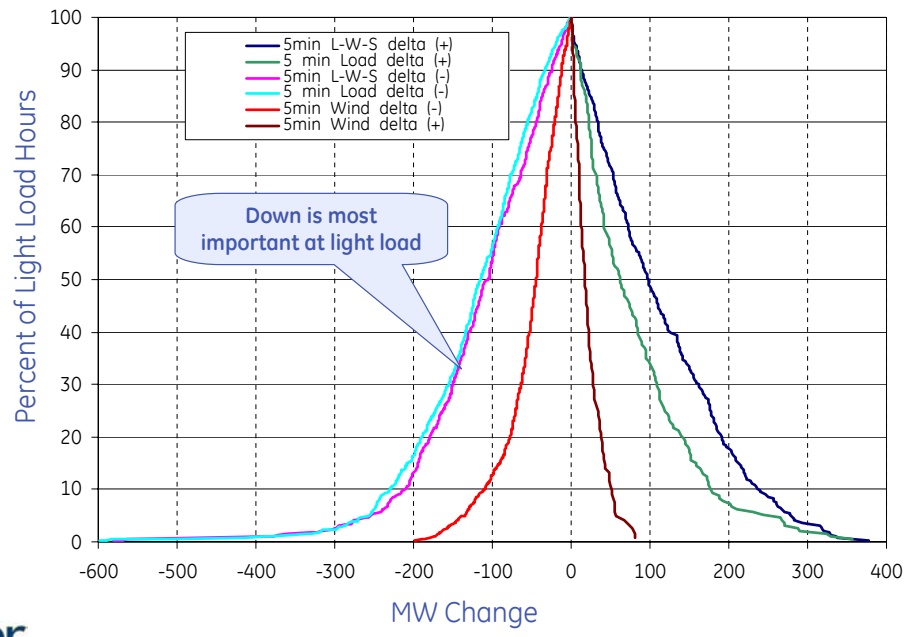
2006 - 2010 Statistical Analysis: Light Load (10th Decile) Variability

	σ 1-Hour Δs (MW)	σ 5-Min Δs (MW on 15-Min RA)	σ 1-Min Δs (MW from 15-Min RA)	Max, Min 1-Hour Δs (MW)	Max, Min 5-Min Δs (MW on 15-Min RA)	Max, Min 1-Min Δs (MW from 15-Min RA)
2006 Load	669	86.5	40.8	1707, -2567	154,-257	200,-194
2006 L-W-S	699	89.2	40.9	2448, -2613	174,-257	198,-193
Change	30	2.7	0.1	741, -46	20, 0	-2,1
2010 Load	734	94.9	44.8	1871, -2815	169,-282	219,-213
2010T L-W-S	933	109.1	45.9	2939, -3427	231,-259	213,-228
Change	199	14.2	1.1	1068, -612	62, 23	-6, -15
2010X L-W-S	1081	114.7	47.7	3250, -4141	254, -250	203, -224
Change	347	19.8	2.9	1379, -1326	85,32	-16,-11

Wind and Solar increase the 1-hour load delta by 347 MW (47%).

Pumped storage hydro contributes to light load variability

2010X Light Load (10th Decile) 5min Delta Duration Curves



CPS2 Discussion

- CPS2 is highly non-linear.
  - a function of fast net load variability and
  - the ability of regulation to respond
- 1 minute delta σ is one measure of the fast variability.
- Change in expectation of fast variability is one reasonable proxy for anticipated change in CPS2 if regulation strategy is held constant.
- Minimum CPS2 is 90%, but is usually higher (i.e., better)
- For 2010T, the increase in 1-min delta σ due to intermittent renewables is 1.6 MW/min (from 49.1 MW/min to 50.7 MW/min).
  - 90% CPS2 would be expected to decline to 88.9%
  - 95% CPS2 would be expected to decline to 94.2%
- For 2010X, the increase in is 2.5 MW/min (from 49.1 MW/min to 52.4 MW/min).
  - 90% CPS2 would be expected to decline to 87.7%
  - 95% CPS2 would be expected to decline to 93.3%
- Without additional regulation, CPS2 performance would be expected to decline ~1-2% due to the increase in fast variability.

Statistical Analysis: Hourly Forecast Errors

Variability of intermittent resources is reflected in delta statistics.

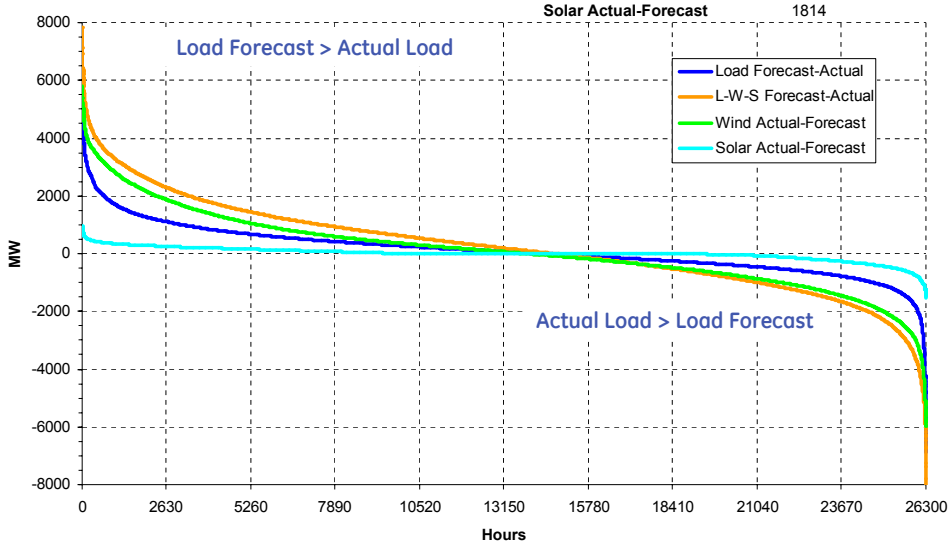
Uncertainty of intermittent resources is reflected in forecast error statistics.

Just as variability of intermittent resources is meaningful only in the context of existing load variability, so too, the uncertainty of intermittent resources is only meaningful in the context of existing load forecast error.

2010X Day Ahead Forecast Error Duration Curves

All Years	MW
Load F-A (Sigma)	857
Wind+Solar A-F (Sigma)	1566
L-W-S F-A (Sigma)	1620

	Positive Energy (GWh)	Negative Energy (GWh)
Load Forecast-Actual	9612	-6442
L-W-S Forecast-Actual	19453	-13142
Wind Actual-Forecast	14723	-11583
Solar Actual-Forecast	1814	-1814

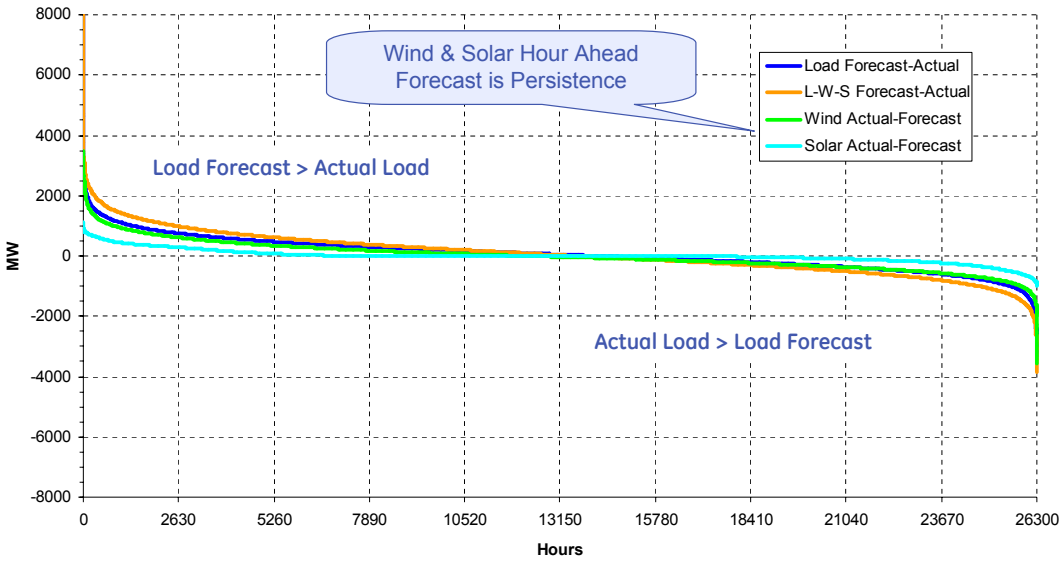


All 3 load years (2002, 2003, 2004) included

2010X Hour Ahead Forecast Error Duration Curves

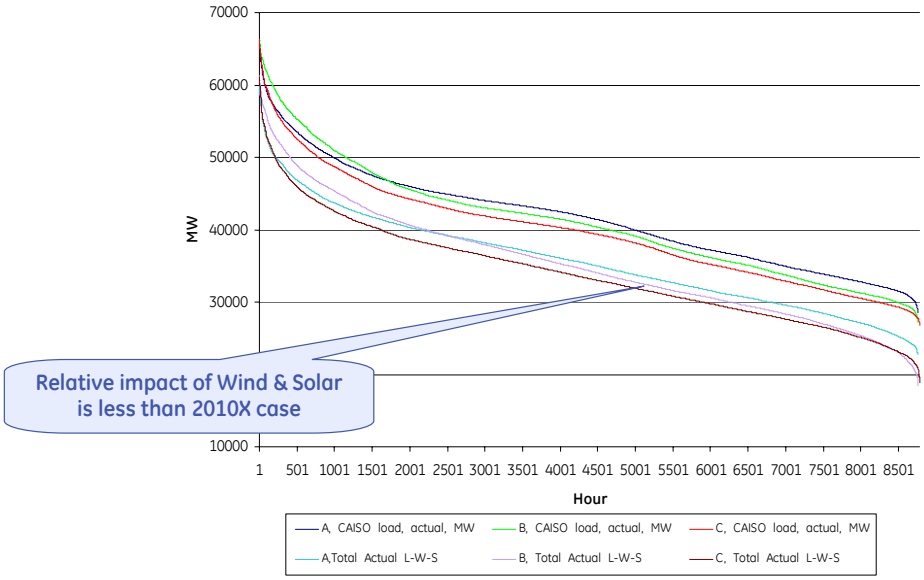
All Years	MW
Load F-A (Sigma)	606
Wind+Solar A-F (Sigma)	706
L-W-S F-A (Sigma)	762

	Positive Energy (GWh)	Negative Energy (GWh)
Load Forecast-Actual	6508	-4810
L-W-S Forecast-Actual	8252	-6553
Wind Actual-Forecast	4797	-4796
Solar Actual-Forecast	1703	-1703



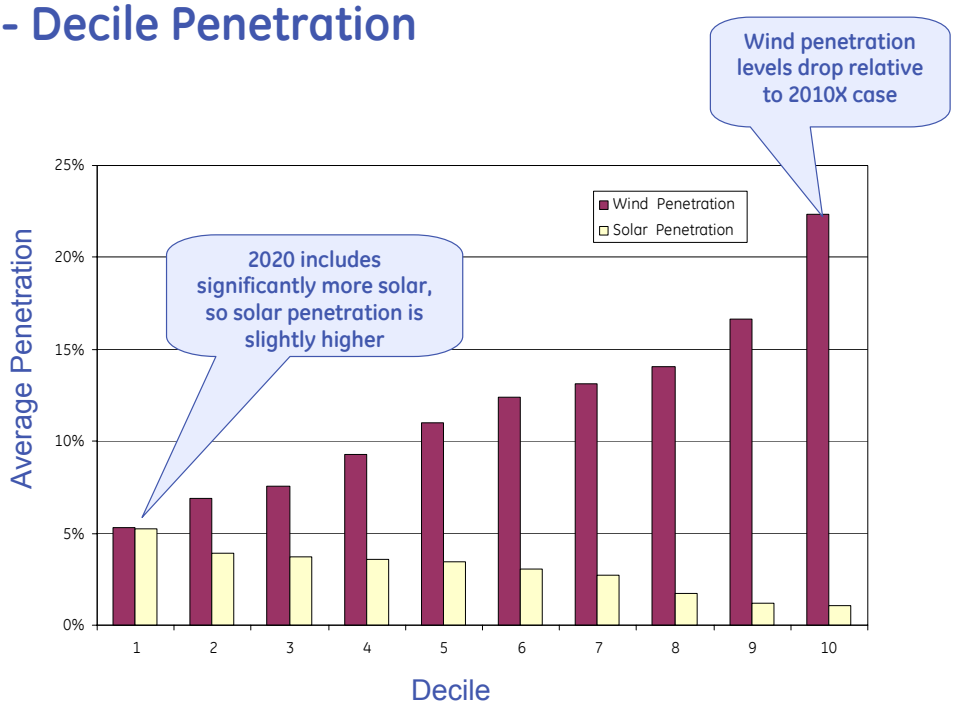
Statistical Analysis: 2020 Case

2020-ABC Load-Wind Duration Curves



A = 2002 load shape
B = 2003 load shape
C = 2004 load shape

2020 - Decile Penetration



2010X vs 2020 Statistical Analysis: Total Variability

	σ 1-Hour Δs (MW)	Max, Min 1-Hour Δs (MW)
2010 Load	1575	6714, -5617
2010T L-W-S	1623	6312, -5713
Change	48	-402, -96
2010X L-W-S	1704	7219, -5986
Change	129	505, -37
2020 Load	1977	8427,-7049
2020 L-W-S	2019	8747,-7351
Change	42	321,-302

Relative impact of intermittent renewable generation is less in 2020 than in 2010x case.