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IRRP Stakeholder Meeting on Renewable Integration Requirements

Jim Blatchford
Sr. Policy Issues Rep.
Facilitator

IRRP Stakeholder Meeting (Teleconference)
October 20, 2009

Overview / Call Objective

- Provide status of ongoing efforts to assess the adequacy of the existing fleet to manage 20% RPS (and higher RPS)
- Explain updates to the study methodology
- Discuss the draft production simulation results from the “wind only” case, including overgeneration results
- Discuss alternative over-generation analysis
- Discuss coordinated study effort to evaluate operational and storage requirements with KEMA/CEC
- Discuss the ISO’s development of market and operational metrics to inform the ongoing evaluation of renewable integration

Call Agenda

9:00 - 9:10	Introduction	Jim Blatchford
9:10 – 9:20	Status of IRRP analyses	Grant Rosenblum
9:20 – 10:00	Updates to Integration Requirements Analysis	Clyde Loutan
10:00 – 10:50	Updates to Production Simulation Methodology	Udi Helman
10:50 - 11:15	Overgeneration Analysis	Clyde Loutan
11:15 - 11:40	KEMA/ISO Renewable Study	David Hawkins
11:40 – 12:00	Renewable Metrics and Next Steps	Grant Rosenblum

Status of ISO Analysis of Generation Fleet Adequacy under a 20% RPS (and higher RPS)

Grant Rosenblum
Manager, IRRP

David Hawkins
Lead Renewables Power Engineer

Udi Helman, PhD
Principal, Markets and Infrastructure Division

Clyde Loutan
Senior Advisor, Markets and Infrastructure Division

Status Report

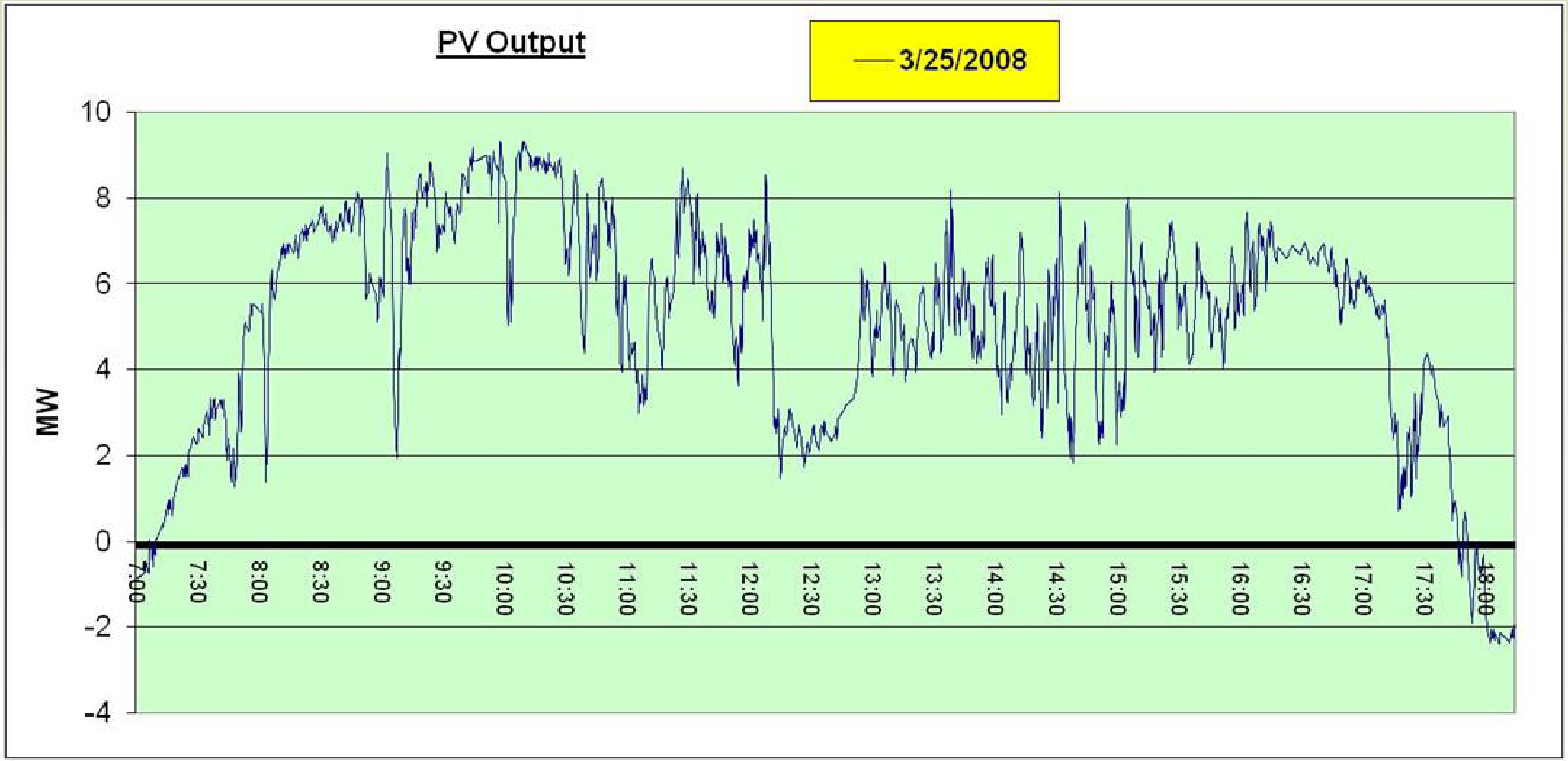
California ISO research and simulation tools to assess integration of variable generation renewables

- As system and market operator, CAISO needs accurate assessments of the operational impacts of variable generation renewables, both to ensure reliability and to support market procurement/design to facilitate integration
- CAISO research that began in 2006-7 and continues today has sought to capture more operational and market detail than most prior studies
- Several modeling and analytical efforts are underway simultaneously

Why the delay in the 20% RPS fleet adequacy study?

- Last stakeholder discussion on fleet adequacy study in January 2009
- Most production simulation results were done by May 2009
- However, these results assumed incremental wind resources only; during 2009, calculating the operational requirements of solar technologies became a priority
- Also, need to get 33% RPS operational study underway
- Current presentation explains subsequent changes to 20% RPS fleet adequacy study (and uses in the 33% RPS operational study)

Solar PV plant output variability (partly-cloudy day, 10-second time-step)



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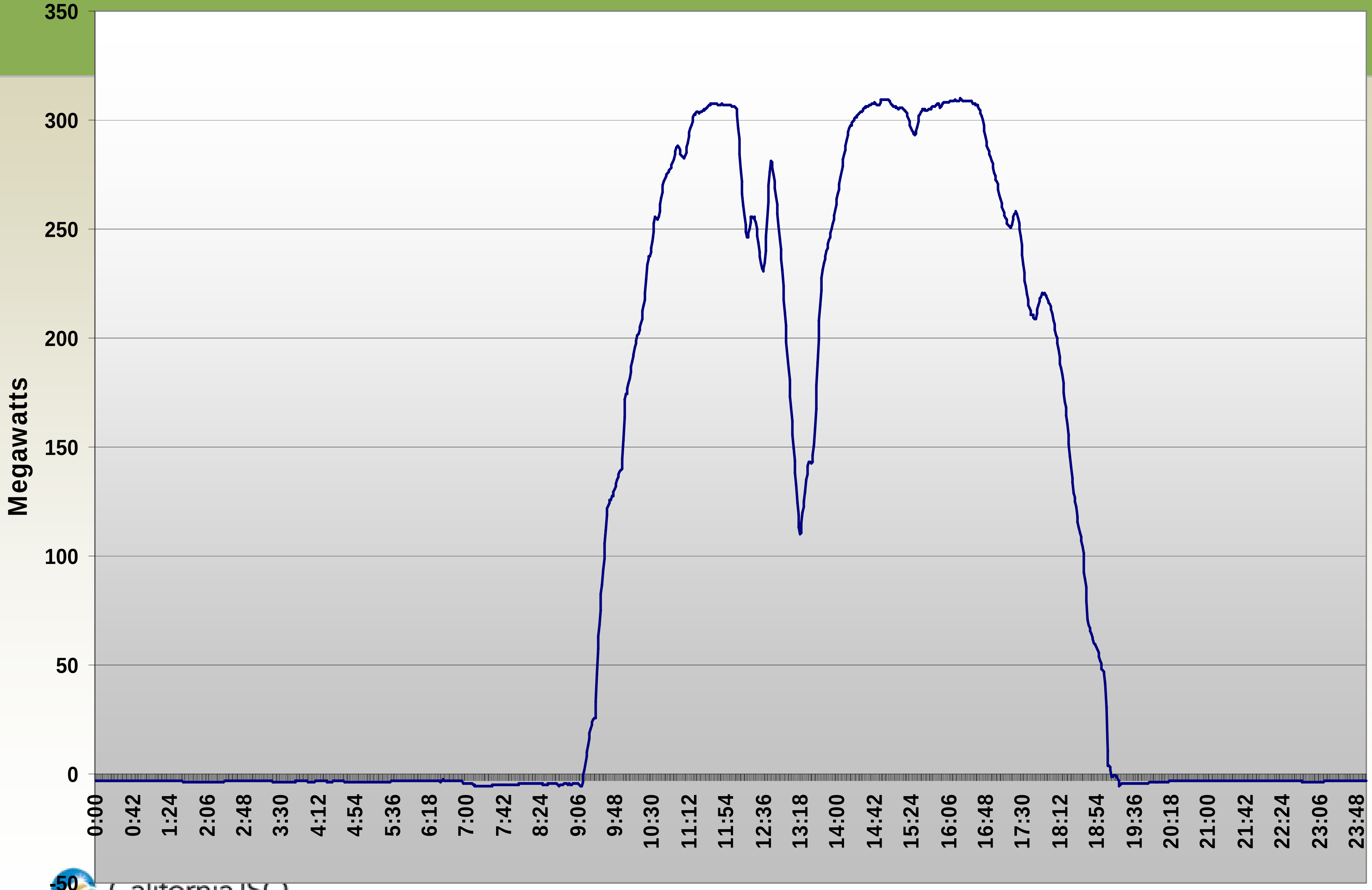
April 21 - Concentrated Solar



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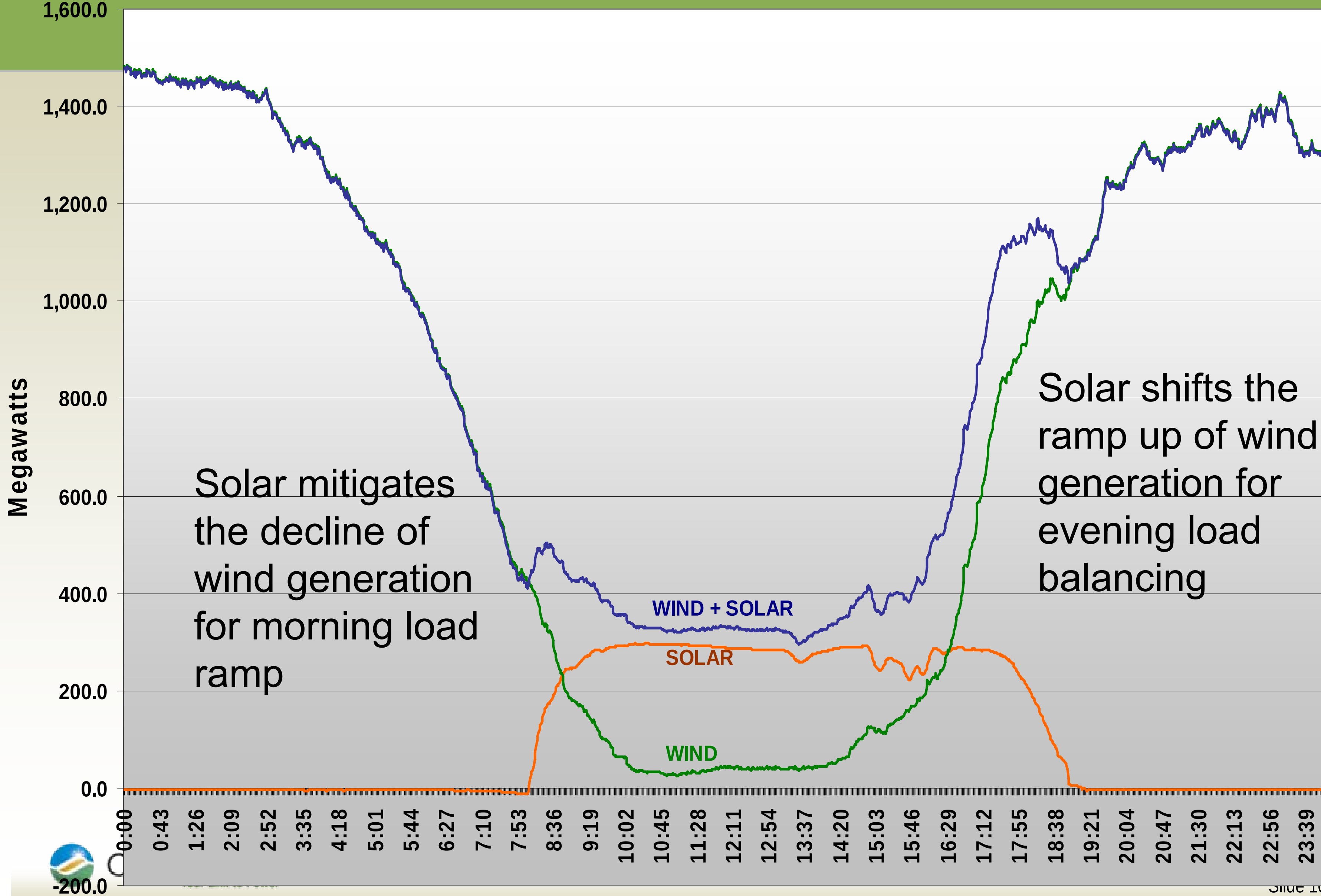
April 12 - Wind + Solar



The Fleet Adequacy analysis currently has two key components

1. Simulation of renewable integration operational requirements (2007 study methodology and updates)
   - Ancillary service requirements (Regulation)
   - Generic system requirements – ramp, changes in economic dispatch
2. Production simulation with zonal network model
   - Unit commitment and dispatch to evaluate capabilities of generation (and non-generation) resources to integrate variable renewables
   - Ability of existing fleet and additions to meet ramp requirements
   - Effect on commitment and dispatch of day-ahead and hour-ahead forecast error

Step 1: Analysis of Renewable Integration Operational Requirements

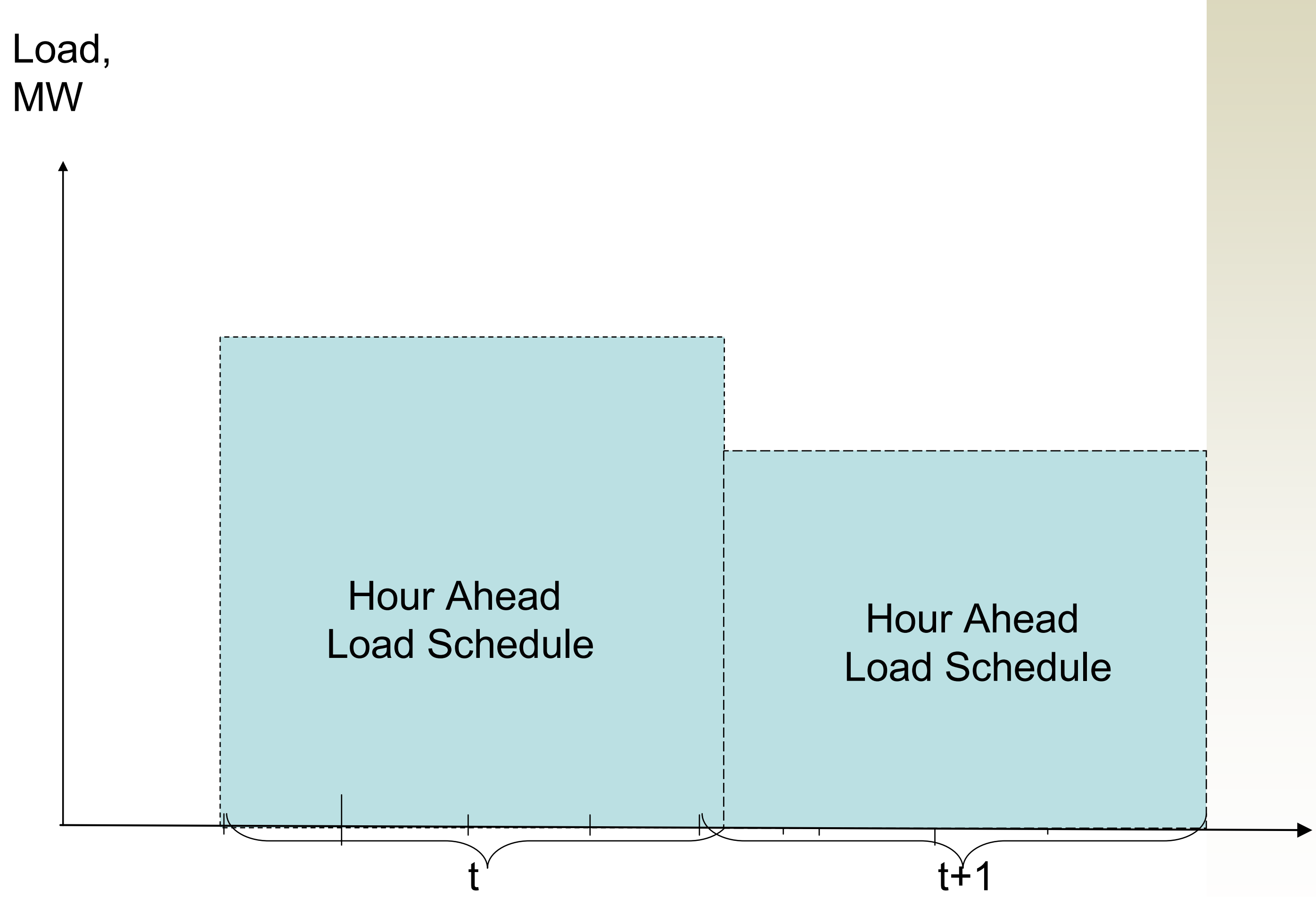
Methodology to Assess Intra-Hour Operational Requirements

- Objective is to estimate intra-hour characteristics of Regulation, 5 minute Economic Dispatch (Load Following) and ramp rate magnitude and duration
- Methodology originally used in ISO 2007 study, now updated
- Forecast actual load and renewable output under 20% RPS
  - Load incremented by 1.5% annually
  - 2012 wind output based on TrueWind simulation
  - Solar profiles under development
- Monte Carlo simulation that generates realistic hour-ahead and 5 minute-ahead load and wind forecast errors, based on statistical properties of the actual 2006 errors
  - autocorrelation
  - standard deviation
  - truncated normal distribution

Methodology to Assess Intra-Hour Operational Requirements (cont.)

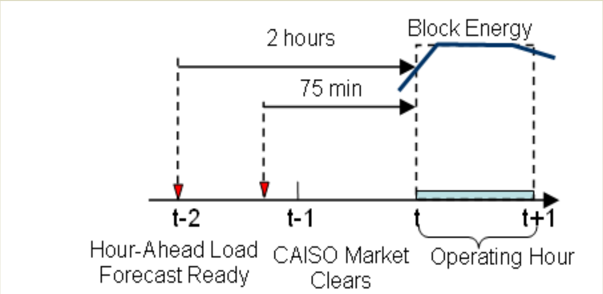
- Based on Monte Carlo simulation, the following quantities are calculated for each interval:
  - 5 minute economic dispatch (load following): the difference between the forecast 5 minute load (net of wind & solar) and the forecast hour-ahead load (net of wind & solar)
  - Regulation: the difference between the actual load (net of wind & solar) and the forecast 5 minute load (net of wind & solar)
  - Ramp rate and duration: estimated ex post using a “swinging door” algorithm (see Makarov, et al. 2009)

Block Hourly Load Schedules



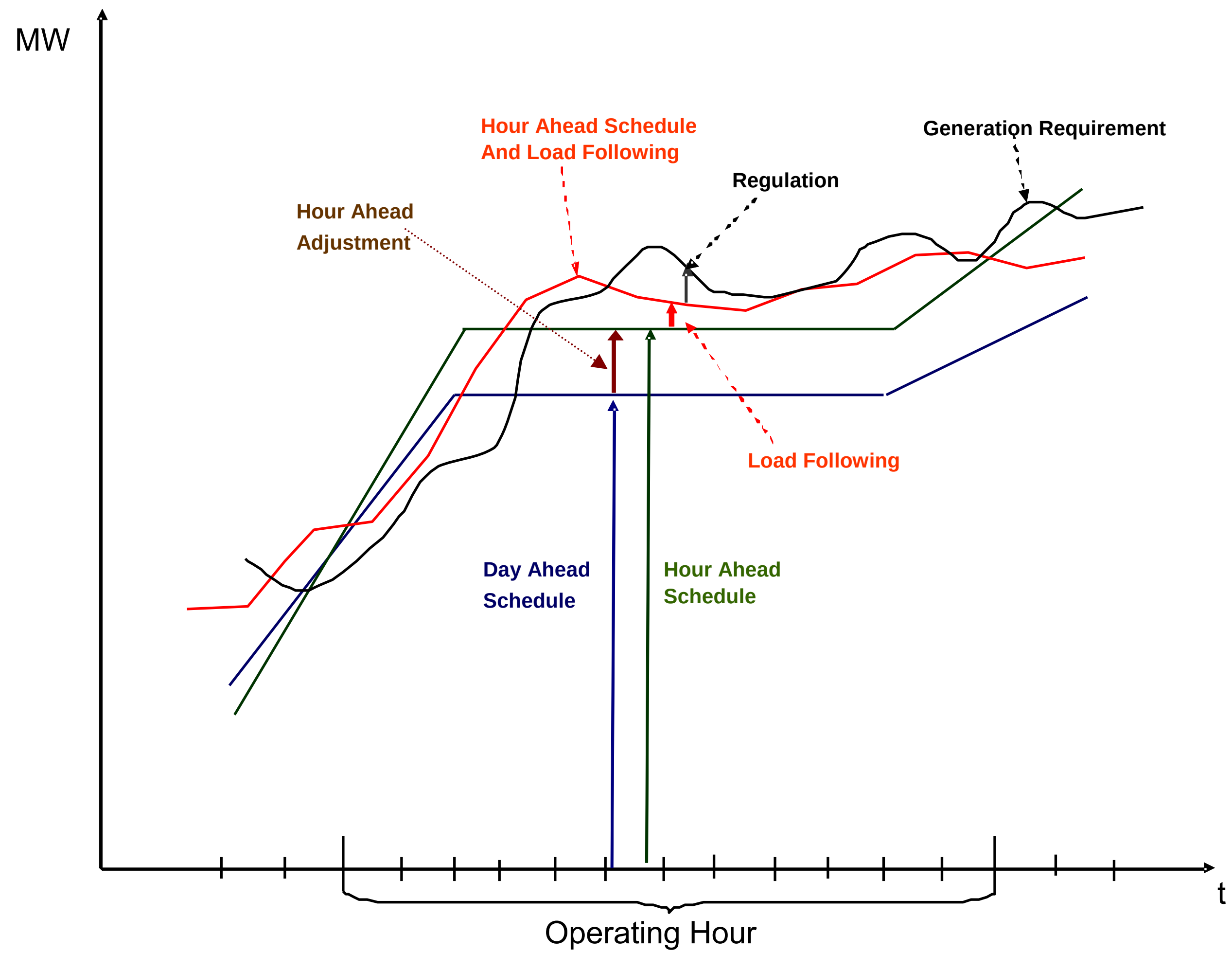
The method approximates actual ISO Hour-Ahead scheduling

- Hour-ahead schedules are hourly block energy schedules including the 20-minute ramps between hours.
- They are provided 75 minutes before the actual beginning of an operating hour.
- The load forecast used for the hour-ahead scheduling process is provided 2 hours before the beginning of an operating hour.
- The forecast error is simulated using a TND random number generator based on the statistical characteristics of the load forecast error (derived from 2006/2007 data)



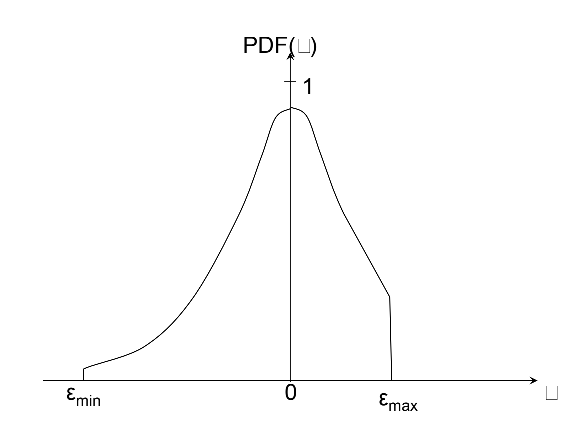
- The hour-ahead load schedule: $$L_{ha,1hr} = \Re_{20}\left\{avg_{1hr}\left(L_a\right) - \varepsilon_{L,ha}\right\}$$
- The hour-ahead wind generation schedule: $$G^w_{ha,1hr} = \Re_{20}\left\{avg_{1hr}\left(G^w_a\right) - \varepsilon_{w,ha}\cdot CAP^w\right\}$$
- The hour-ahead solar generation schedule: $$G^s_{ha,1hr} = \Re_{20}\left\{avg_{1hr}\left(G^s_a\right) - \varepsilon_{s,ha}\cdot CAP^s\right\}$$

CAISO Scheduling Process



Simulate Forecast Errors – Load, Wind

- The real-time and hour-ahead load and wind forecast errors are simulated using a random number generator based on the statistical characteristics of the actual real-time and actual hour-ahead load and wind forecast error
- The distribution of forecast errors is an unbiased Truncated Normal Distribution (TND)
- Same statistical characteristics of the forecast error will be observed in the year 2012.
- A new non-linear optimization-based random number generator is used to produce forecast errors.



$$\min(f(a,b,c,d,\sigma_e))$$

Table 1
Real-time Load Forecast Characteristics

Average	1.1
Minimum	-349.5
Maximum	349.4
Std. Dev.	97.8
Autocorrelation	0.6

Table 2
Hour-Ahead Load Forecast Characteristics of the Yr. 2006 (in MW)

Seasons	Winter	Spring	Summer	Fall
Average	-22.49	-24.05	-130.43	-69.21
Min	-2680.12	-2101.08	-3770.73	-2627.90
Max	1842.06	1930.54	2446.12	2080.98
Std. Dev.	637.37	601.34	900.13	687.52
Autocorrel ation	0.70	0.73	0.89	0.83

Table 3
Estimated Hour-Ahead Wind Generation Forecast Characteristics (in Fraction of Capacity)

Seasons	Winter	Spring	Summer	Fall
Average	0.00012	-0.0005	-0.0005	0.0006
Minimum	-0.3568	-0.4331	-0.3219	-0.3193
Maximum	0.3092	0.3084	0.3074	0.3966
Std. Dev.	0.0723	0.0899	0.0796	0.0792
Autocorrelation	0.6106	0.7061	0.6519	0.5939

Simulate Forecast Errors – Solar

- The clearness index (*CI*) for a given period is obtained by dividing the observed global radiation *Rg* by the extraterrestrial global irradiation *R*:

$$k = Rg/R$$

- where *Rg* is the horizontal global solar radiation, *R* is horizontal extraterrestrial solar radiation.
- If the weather condition of a day is like between a sunny day and a very cloudy day, the standard deviation of the solar forecast errors will vary. Thus, the standard distribution of the solar forecast errors can be described as a function of a parameter ξ, .

Clearness Index and Std. Dev. Of solar forecast

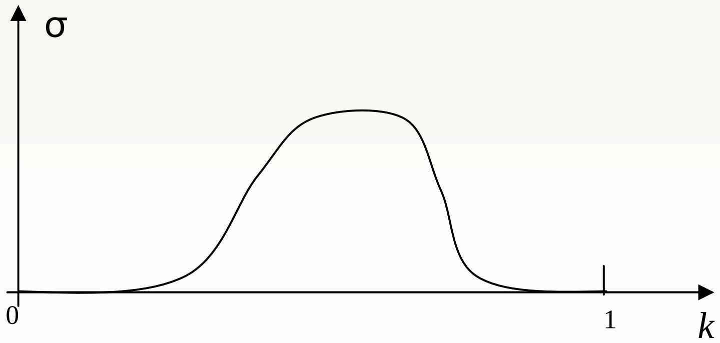
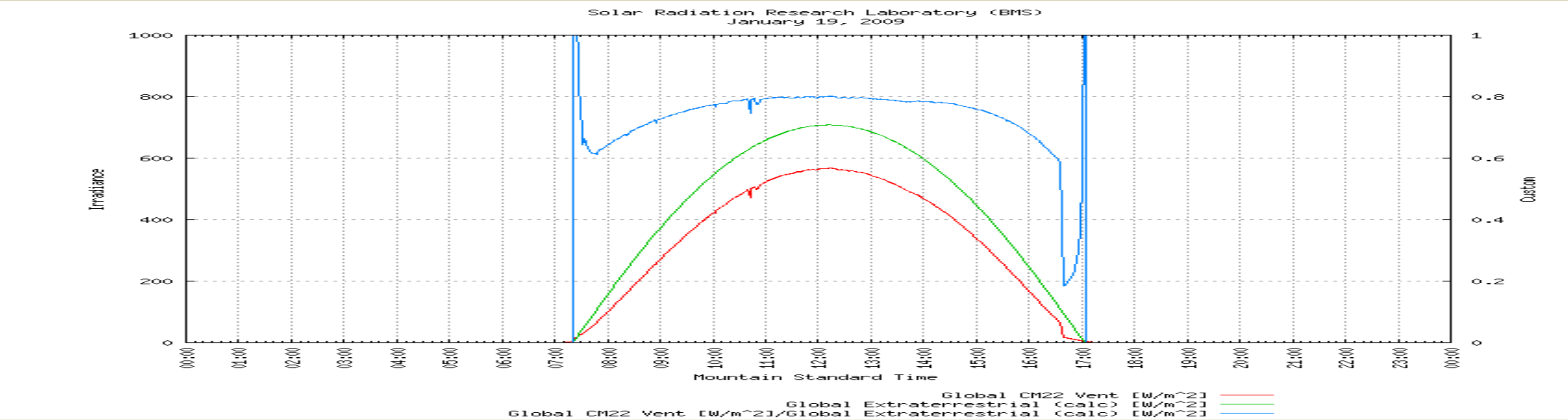
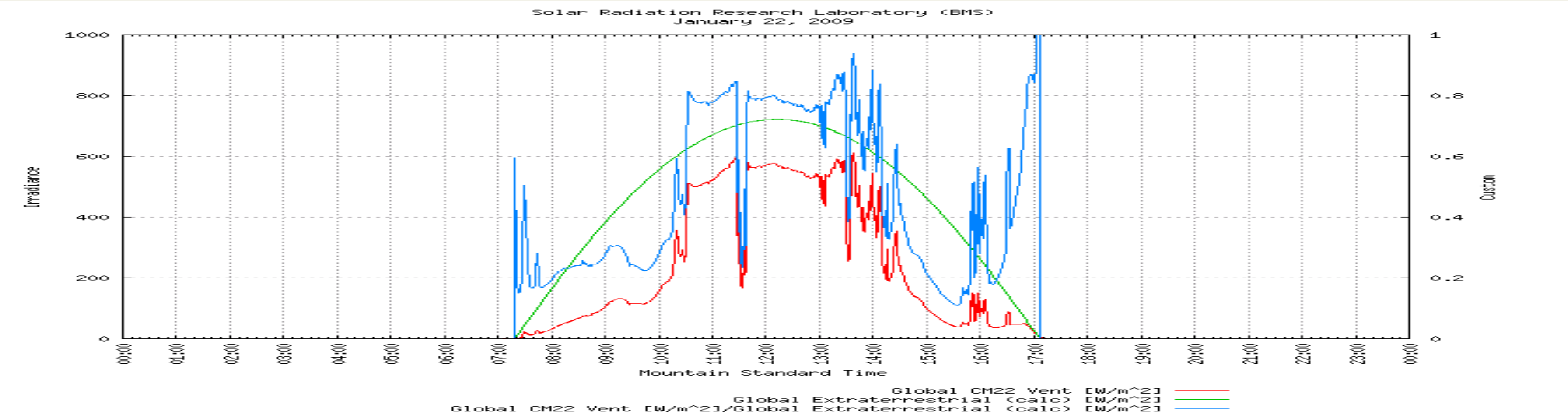


Fig.9. Clearness index v.s. standard deviation of solar forecast errors.

Simulate Forecast Errors – Solar

Daily pattern of the solar radiation of clearness index.

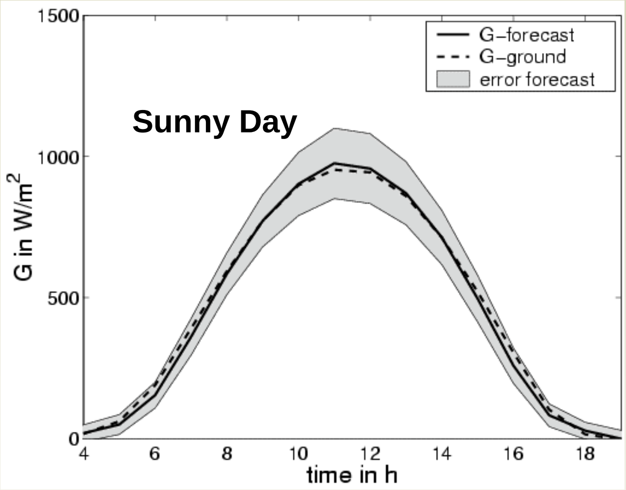


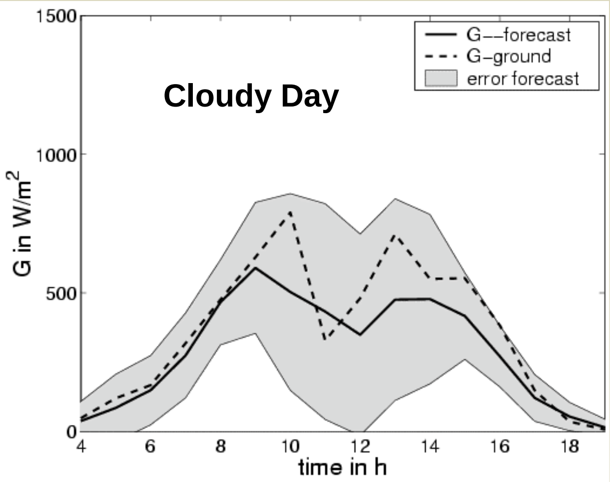


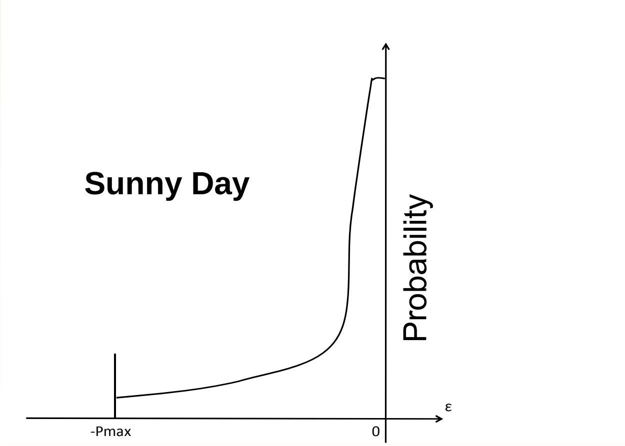
Forecast Error

Fig.8. Distribution of solar forecast error in very cloudy day and a very sunny day.

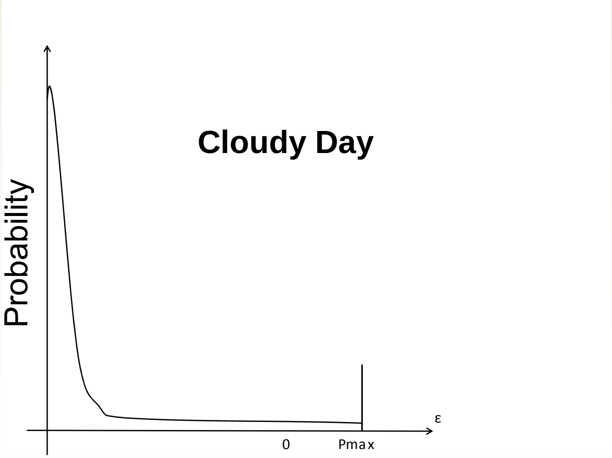
Changes of the solar irradiance error depending the clearness index.





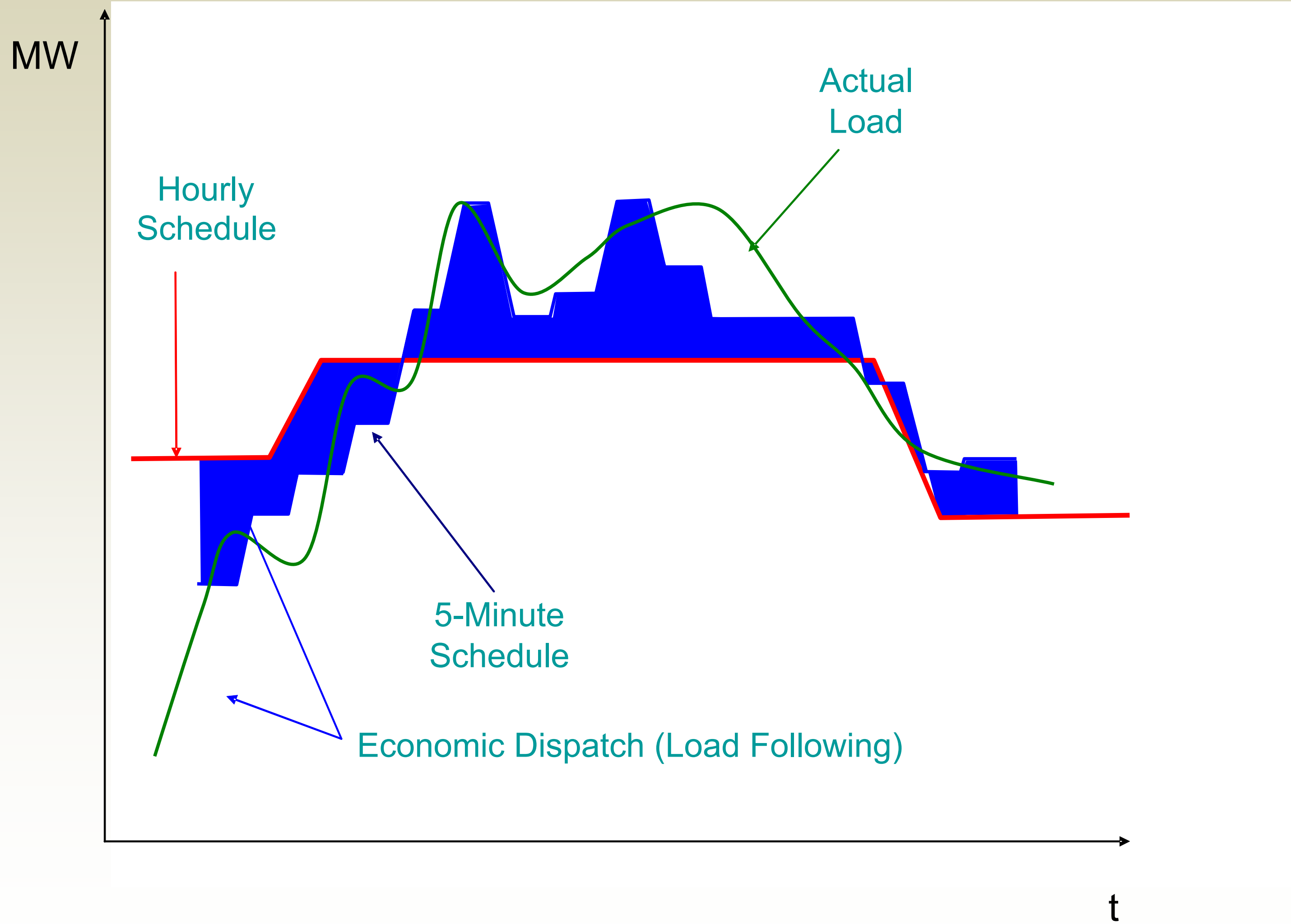


Forecast Error



Forecast Error

Five Minute Economic Dispatch (Load Following) Requirement shown as blue shaded area



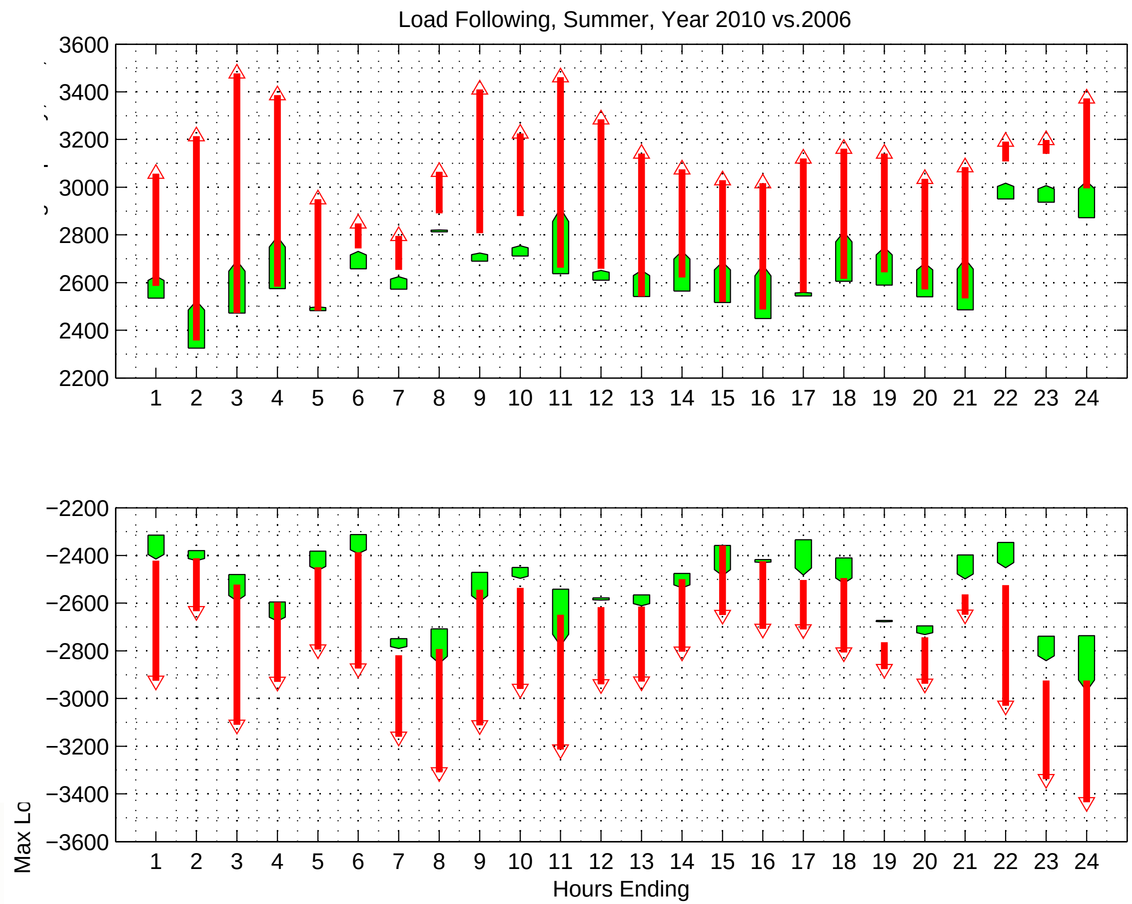
Changes in Five Minute Economic Dispatch/Load Following Capacity -- Results will be similar to the 2007 study shown below (results shown are for incremental wind resources)

The maximum upward capacity requirement of 3,500 MW occurs during HE3 and HE11

The maximum increase of 800 MW occurs during HE3 (3,500 – 2,700)

The maximum downward capacity requirement of 3,450 MW occurs during HE24

The maximum downward capacity increase of 500 MW (3,050 -2,450) occurred in HE22



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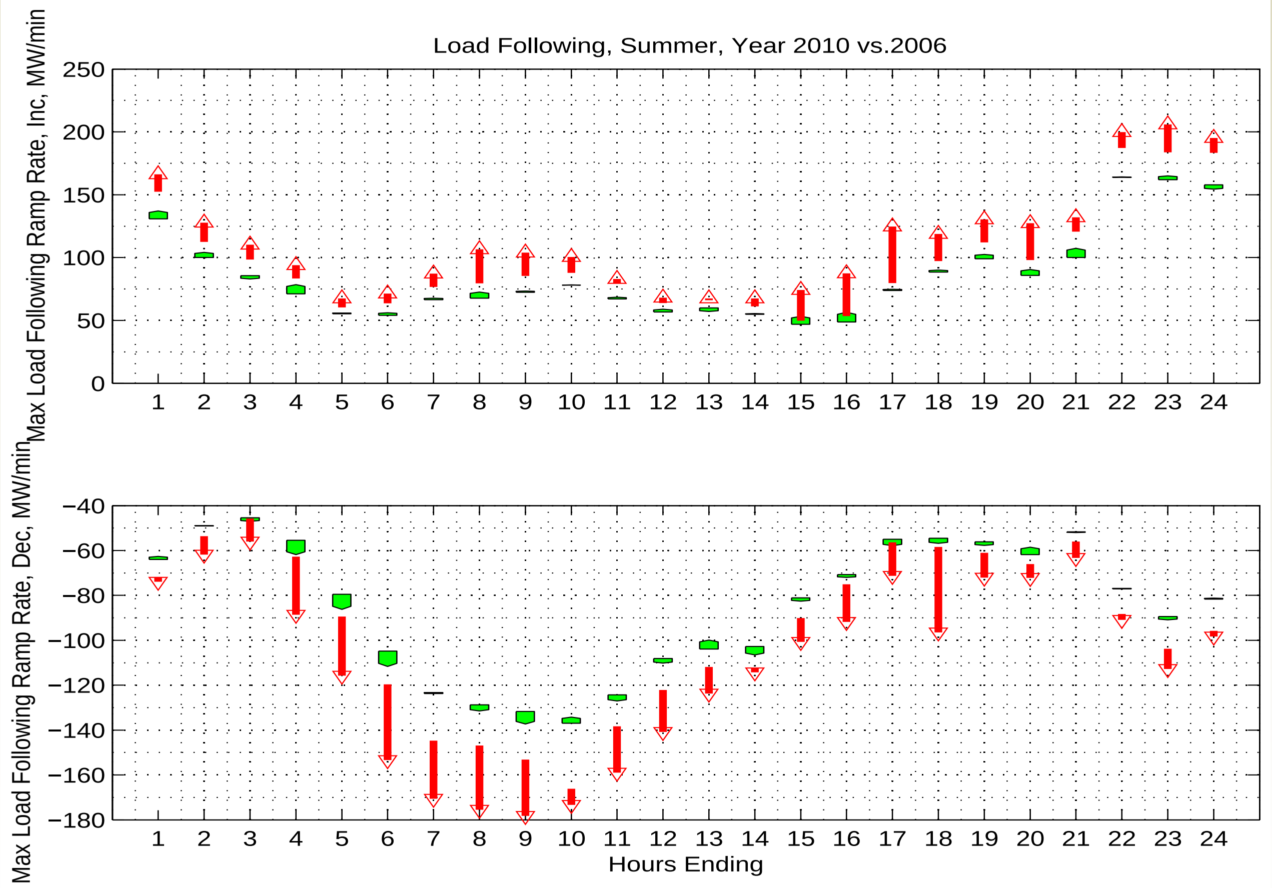
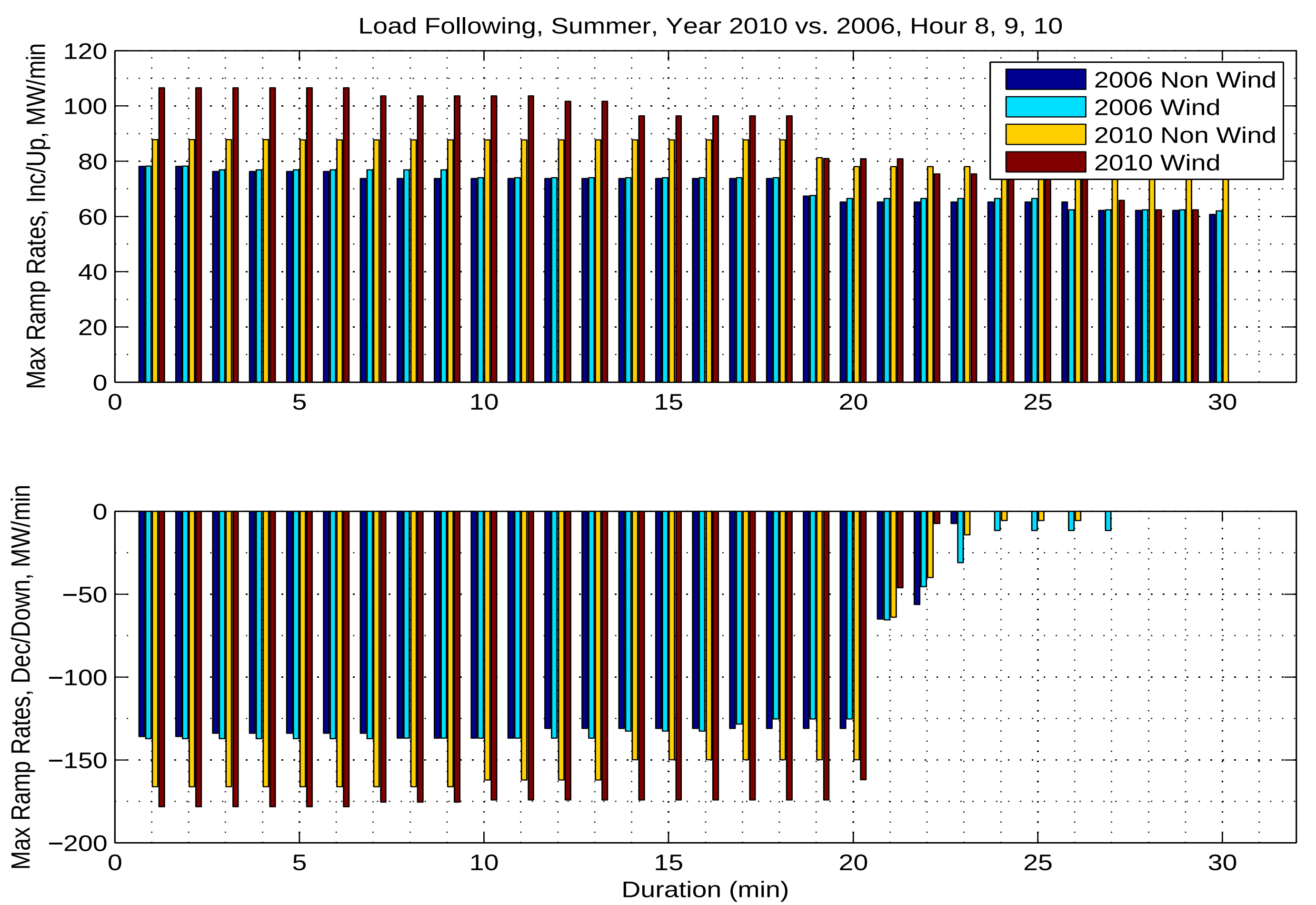
Load Following Ramping Requirement -- Results will be similar to the 2007 study shown below (results shown are for incremental wind resources)

It is expected that both the maximum upward and downward load following ramping requirements in 2010 will increase by 40 MW/min.

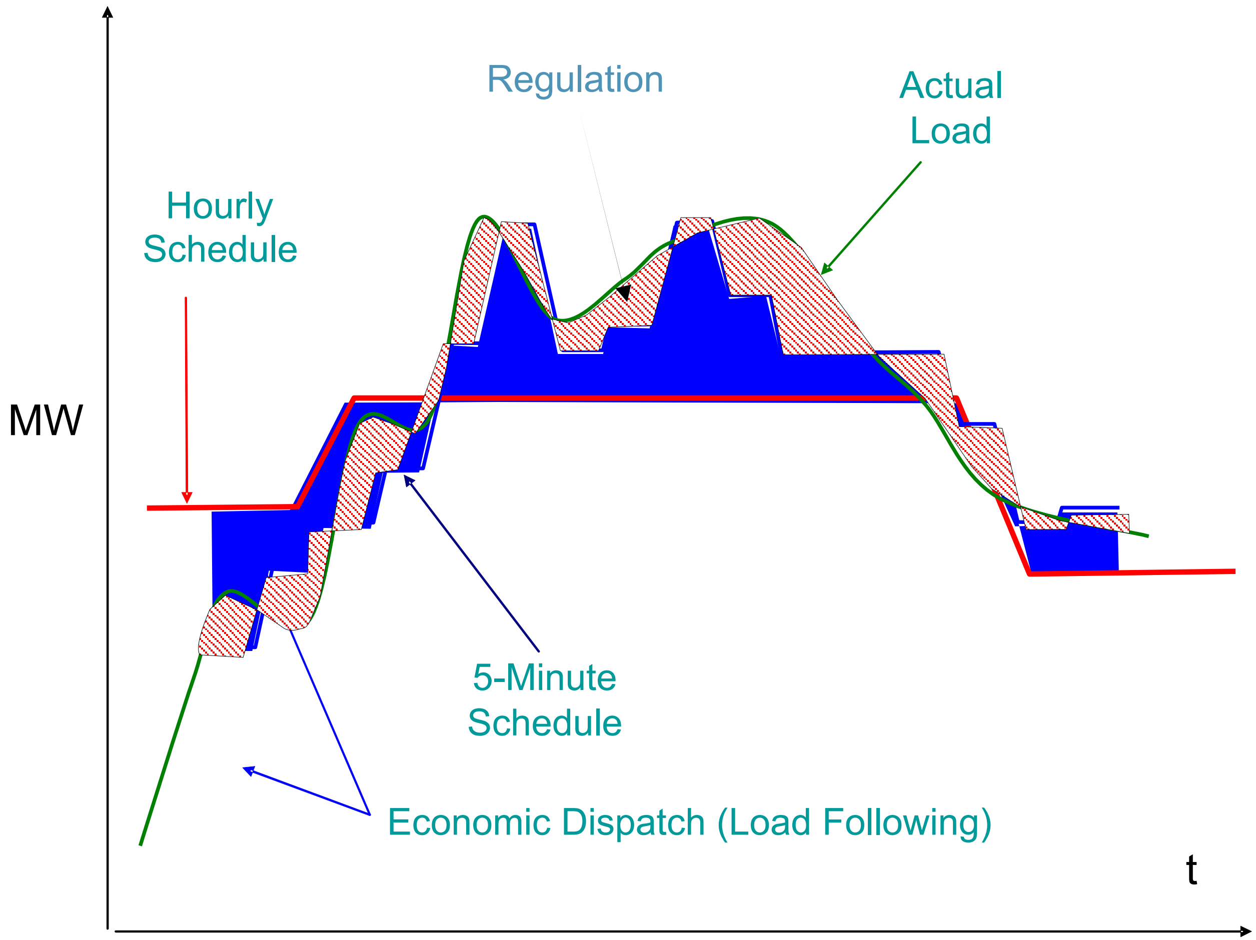


Load Following Ramp Duration

The upward and downward ramp durations are required for approximately 30 and 20 minutes, respectively.



Regulation Requirement shown as red shaded area



CAISO Real-Time Scheduling

- The real-time dispatch is automatically conducted by the CAISO's market applications using 15-minute intervals for RTUC and 5-minute interval for RTED
- The desired changes of generation are determined in real-time for each 5-minute dispatch interval 5 minutes before the actual beginning of the interval.
- System information used for dispatch is dated back 7.5 minutes before the beginning of the interval.
- Units start to move toward the new set point 2.5 minutes before the interval begins.
- They are required to reach the set point in the middle of the interval (2.5 minutes after its beginning).

- The real-time load forecast: $L_{rtf,5\min} = \Re_5\left\{avg_{5\min}(L_a) - \varepsilon_{L,rtf}\right\}$
- Real-time wind forecast (naïve persistence model): $G^w_{rtf,5-\min}[t,t+5] = G^w_a[t-8]$
- Real-time solar forecast (naïve persistence model): $G^s_{rtf,5-\min}[t,t+5] = G^s_a[t-8]$

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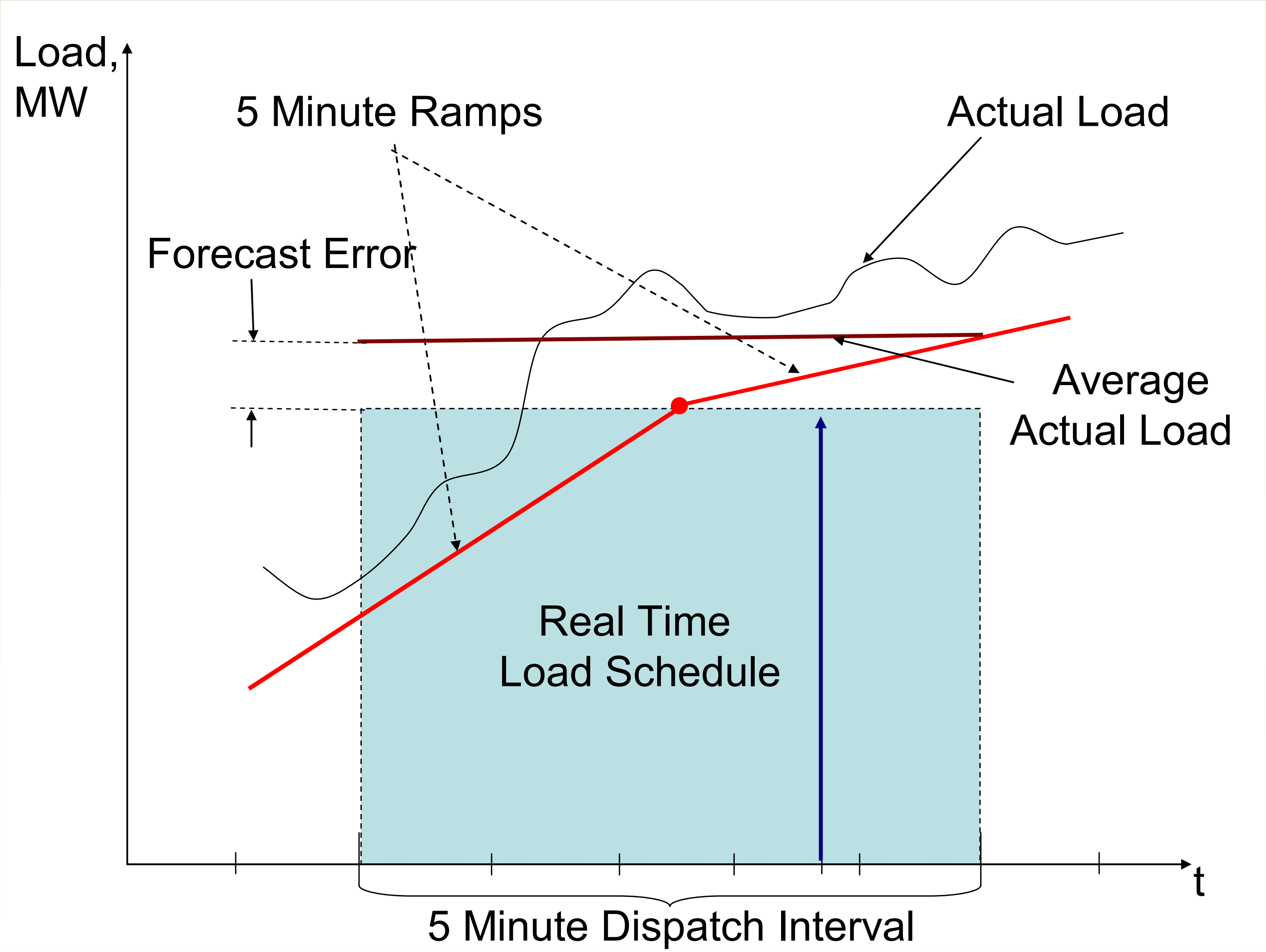
5-Minute Dispatch



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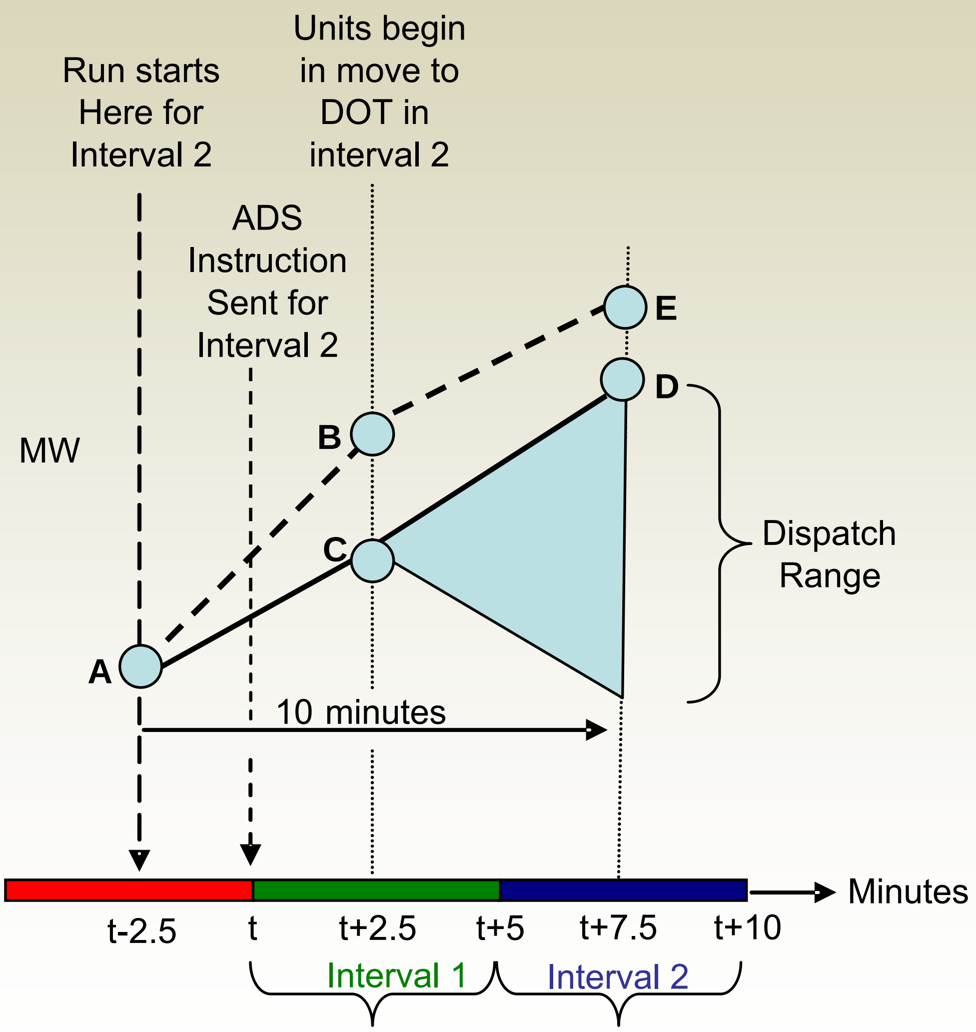
Market timelines benefit renewable integration

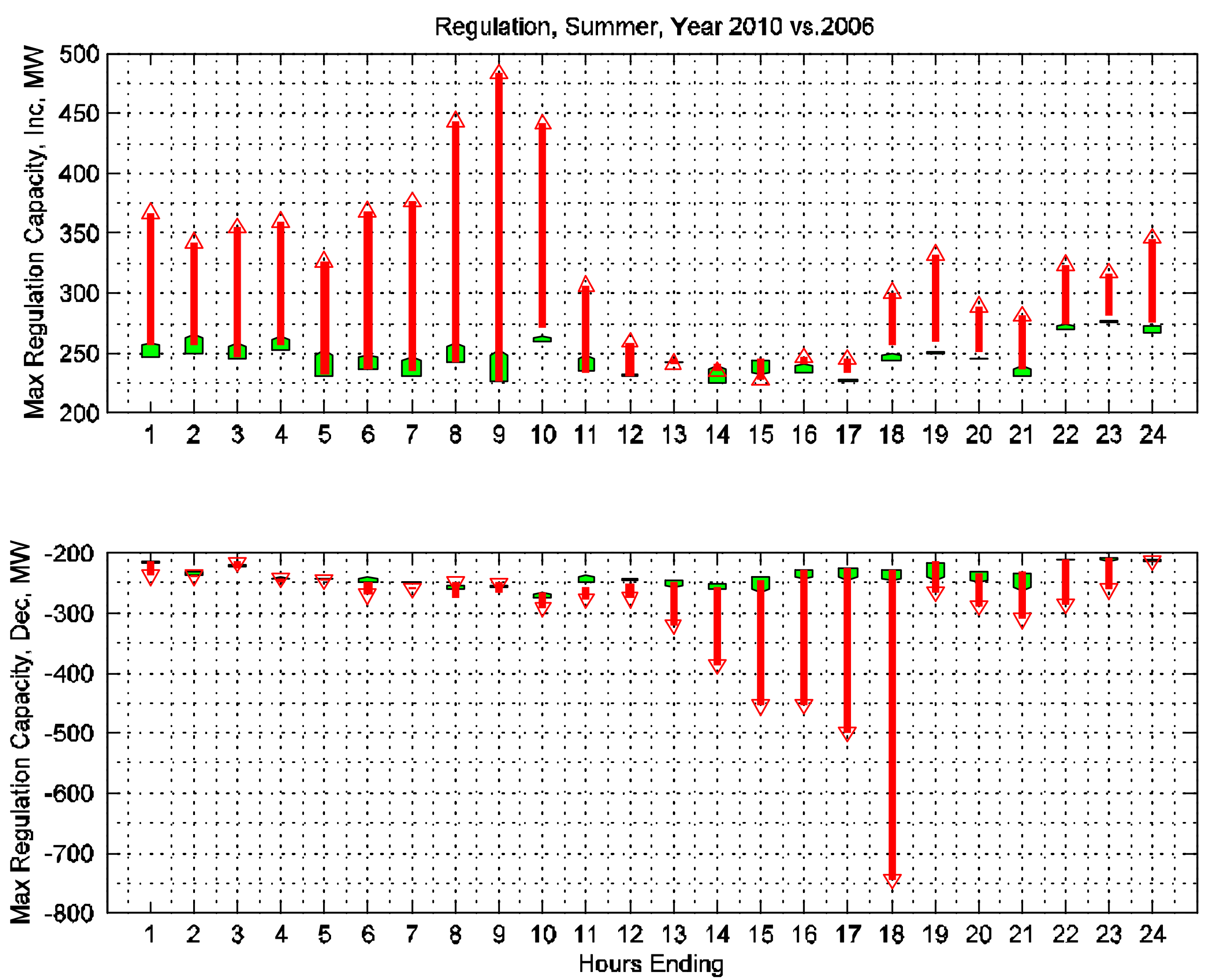
The Real Time Economic Dispatch software runs every five-minutes starting at approximately 7.5 minutes prior to the start of the next Dispatch Interval and produces Dispatch Instruction for Energy for the next Dispatch Interval and advisory Dispatch Instructions for as many as 13 future Dispatch Intervals.



Regulation capacity requirements evaluated by hour -- Results will be similar to the 2007 study shown below (results shown are for incremental wind resources)

The maximum increase of 230 MW occurs during HE9 (480 MW– 250 MW)

The maximum downward increase of 500 MW (750 MW -250 MW) occurred in HE18



Implications of Results for Markets and Need for Further Analysis

- Procurement of Regulation (Ancillary Services) should increase by season and hour in day-ahead market (or after day-ahead market, depending on the ISO)
- Increased ramp requirements, particularly in morning and evening hours
- Results are determined independent of particular commitment or dispatch of generation
- Additional studies are needed to verify that actual fleet in simulated years (e.g., 2012) can provide ramp and load following capabilities (next presentation)

Step 2: Production Simulation

Step 2: Link Results of Step 1 with a Unit Commitment Production Simulation to verify Capabilities of Generation Fleet (and Non-Generation Resources)

- Evaluate 2012 CAISO generation resources to determine their ability to reliably integrate anticipated levels of variable renewable resources
  - Focus on the ability of CAISO fossil-fired resources to provide sufficient flexibility
  - Evaluate the impact of day-ahead and hour-ahead forecast errors on commitment and dispatch
  - Determine the magnitude and frequency of any system operational violations
- Test (or extend) the ability of readily available analytical tools to provide credible integration evaluations
  - Scalable, repeatable

Production Simulation Vendor For This Phase – PLEXOS

Plexos Solutions

- Unit commitment, production cost model
- Can represent zonal or detailed network representation
- Hourly and 10-minute simulation time steps
- Can approximate CAISO market design and procedures with respect to
  - Simulated day-ahead, hour-ahead and real-time dispatch solutions
  - Dynamic co-optimization of energy and AS (i.e. simultaneous solution)
  - Locational prices for energy (if needed)

Modeling Assumptions for 2012 Simulations

- Only CAISO system modeled
  - Zonal topology initially (NP15, SP15)
  - CAISO Master File confidential generation data (Pmin, Pmax; Min. up- and down time; Ramp rates; AS Ranges)
  - Hourly hydro generation (2006 and 2007) and AS contribution (2006) is fixed at the station-level based historical records
  - Hourly net interchange for NP15 and SP15 fixed based on 2006 or 2007 actuals
  - No AS provision assumed from imports
  - Hourly wind, QF, and geothermal generation is based on the 2006 historical profiles; solar profiles under development
  - 2012 generation resource additions included

Potential Violations Evaluated*

1. Regulation-Up
2. Regulation-Down
3. Spin
4. Non-Spin
5. Unserved Energy
6. Over-generation

* *Either insufficient ramping capability or insufficient available capacity results in one of the above violations.*

2012 Ancillary Service Requirements reflect Operational Study Results

Parameter	Units	Incremental Wind Requirement	Wind + Solar Requirement
Reg-Down	MW	350-750 *	TBD *
Reg-Up	MW	350-530 *	TBD *
Spin	MW	0.5*(3%*L + 3%*G)	0.5*(3%*L + 3%*G)
Non-Spin	MW	0.5*(3%*L + 3%*G)	0.5*(3%*L + 3%*G)

* Regulation MW vary by TOD and season

Summary of Simulation Methodology for this Study Phase – Three Steps

1. 2012 all hours "day-ahead" (DA) unit commitment and dispatch simulation on hourly time-step with stochastic modeling of load and wind incorporating day-ahead forecast errors
2. 2012 all hours "hour-ahead" (HA) unit commitment and dispatch simulation on hourly time-step with stochastic modeling of load and wind incorporating hour-ahead forecast errors
3. Selected days/hours in 2012 subject to sequential DA-HA-Real-Time unit commitment and dispatch sequence; RTD is conducted on ten-minute time-step

Summary of Simulation Methodology for this Study Phase – Structure of Analysis

[*Day-Ahead*] "Actual" Wind/Solar Output and Load
+ DA Forecast Error on hourly time-step

↓

[*Hour-Ahead*] "Actual" Wind/Solar Output and Load
+ HA Forecast Error on hourly time-step

↓

[*Real Time*] "Actual" Wind/Solar Output and Load
on 10 minute time-step

Summary of Inputs and Stochastic Modeling

- Inputs
  - 2012 “actual”/real-time load forecasts for IOU’s (based on 2006, 2007)
  - 2012 “actual”/real-time wind and solar generation forecasts for 5 zones
  - 2012 supply = hourly hydro, QF, Geothermal, import and export profiles based 2006 or 2007 historical hourly generation; new resource additions
- Simulation mode - 100-iterations
- Stochastic drivers
  - Convergent Monte Carlo for generator forced outage modeling
  - 2012 hourly DA/HA load forecasts with forecast deviations modeled with stochastic process with parameters derived from the 2006 and 2007 historical hourly DA/HA load forecast errors by season
  - 2012 hourly DA/HA wind and solar generation forecasts with forecast deviations modeled with stochastic process with parameters derived from the 2006 and 2007 historical hourly DA/HA wind generation forecast errors

Purpose of Different Simulations and Interpretation of Results

- DA and HA "uncoupled" hourly simulations –
  - "Screen" for hours that might have RTD violations; so examine selected days/hours with DA/HA violations
  - Suggest frequency/magnitude of violations over year (duration curve) as seen from several hours forward
  - 100 iterations
- Caveats –
  - DA/HA frequency/magnitude results need to be checked through RTD simulations
  - Screen will not reflect RT hours with possible violations that are missed through hourly averaging and forecast error

Purpose of Different Simulations and Interpretation of Results (cont.)

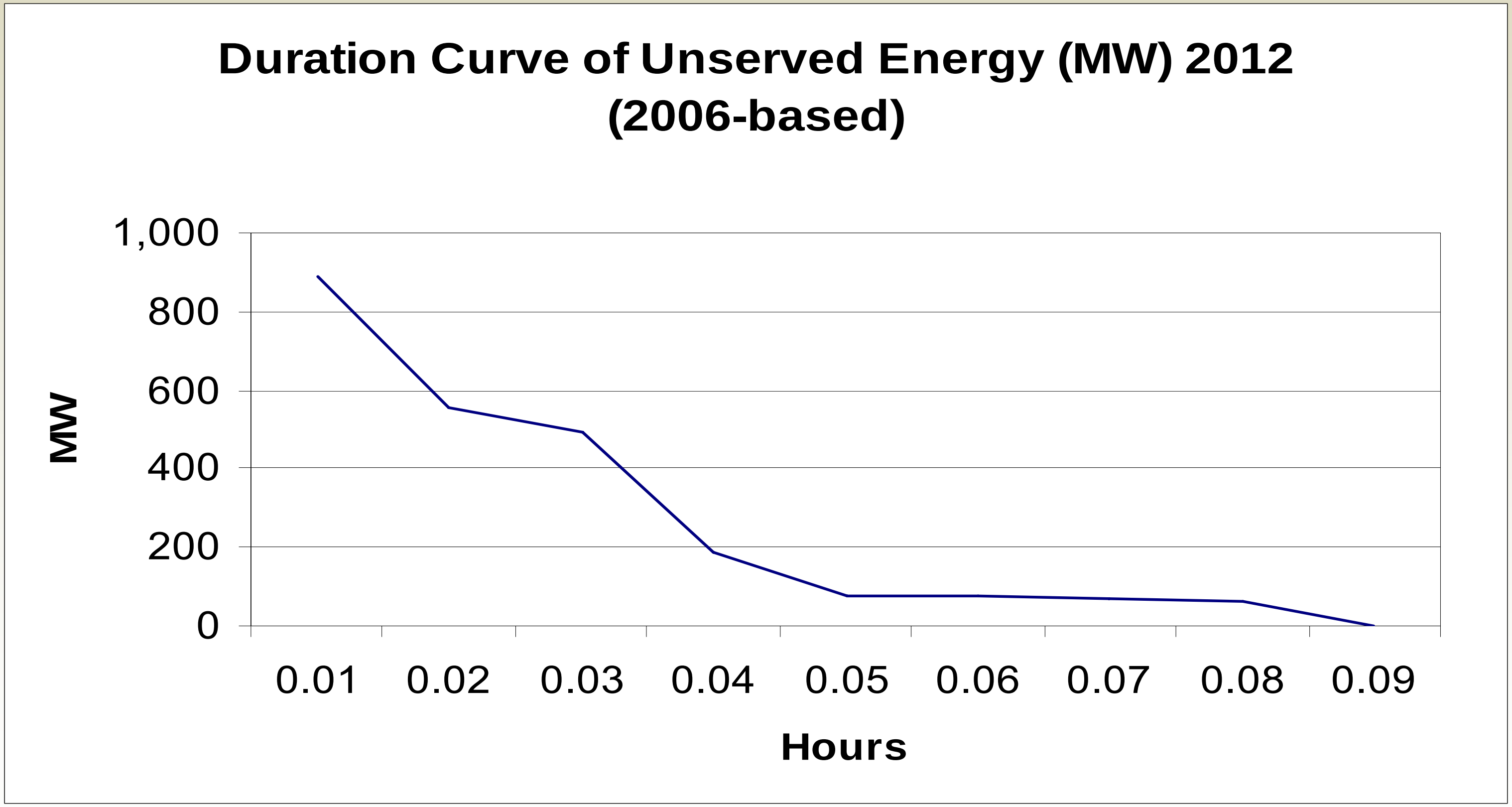
- DA-HA-RTD “coupled” simulations –
  - Assess whether fleet can resolve *forecast* violations in DA and HA simulations in RTD
  - Assess whether fleet will encounter violations in RTD *not forecast* in DA and HA simulations
  - Correct for effects of hourly averaging on DA-HA unit commitment
- Caveats –
  - Does not reflect forecast uncertainty during dispatch hour

Draft Results of Incremental Wind Resources Only to Meet 20% RPS

- The first phase of analysis evaluated additional wind resources to meet the 20% RPS (consistent with ISO’s 2007 renewable integration study)
- Draft results are discussed in next slides

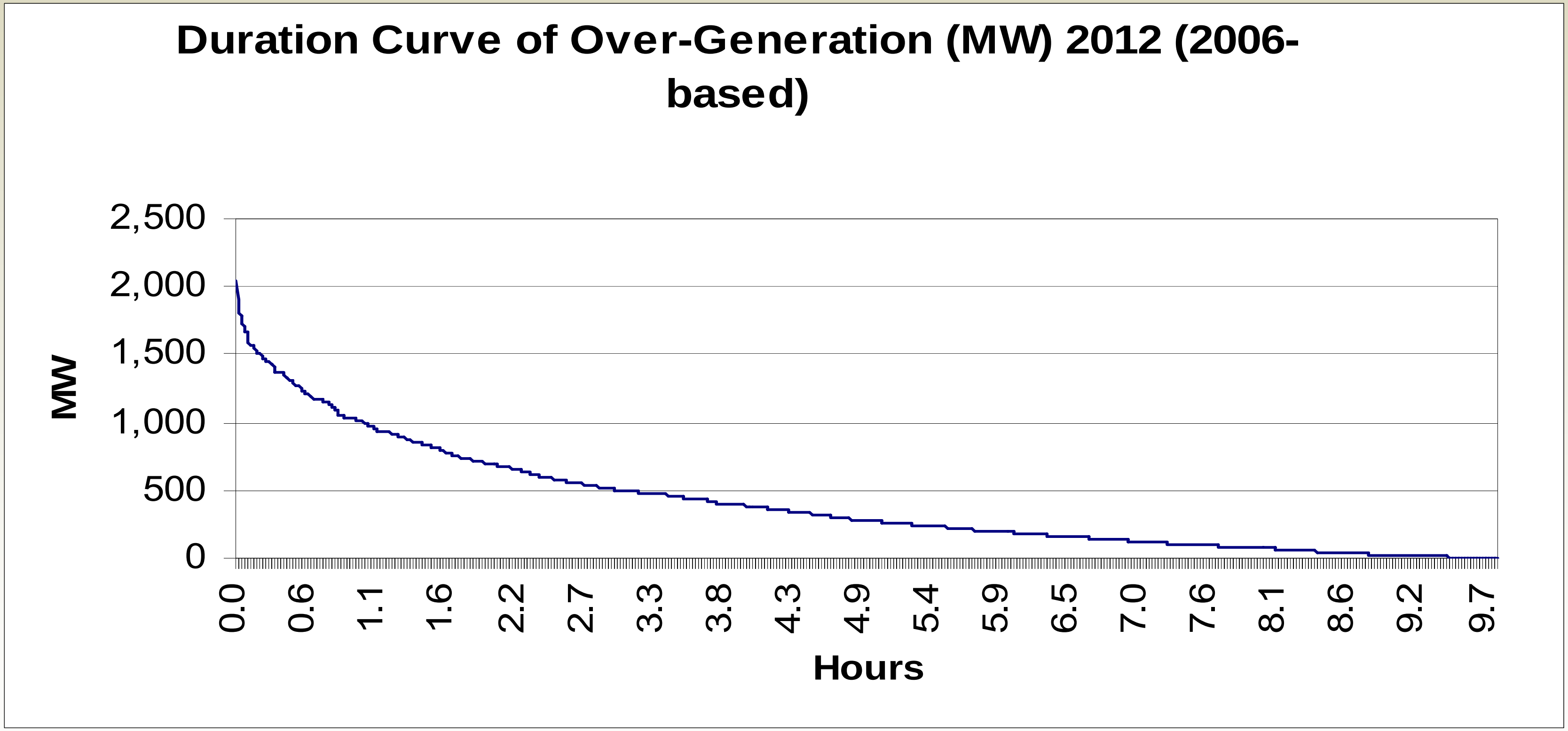
DA Simulation Annual Unserved Energy Duration Curve (2006-based simulation)

DRAFT RESULTS



DA Simulation Annual Over-generation Duration Curve (2006-based simulation)

DRAFT RESULTS



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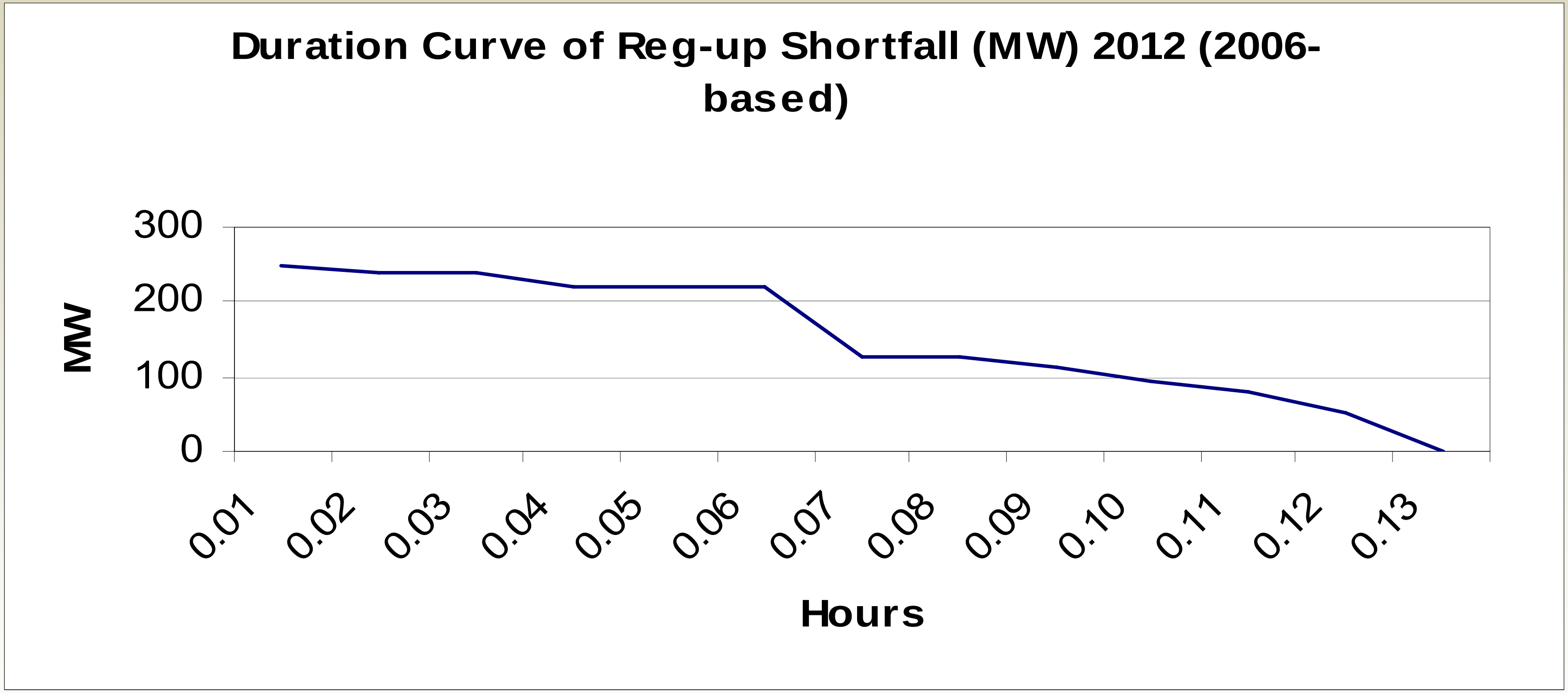
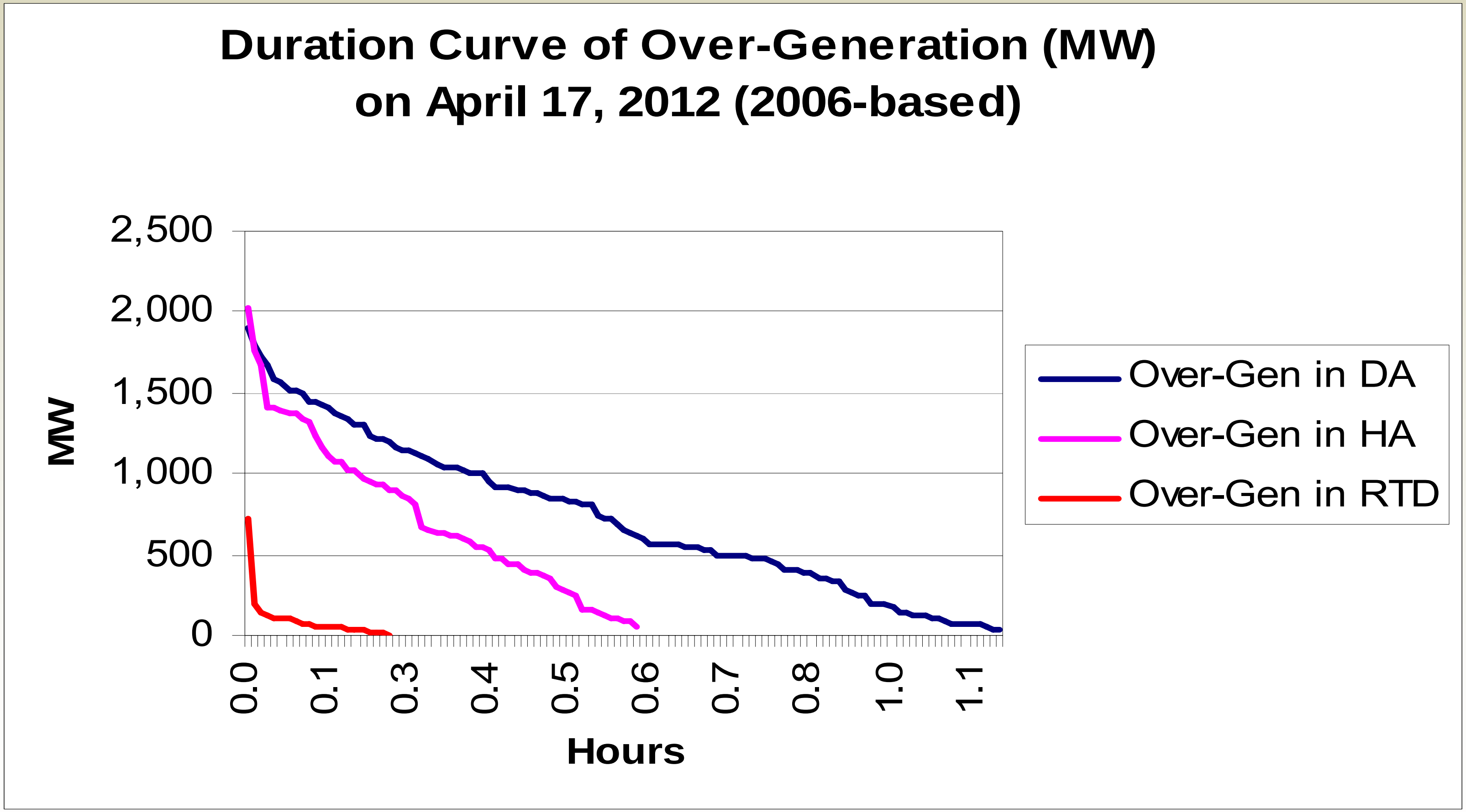
DA Simulation Annual Regulation-up Shortfall Duration Curve (2006-based simulation)

DRAFT RESULTS



DA-HA-RTD Duration Curves of Over-generation on April 17, 2012 (2006-based simulation)

DRAFT RESULTS



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Summary of Violation Occurrences in the DAM-HAM-RTD Simulations

DRAFT RESULTS

Violation Occurrences from 100-iteration Simulations										
	Service	Overgeneration			Reg-up shortfall			Unserved Energy		
Date	Market	DAM	HAM	RTD	DAM	HAM	RTD	DAM	HAM	RTD
February 27, 2012	2006-based									
April 17, 2012	2006-based	99	49	105						
May 7, 2012	2006-based	108	82	8						
June 24, 2012	2006-based			1						
July 23-24, 2012	2006-based				6	2		5		
September 3, 2012	2006-based									
February 27, 2012	2007-based									
July 3, 2012	2007-based									
August 30, 2012	2007-based				5	2		3	2	

Current phase of production simulation

- Evaluate a renewable resource mix more consistent with current IOU contracts/short-listed projects
- Add solar thermal/solar PV production profiles consistent with CPUC RPS contracts/IOU short-listed projects
- Also add a benchmark "all-gas" case for evaluating integration cost changes and impacts on generators
  - Changes in # starts/stops
  - Changes in hours at Pmin
  - Changes in cycling and ramping

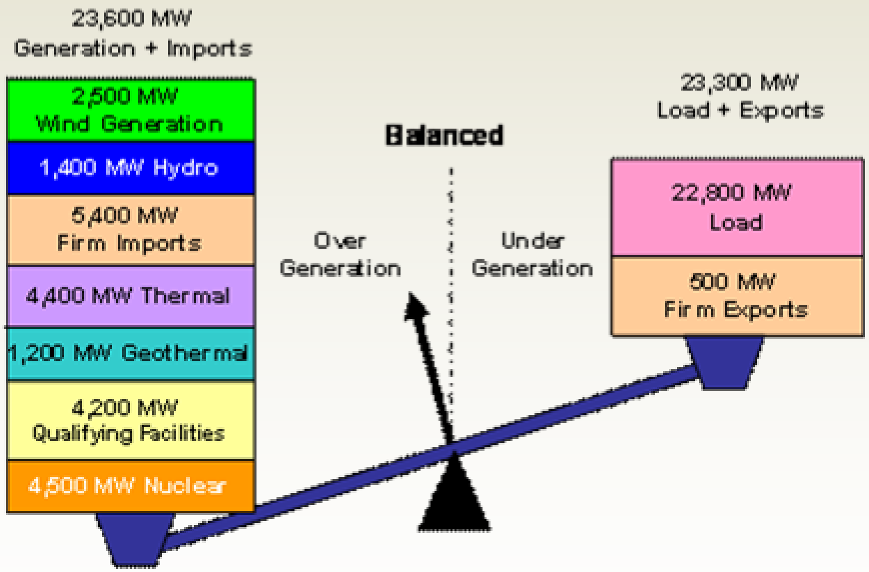
Next phase of production simulation research

- ISO is sponsoring in-house research that would further include
  - Full network model (DC power flow)
  - Additional hydro flexibility
  - Additional granularity on commitment decisions (more reflective of actual market procedures)
  - Quantify market benefits of improved wind and solar forecasts
- ISO is also evaluating more realistic simulation tools to evaluate operational impacts of incremental renewable resource additions (e.g., year by year)

Over-Generation Analysis

Over-Generation Analysis

- Identify and quantify the frequency, duration and magnitude of over-generation
- Sensitivities
  - High Hydro
  - Low Hydro



Typical concerns during over-generation

- System frequency is higher than 60 Hz,
- Area Control Error (ACE) is higher than normal and potential control performance violations can occur,
- Grid operators have difficulties controlling the system due to insufficient regulating capacity,
- Potential inability to quickly arrest frequency decline following a disturbance,
- Excess energy flows to neighboring BAs as inadvertent energy, and
- Real-time energy market prices may be negative

Approaches to Over-Generation Analysis

1. Production Simulation (already discussed)
   - Could underestimate actual frequency and magnitude due to better optimization of system resources than is possible in actual operations
2. Extrapolation from historical experience
   - Using statistical analysis, historical generation by technology, and assumptions about thermal and hydro min gen, imports, etc.
   - Could overestimate actual frequency and magnitude by not fully accounting for dynamic optimization

- *Note*: neither approach to date considers impact of dispatch of wind resources, storage or demand response; future simulations may conduct such sensitivities

Average Production by Resource Type (2006 Actual vs. Expected 2012 levels)

High Hydro --- Average Generation by Technology								
	Spring		*Summer*		*Fall*		*Winter*	
	2006 MW	***2012 MW***	***2006 MW***	***2012 MW***	***2006 MW***	***2012 MW***	***2006 MW***	***2012 MW***
Nuclear	2,522	4,500	4,526	4,500	3,620	4,500	3,468	4,500
Hydro	3,823	3,500	2,707	2,700	1,009	1,000	2,337	2,000
Thermal	3,822	3,100	4,325	4,400	5,573	4,500	5,263	4,000
Qualifying Facilities	3,339	3,000	4,021	4,000	4,238	4,000	3,651	3,500
Geothermal	783	1,200	789	1,200	794	1,200	800	1,200
Imports	5,149	4,000	5,511	4,500	4,744	4,200	4,630	4,000
Total Generation plus Interchange	***19,438***	***19,300***	***21,879***	***21,300***	***19,978***	***19,400***	***20,149***	***19,200***
Average Wind - 2006	***711***		***1,043***		***430***		***324***	
Average Load - 2006	*20,149*		*22,922*		*20,408*		*20,473*	
Minimum Load	19,064	20,800	20,837	22,800	19,189	21,000	18,737	20,500
Maximum Renewable that can be Integrated - 2012		***1,500***		***1,500***		***1,600***		***1,300***

Production by Resource Type (2007 Actual vs. Expected 2012 levels)

Low Hydro --- Average Generation by Technology								
	Spring		Summer		Fall		Winter	
	2007 MW	2012 MW	2007 MW	2012 MW	2007 MW	2012 MW	2007 MW	2012 MW
Nuclear	4,279	4,500	4,179	4,500	3,886	4,500	4,196	4,500
Hydro	1,108	1,100	1,392	1,400	879	900	811	800
Thermal	3,107	4,000	4,140	4,400	5,587	4,100	5,667	4,000
Qualifying Facilities	3,744	3,700	4,305	4,200	4,125	4,000	4,402	4,000
Geothermal	801	1,200	827	1,200	816	1,200	798	1,200
Imports	7,023	4,600	6,947	5,400	5,065	4,500	4,598	4,500
Total Generation plus Interchange	20,062	19,100	21,790	21,100	20,358	19,200	20,472	19,000
Average Wind - 2007	823		1,087		308		386	
Average Load - 2007	20,885		22,877		20,666		20,858	
Minimum Load	19,699	20,800	21,020	22,800	19,630	21,000	19,414	20,500
Maximum Renewable that can be Integrated - 2012		1,700		1,700		1,800		1,500

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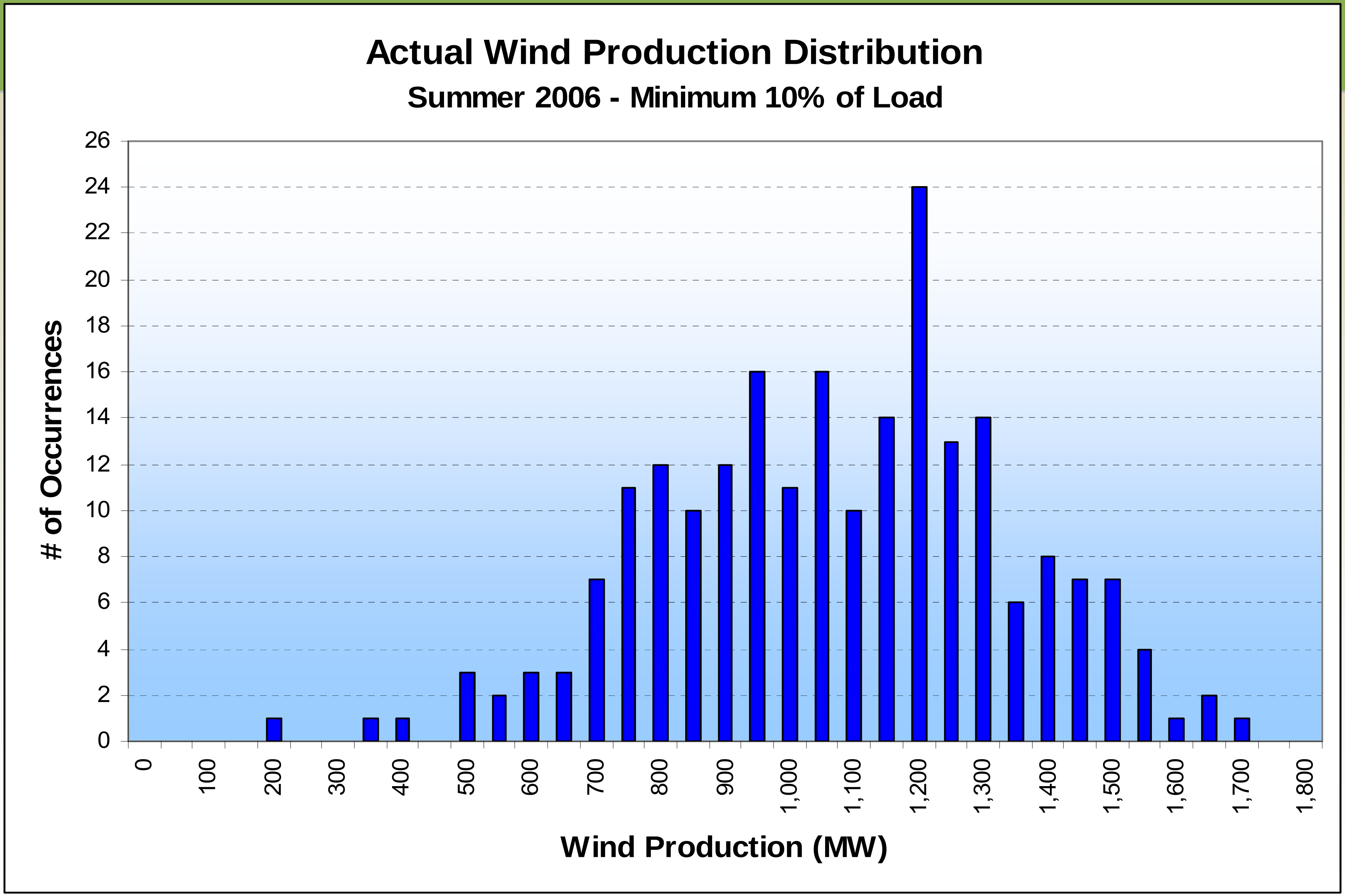

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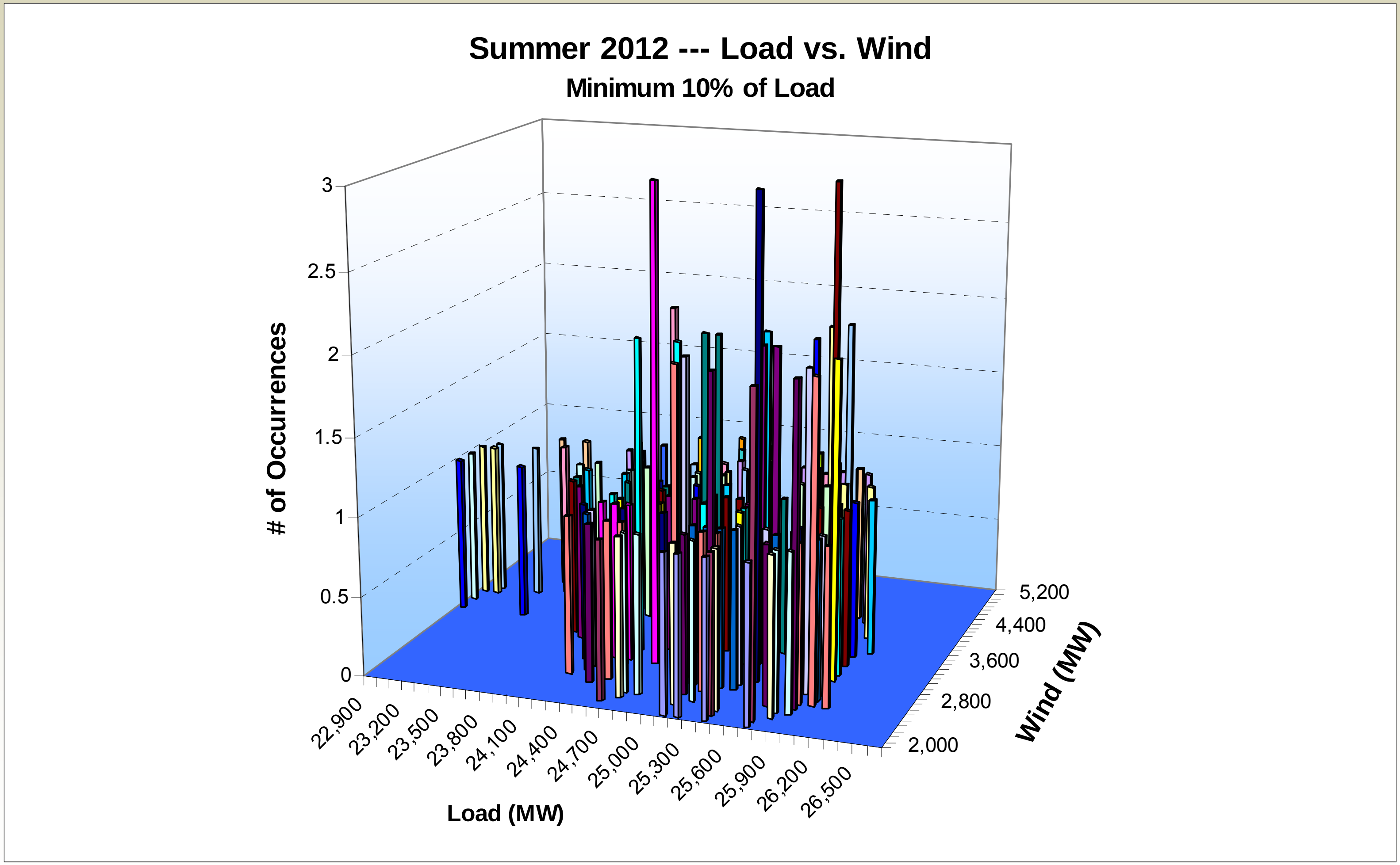
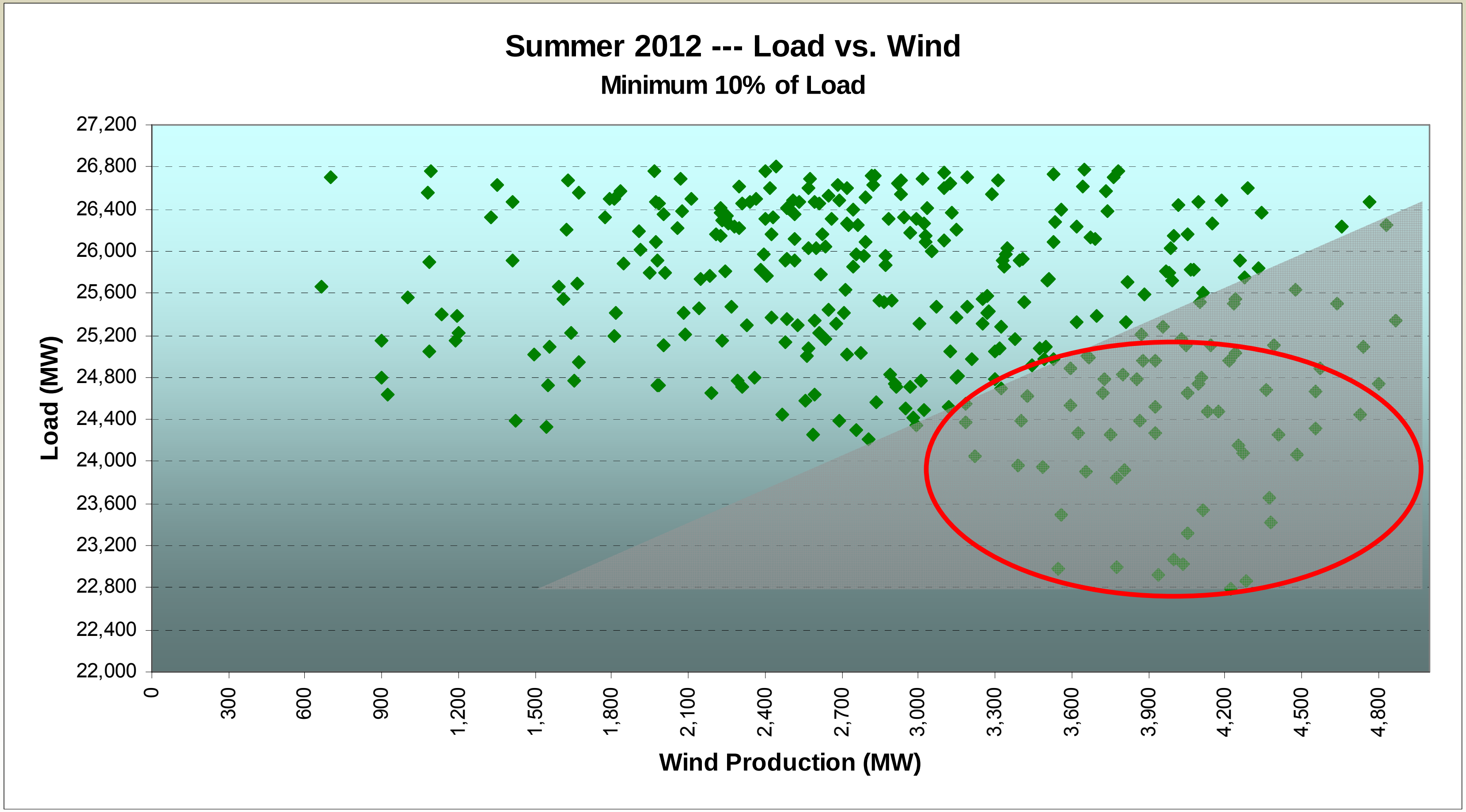
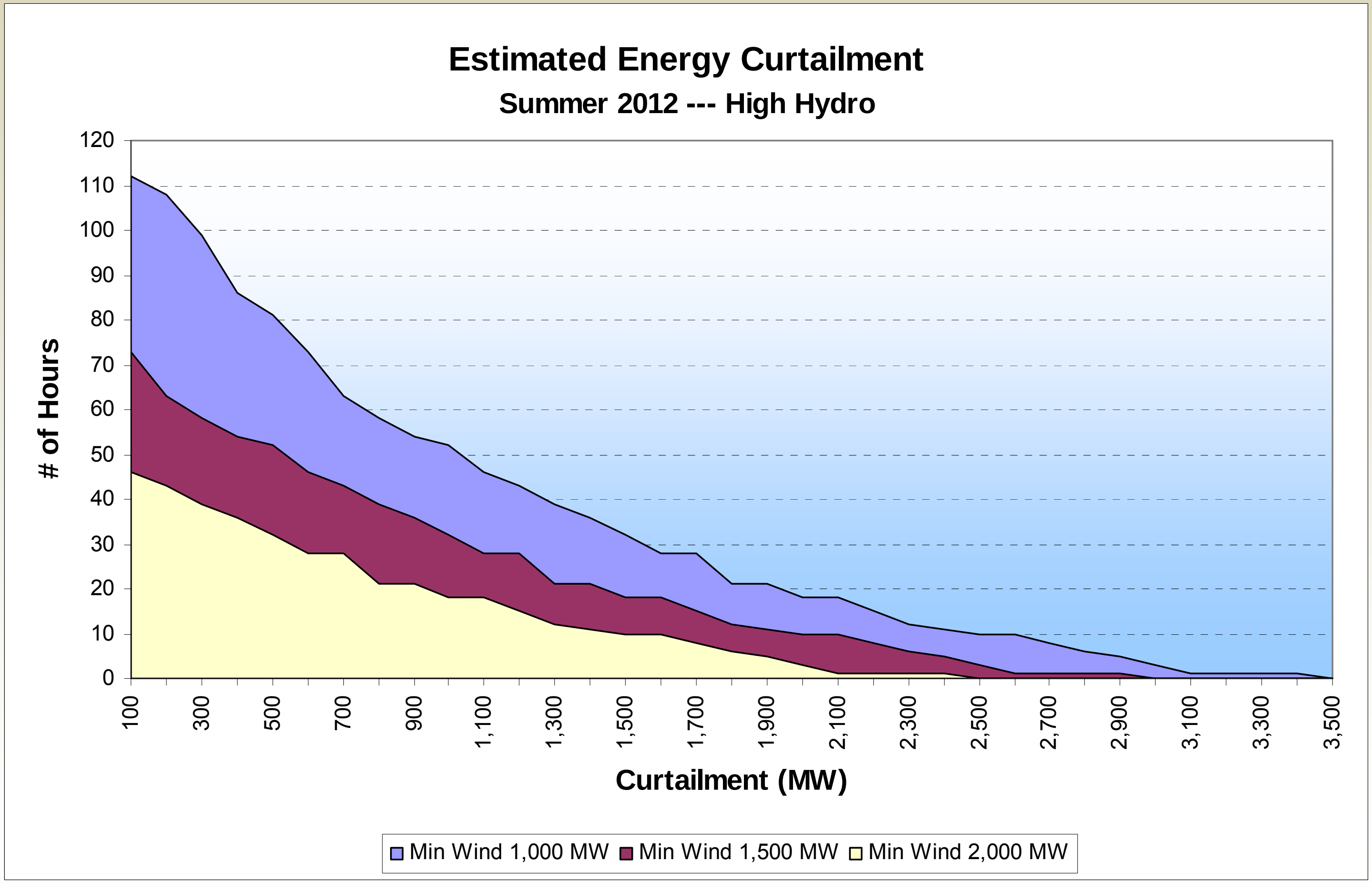
Projected Load vs. Wind for summer 2012



Expected Curtailment in 2012 shown in Grey



Expected Curtailment under High Hydro Conditions

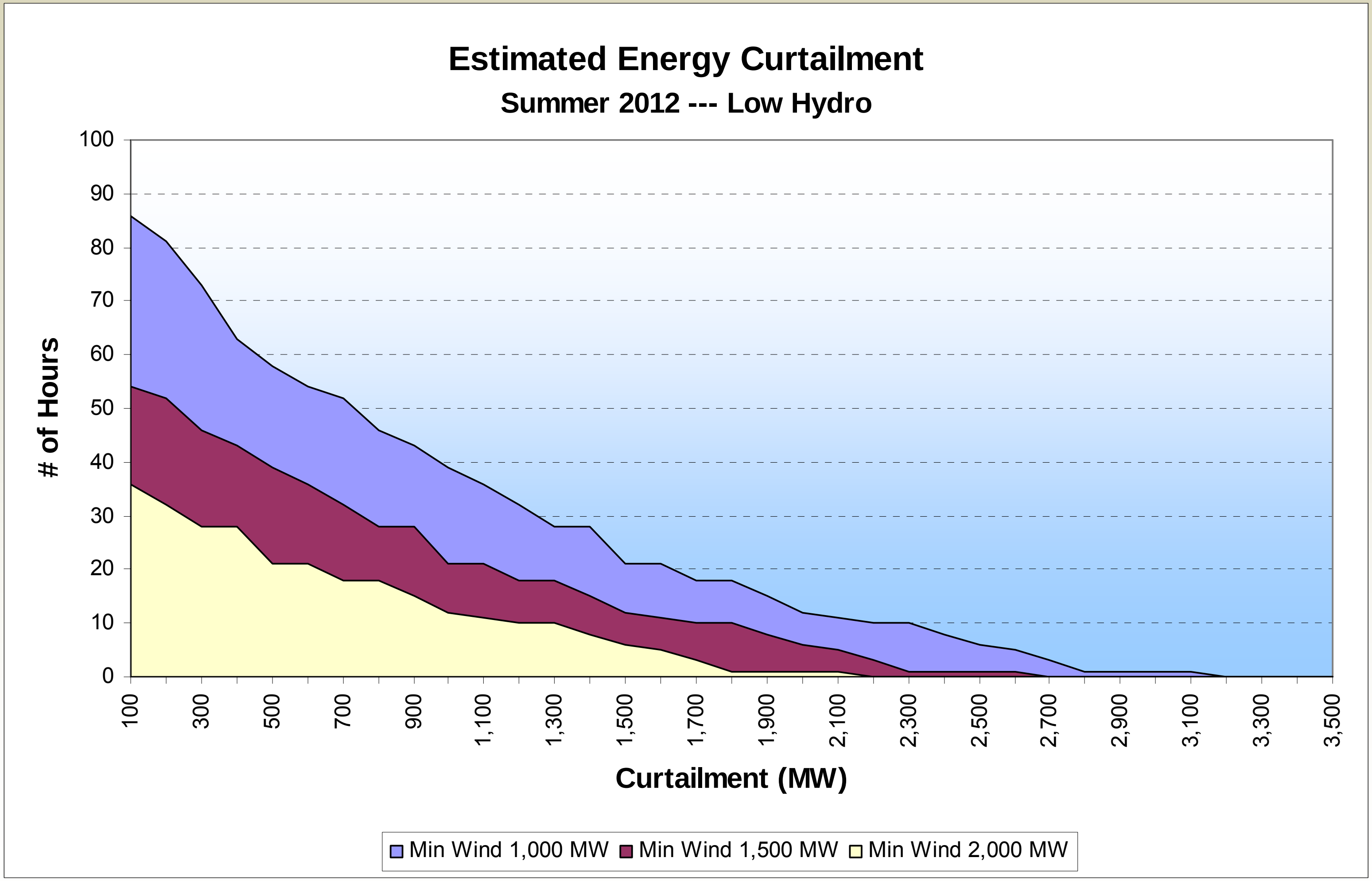


Expected curtailment during high hydro conditions

Expected Curtailment High Hydro --- 20% RPS								
Spring		***Summer***		***Fall***		***Winter***		
Maximum Wind (MW)	***Expected Curtailed (Hrs)***	***Maximum Wind (MW)***	***Expected Curtailed (Hrs)***	***Maximum Wind (MW)***	***Expected Curtailed (Hrs)***	***Maximum Wind (MW))***	***Expected Curtailed (Hrs)***	***Total (Hrs)***
1,000	***130***	1,000	***112***	1,100	***57***	800	***34***	***333***
1,500	***91***	1,500	***73***	1,600	***25***	1,300	***12***	***201***
2,000	***46***	2,000	***46***	2,100	***6***	1,800	***4***	***102***

Expected Curtailment High Hydro --- 20% RPS								
Spring		***Summer***		***Fall***		***Winter***		
Maximum Wind (MW)	***Expected Curtailed (MWh)***	***Maximum Wind (MW)***	***Expected Curtailed (MWh)***	***Maximum Wind (MW)***	***Expected Curtailed (MWh)***	***Maximum Wind (MW)***	***Expected Curtailed (MWh)***	***Total (MWh)***
1,000	***116,600 2.74%***	1,000	***120,000 2.17%***	1,100	***30,700 0.83%***	800	***17,700 0.53%***	***285,000***
1,500	***60,300 1.42%***	1,500	***71,400 1.29%***	1,600	***9,300 0.25%***	1,300	***5,400 0.16%***	***146,400***
2,000	***24,100 0.57%***	2,000	***41,400 0.75%***	2,100	***1,600 0.04%***	1,800	***1,200 0.04%***	***68,300***

Expected Curtailment under Low Hydro Conditions



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Expected Curtailment under Low Hydro Conditions

Expected Curtailment Low Hydro --- 20% RPS								
Spring		*Summer*		*Fall*		*Winter*		
Minimum Wind (MW)	*Expected Curtailed (Hrs)*	*Minimum Wind (MW)*	*Expected Curtailed (Hrs)*	*Minimum Wind (MW)*	*Expected Curtailed (Hrs)*	*Minimum Wind (MW)*	*Expected Curtailed (Hrs)*	*Total (Hrs)*
1,200	***130***	1,200	***86***	1,300	***41***	1,000	***26***	***283***
1,700	***64***	1,700	***54***	1,800	***16***	1,500	***10***	***144***
2,200	***30***	2,200	***36***	2,300	***2***	2,000	***3***	***71***

Expected Curtailment Low Hydro --- 20% RPS								
Spring		*Summer*		*Fall*		*Winter*		
Minimum Wind (MW)	*Expected Curtailed (MWh)*	*Minimum Wind (MW)*	*Expected Curtailed (MWh)*	*Minimum Wind (MW)*	*Expected Curtailed (MWh)*	*Minimum Wind (MW)*	*Expected Curtailed (MWh)*	*Total (MWh)*
1,200	***80,300 1.88%***	1,200	***88,100 1.66%***	1,300	***19,800 0.54%***	1,000	***11,500 0.35%***	***199,700***
1,700	***35,700 0.84%***	1,700	***52,000 0.94%***	1,800	***5,100 0.14%***	1,500	***3,100 0.09%***	***95,900***
2,200	***12,400 0.29%***	2,200	***28,600 0.52%***	2,300	***700 0.02 %***	2,000	***400 0.01 %***	***42,100***

Overview of KEMA Renewables Project

Objective of the KEMA Renewables Project

1. Simulate and analyze the impact of renewable generation on system performance with respect to AGC / system regulation and balancing energy / real time dispatch requirements and energy storage requirements.
    - Validate the KEMA dynamic simulation model
2. Measure the impacts of increasing percentages of renewables on the California Grid and how storage can be utilized to mitigate those impacts
    - Identify potential changes to the market systems and dispatch algorithms required to accommodate energy storage

Study process and timeline

- R&D/PIER project funded by the CEC
  - Work started in June 2009
- Major Tasks
  - Task 1 – Calibrating KEMA Simulation model to California ISO
  - Task 2 – Define Simulation Scenarios (June – July 2009)
  - Task 3 – Run Simulation Scenarios (July – Sept. 2009))
  - Task 4 – Analyze the Results (Aug. - Sept 2009)
  - Task 5 – Prepare Final Report (Oct. 2009)

Scenarios selected

- 5 “Interesting” days selected for the scenario analysis
  - June 5, 2008 – Major generator trip – used to calibrate model
  - July 9, 2008 – High summer load day with significant wind and solar generation
  - October 20, 2008 – Fall load day with variable gen.
  - February 9, 2009 – Winter load day with variable gen.
  - April 12, 2009 – Spring load day, post MRTU, with variable gen.
- Actual hourly data used for
  - **Generator production schedules** and **Import schedules**
- 4 second data used for
  - **ACE, Frequency, Load and Regulation**

Preliminary results to date

- Results correlate with results from other studies
- Large solar ramps, both up and down, are going to be a major operating issue
- Large storage (2-4 hours) with fast response mitigate the large ramps and control ACE
- Large amounts of regulation by itself does not solve the ramping problem for 33 % Renewables

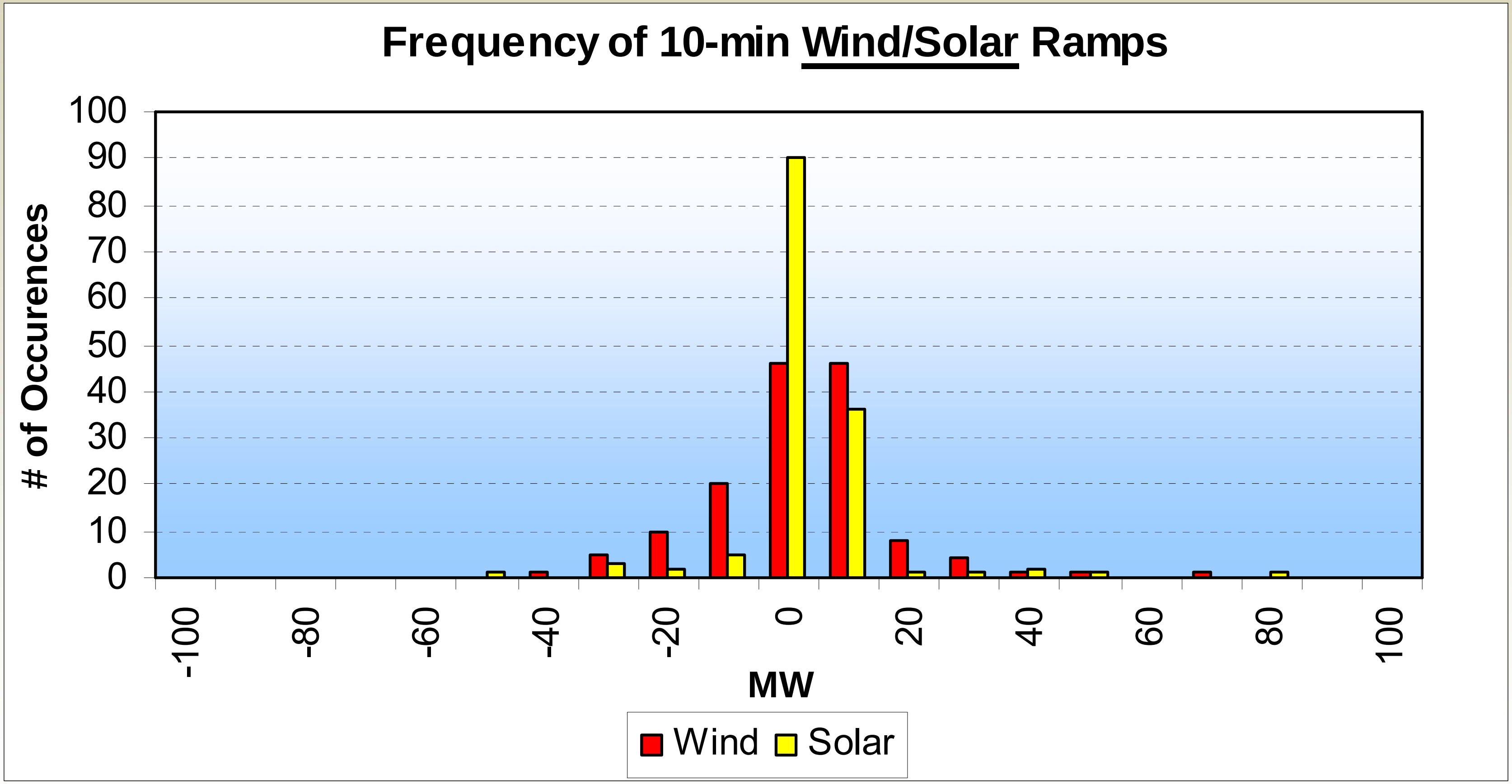
Renewable Metrics and Conclusions

ISO is developing daily metrics relevant to the impacts on thermal fleet of renewable integration

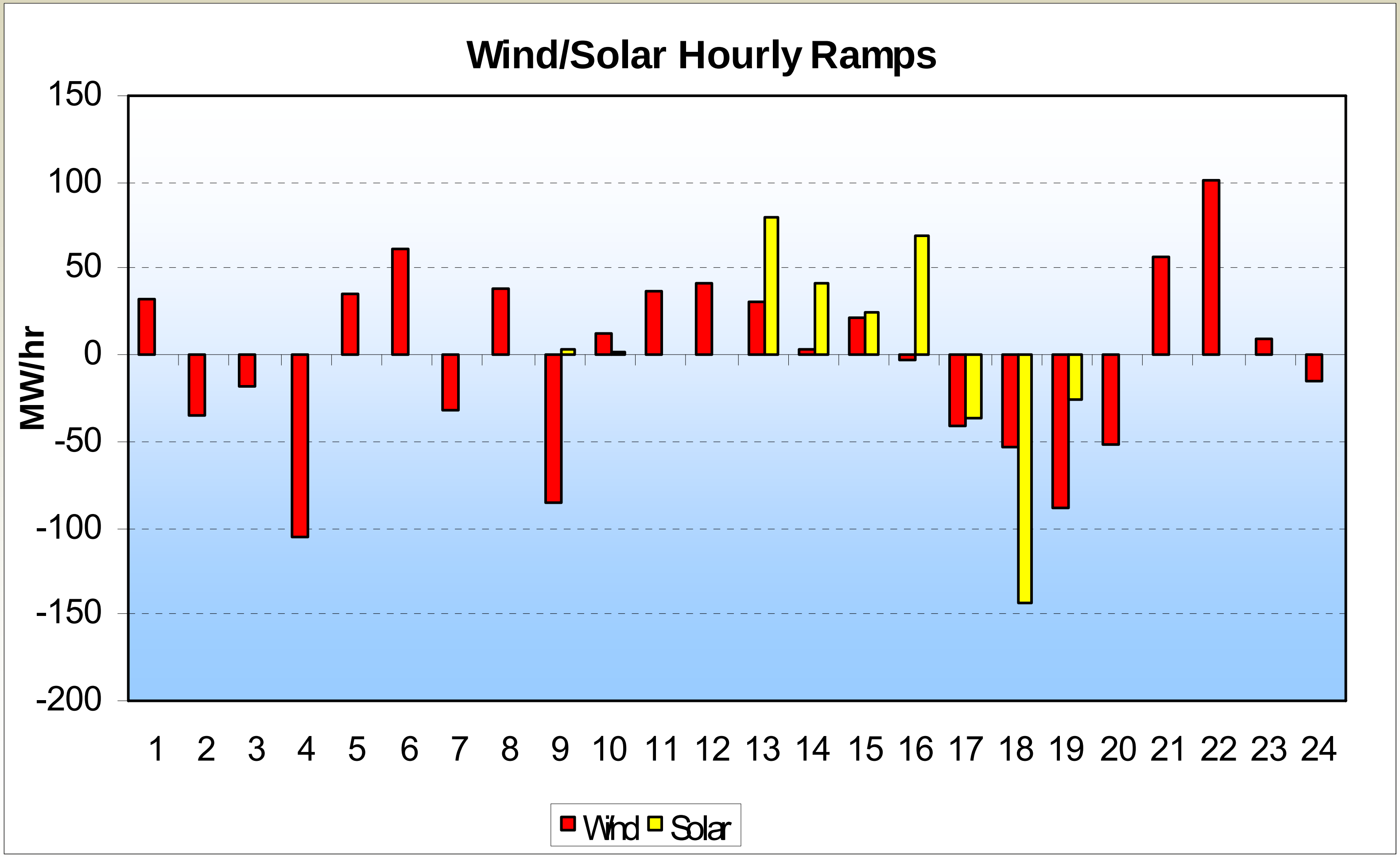
- Load/Wind, Load/Solar, Solar/Wind correlations
- Wind/solar ramps (by hour, 10 minutes)
- Max Upward/Downward ramps
- ACE/Regulation/Wind profile
- Several others

These metrics will be monitored over time and compared to simulated results

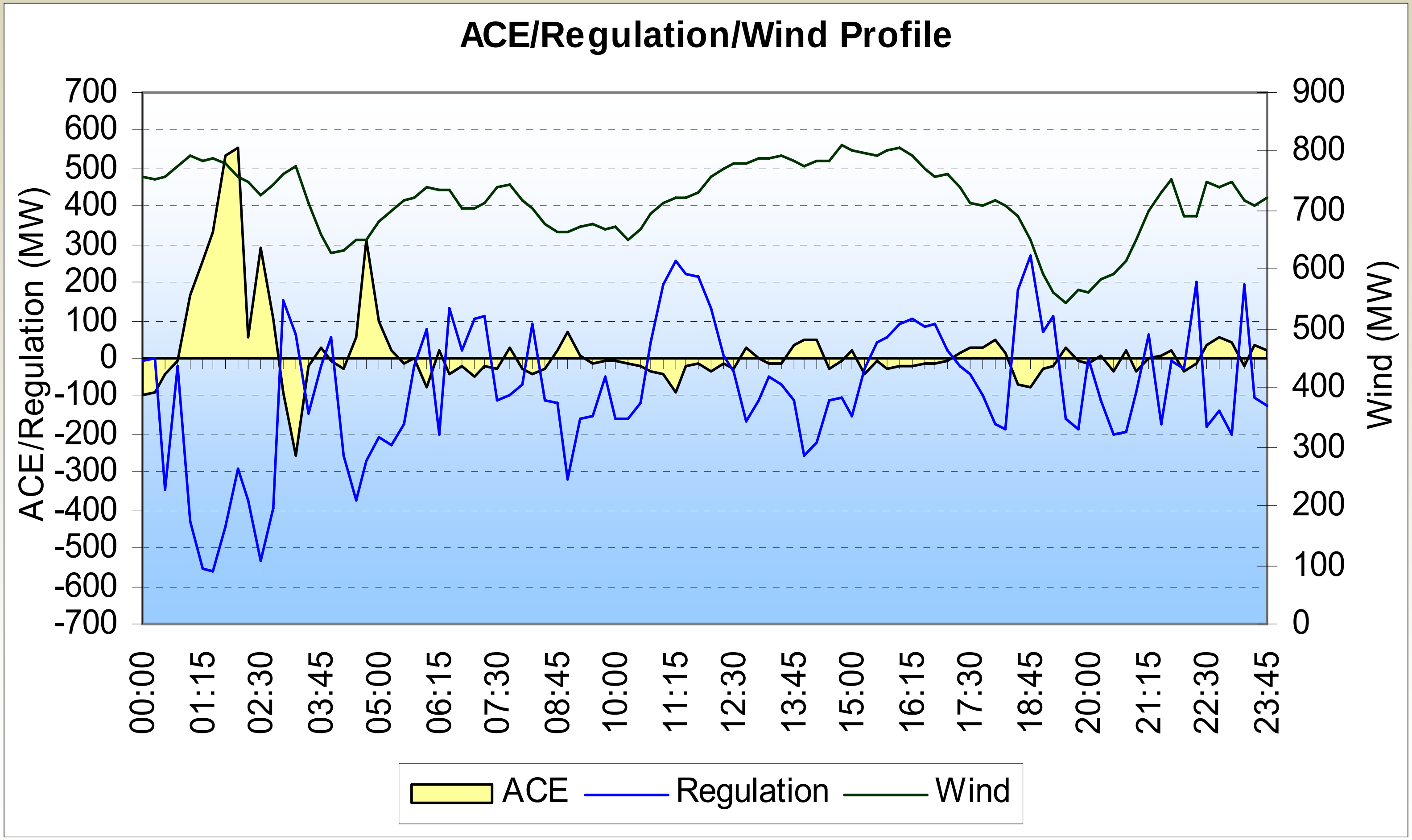
Sample Day – Frequency of 10-minute Wind/Solar ramps



Sample Day – Wind/Solar Hourly Ramps



Sample Day – ACE/Regulation/Wind profile



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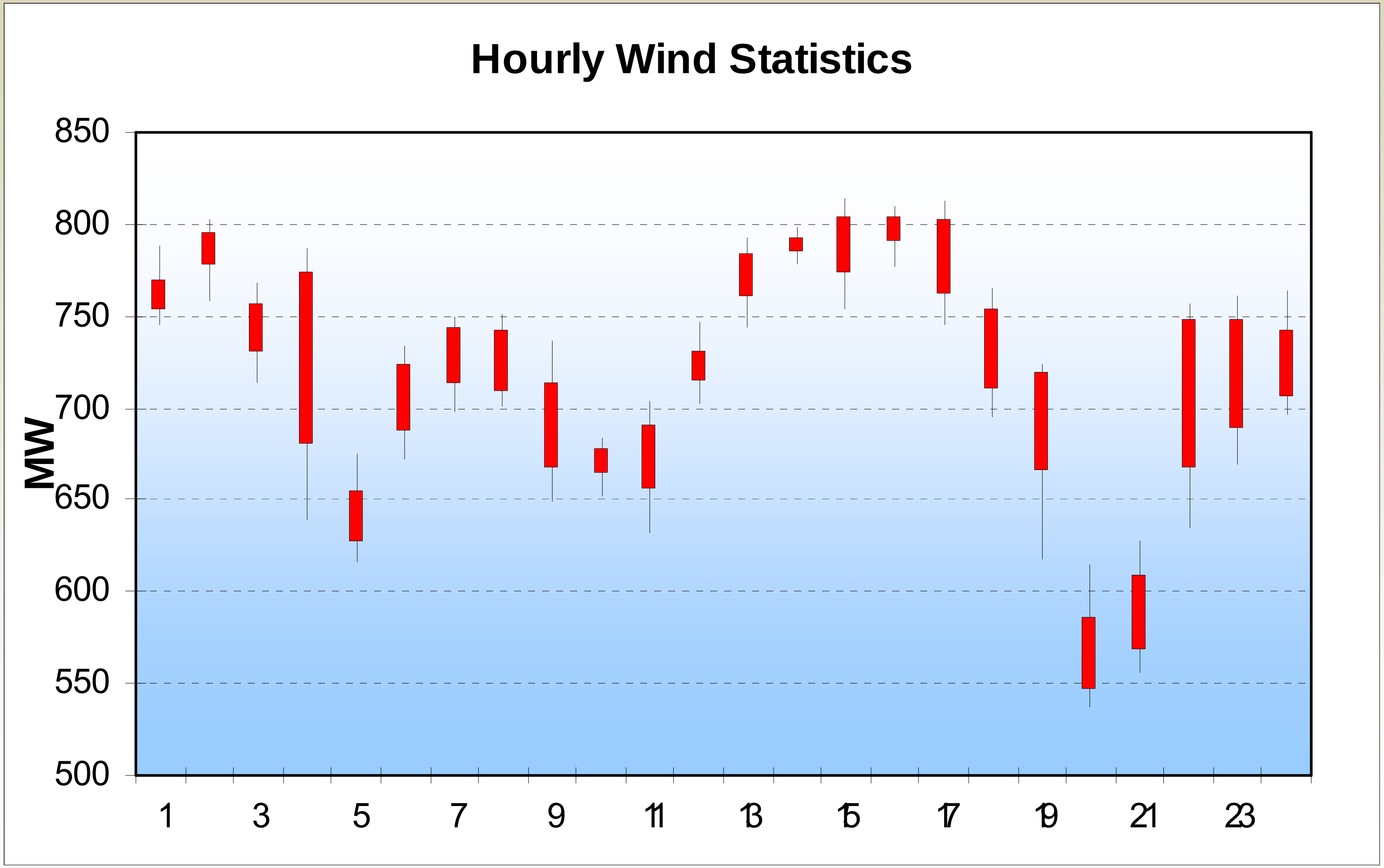
Hourly wind statistics



Sample Day – Max Upwards and Downwards Ramps

Maximum Upward Ramp				
	3-Hour	**1-Hour**	**10-min.**	**5-min**
Load (MW)	6,255	3,053	826	442
	4:20	*5:55*	*5:56*	*5:59*
Wind (MW)	218	157	54	37
	19:41	*20:38*	*22:29*	*14:37*
Load-Wind (MW)	6,175	3,079	813	440
	4:20	*5:55*	*5:56*	*5:59*
Maximum Downward Ramp				
	3-Hour	**1-Hour**	**10-min.**	**5-min**
Load (MW)	5,813	2,224	458	325
	20:52	*21:58*	*22:25*	*3:44*
Wind (MW)	243	162	70	43
	16:30	*18:34*	*21:59*	*14:33*
Load-Wind (MW)	5,933	2,271	495	322
	20:52	*22:09*	*22:23*	*3:44*

**** Time indicates the start of respective ramps.

Concluding comments and opportunities for feedback

- Implications for procurement of Regulation (Ancillary Services), and how markets and forward procurement processes elicit needed generation and non-generation resource characteristics, are being further assessed
  - Operational tools utilizing aspects of these Regulation and ramp forecasting methods may be incorporated into market procedures
- Comments or questions on this presentation are welcome
- Draft report will offer opportunity for detailed comments

Other CAISO Initiatives Related to Fleet Adequacy

- 33% RPS operational study
- Integration of Demand Response
- Integration of Storage Resources
- Analysis of Plug-in Hybrid Electric Vehicles (PHEV)
- Smart Grid

Some References

- California ISO, Integration of Renewable Resources, November 2007 (available at www.caiso.com)
- Makarov et al., Operational Impacts of Wind Generation on California Power Systems, *IEEE Transactions on Power Systems*, 24, 2, May 2009
- California ISO, Integration of Renewable Resources Program: http://www.caiso.com/1c51/1c51c7946a480.html

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