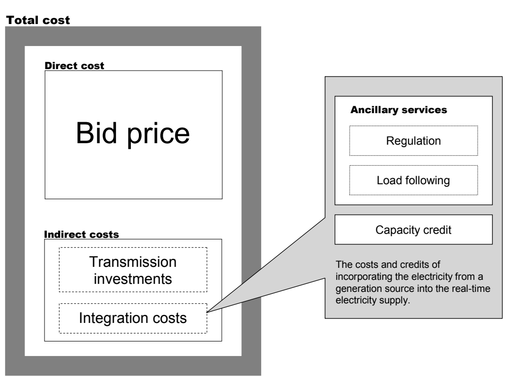
CALIFORNIA RENEWABLES PORTFOLIO STANDARD RENEWABLE GENERATION INTEGRATION ANALYSIS

Brendan Kirby
Oak Ridge National Laboratory

Michael Milligan
National Renewable Energy Laboratory

Yuri Makarov and David Hawkins
California ISO

Kevin Jackson and Henry Shiu
California Wind Energy Collaborative



Goals

- *Estimate integration costs and capacity credit for various renewable resources.*
- *Develop a methodology that can be applied during the renewable generation selection process.*
- *The final methodology will:*
  - *use input data and analysis tools available in the public domain*
  - *be fair, transparent, and coherent*
  - *provide cost estimates that are representative of California*
  - *be clearly defined, provide repeatable results, and be analyst independent*

Timeline

March 18, 2003
Strategy and schedule of analysis presented at CPUC/CEC RPS least-cost/best-fit workshop

April 23, 2003
Released proposed analysis methodology

April 29, 2003
Discussion of proposed analysis methodology with Working Group

June 30, 2003
CEC's guidelines for least-cost/best-fit due

November 22, 2002
In CalWEA workshop Wind Valuation and Integration: Incorporating Wind in the Least-Cost/Best-Fit Process, *the Working Group is formed and the issue is discussed*

January 17, 2003
In a follow-up conference call, the Integration Analysis Methods Group is formed and tasked with developing the methodology

. . . . . .

Phase I • through 2nd Quarter 2003
Analysis of integration costs for existing renewable and non-renewable generation

Phase II • through 4th Quarter 2003
Evaluate attributes affecting integration analysis

Phase III • through 2nd Quarter 2004
Finalize methodology to identify integration costs and capacity values to be applied to bids for new and existing renewables

Deliverable
Methodology

PHASE I:
Analysis of Integration Costs for Existing Generation

- *Determine a methodology for evaluating the integration costs and capacity credit by examining California's existing renewable and non-renewable generation.*
- *Primary investigators in Methods Group:*
  - *Brendan Kirby, ORNL*
  - *Michael Milligan, NREL*
  - *David Hawkins, California ISO*
  - *Yuri Makarov, California ISO*
- *The Methods Group released the draft methodology report for public discussion on April 23, 2003.*
- *Completion of Phase I is expected in June 2003.*

PHASE II:
Evaluate Attributes Affecting Integration Analysis

- *Identify the key attributes of renewable generators that affect integration costs and capacity credit.*
- *Attributes may include:*
  - *various generator technologies*
  - *location*
  - *climate*
  - *level of penetration*
- *Completion of Phase II is expected in December 2003.*

PHASE III:
Finalize Methodology for Integration Costs and Capacity Credit for RPS Bids

- *Modify the methodology developed in Phase I so that the attributes identified in Phase II can be correctly modeled in the analysis.*
- *The final methodology will be released openly to the public and project bidders.*
- *Completion of Phase III is expected in June 2004.*

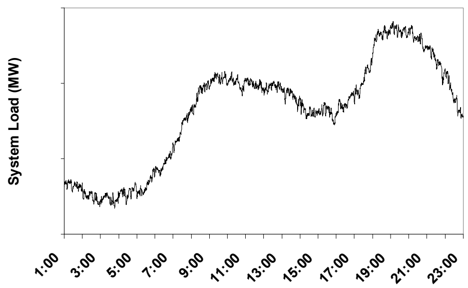
Ancillary Services Analysis: Method 1

Brendan Kirby
Oak Ridge National Laboratory

Analysis Philosophy

- *Prior experience evaluating regulation and load following impacts for other control areas*
  - *Individual loads and generators*
  - *Allocating total system requirements*
- *Not Advocating*
  - *Specific technologies or outcomes*
- *An Advocate For*
  - *Allocation of total system regulation and load following requirements based upon individual impacts*
- *Proposed method previously used for analysis of AEP, CSW, NIPSCO, BPA, ComEd, PJM, Alberta, New Brunswick, Ontario, Xcel, Great River, …*

Under Normal Conditions, Both Short-Term and Long-Term *Aggregate System* Fluctuations Have To Be Balanced

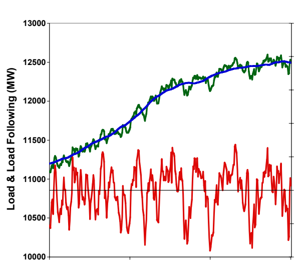


Balancing the Electrical System

- *Regulation & load following (or supplemental energy) balance the system under normal conditions.*
- *Both address the time varying characteristic of balancing generation and load under normal operations.*
- *The "system" only has to compensate for the aggregation.*
- *The aggregation is composed of individual loads and generators with* diverse *characteristics.*
- *Aggregation greatly reduces the total amount of regulation and load following.*

Decomposition of Control Area Loads

- *Control area load & generation can be decomposed into three parts:*
  - *Base Energy*
  - *Regulation*
  - *Load Following*



Regulation & Load Following Differ

	REGULATION	LOAD FOLLOWING
Patterns	Random, uncorrelated	Largely correlated
Generator control	Requires AGC	Manual
Maximum swing (MW)	Small	10 – 20 times more
Ramp rate (MW/minute)	5 – 10 times more	Slow
Sign changes	20 – 50 times more	Few

Aggregation Greatly Benefits Regulation And Uncorrelated Load Following

Unlike energy, individual load intrahour fluctuations are generally uncorrelated

$$\mu_{SYSTEM} = \sum \mu_{INDIVIDUAL}$$

- *Energy requirement*

$$\sigma_{SYSTEM} = \sqrt{\sum \sigma^2_{INDIVIDUAL}}$$

- *Fluctuations*

Aggregation of Two Entities

	Size	σ	Regulation
A	1000	20	60
B	1000	20	60
Total	2000	28	85

Allocation Choices

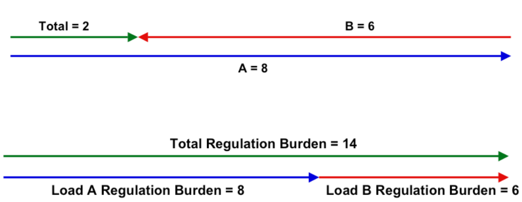
- *A & B share requirements equally*
  - *Reserve A = 42*
  - *Reserve B = 42*
- *B "joins" A and provides "full compensation" (incremental impact)*
  - *Reserve A = 60*
  - *Reserve B = 25*

Individual Regulation Burden Can Be Measured And Allocated

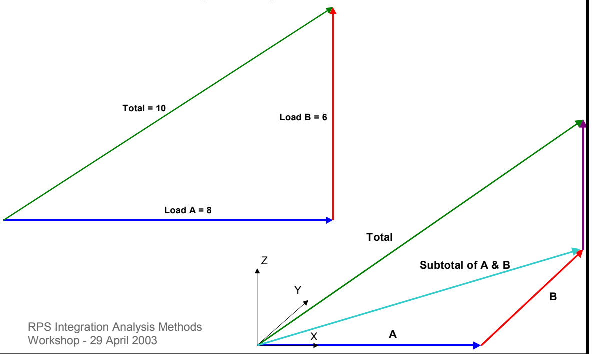
The allocation method should:

- *Recognize positive and negative correlations*
- *Be independent of subaggregations*
- *Be independent of order in which loads added to system*

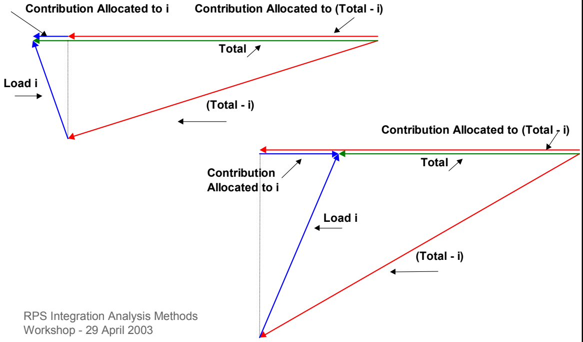
Allocation Simple When Burdens Are Correlated



Allocation Also Simple When Burdens Completely Uncorrelated



Generalized Method Treats Positive Or Negative Correlations



The Standard Deviation of the 1 Minute Meter Readings Provides A Good Regulation Metric

$$\sigma_{i\_allocation} = \frac{\left(\sigma_{Total}^2 + \sigma_i^2 - \sigma_{Total-i}^2\right)}{2 * \sigma_{Total}}$$

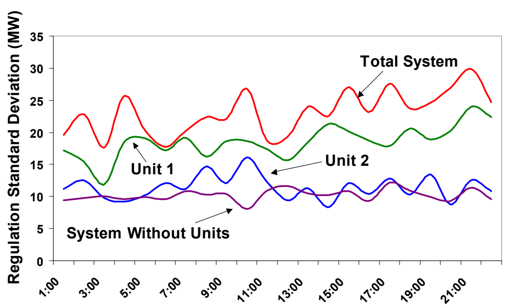
- *Handles correlated and uncorrelated components*
- *Independent of sub-aggregation*
- *Independent of order*
- *Disaggregate as many (few) components as desired*

Method Requires Minimal Data

- *1 minute total system load data*
- *1 minute renewable resource generation data*
- *Hourly system regulation purchase (CAISO web site)*
- *Hourly system regulation price (CAISO web site)*

Method Fairly Allocates Regulation Impact

Identifies High Impact Individuals



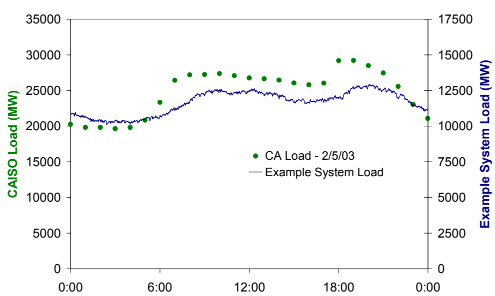
Allocating Regulation *Cost* to Individuals

- *Determine hourly system regulation requirement*
  - *1 minute data for total system load*
  - *Separate regulation from load following*
  - *Hourly standard deviations*
- *Determine hourly individual regulation requirements*
- *Allocate individual hourly regulation requirements*
- *Obtain hourly system regulation purchase amount*
- *Allocate total regulation purchase to individuals*
- *Obtain hourly regulation price*
- *Determine hourly individual regulation cost*

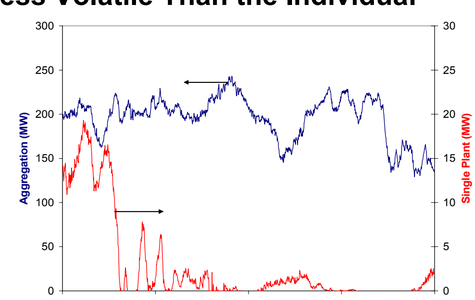
Example Calculation

- *1 minute generation data from several wind plants in California for 1 day*
- *1 minute system load data from a Midwestern utility*
- *CAISO hourly regulation purchases & prices*
- *Because the data is not synchronized and not all from California this is an <u>example of the calculation method only</u>*

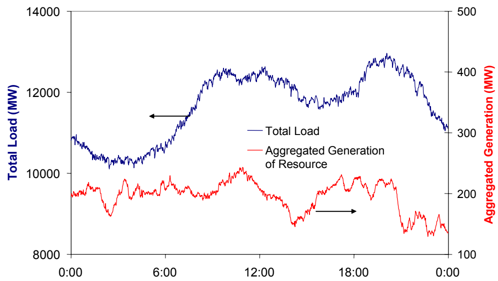
Example System is Smaller & Has Smaller Daily Swing Than California



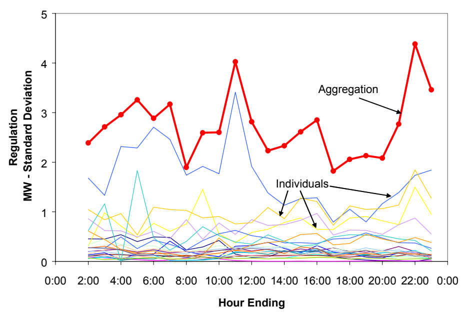
Aggregation of the Analyzed Resource Less Volatile Than the Individual



One Day of Total Load & Total Generation of Analyzed Resource



Individual & Aggregate Regulation Impacts of Analyzed Resource



Example Regulation Results
1 Day

Plant	"A"	"B"	"C"	"D" ...	Aggregated Resource	Total Load	Load & Resource
Average Energy MW	2.3	39.8	1.1	3.7	198	11720	11522
Reg. StDev	0.225	0.771	0.088	0.216	2.729	54.535	54.643
Allocated StDev	-0.003	0.062	0.005	0.003	0.180	54.463	54.643
% of Actual	-1.5%	8.0%	5.8%	1.3%	6.6%	99.9%	100.0%
Allocated Reg. MW	-0.1	1.2	0.1	0.1	3.7	1080	1084
$/MWH of Gen	-$0.07	$0.37	$1.14	$0.22	$0.26	$1.18	$1.21

Load Following Provided From Supplemental Energy

- *Mismatch of schedules and actuals*
- *Only necessary to compensate for aggregation*
- *Schedules obtained from simple, "naïve" persistence model*
- *Supplemental energy redispatched every 10 minutes*

Allocating Load Following *Cost* to Individuals

- *Determine actual system load*
- *Determine actual individuals generation*
- *Determine total system load forecast (CAISO web site)*
- *Determine individual forecast (persistence)*
- *Determine supplemental energy requirements (difference)*
- *Obtain hourly supplemental energy price*
- *Determine individual supplemental energy cost*

Method Requires Minimal Data

- *System load data*
- *Renewable resource generation data*
- *Hourly system supplemental energy price (CAISO web site)*

Example Load Following Calculation
1 day

Plant	"A"	"B"	"C"	"D" …	Aggregated Resource	Total Load
Energy	2.2	39.3	1.1	3.7	196	25249
Forecast	2.9	39.8	1.2	3.7	198	25503
Imbalance	-0.742	-0.468	-0.059	-0.024	-2.5	254
% Error	-34%	-1%	-5%	-1%	-1.3%	1.0%
$/MWh of Gen	$13.72	$0.65	$2.56	$0.60	$0.77	-$0.47

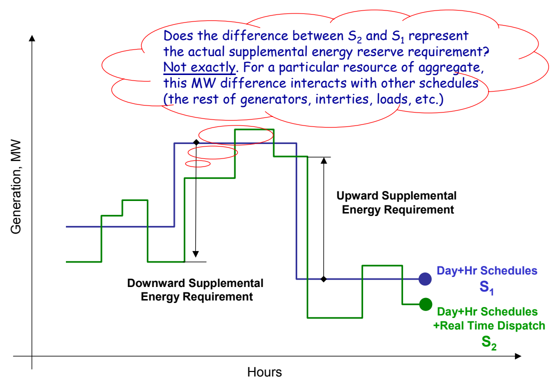
Previous Studies Of Regulation and Load Following Using Identical or Similar Methods

- *PJM – scaling did not account for geographic diversity*
  - *$0.70-2.80/MWh for imbalance payments, reduced with improved scheduling*
  - *$0.05-0.30/MWh for regulation, load paid $0.60/MWh*
- *Xcel – large imbalance penalties assumed*
  - *5% increased regulation with 3-4% penetration*
  - *$1.85/MWh for regulation, imbalance and forecasting*
- *PacifiCorp – preliminary findings*
  - *$5-6/MWh with 20% penetration*
  - *split between imbalance costs and reserve costs*
- *Nordel – very large penetration simulated, up to 21GW & 63%*
  - *No added regulation burden in aggregated Northern Europe*
  - *No impact on contingency reserves*
  - *3-8% load following burden (study did not consider geographic diversity or aggregation with system)*

Ancillary Services Analysis: Method 2

Yuri Makarov
California Independent System Operator

1. Impact on Supplemental Energy Reserve Requirement



Types of Resource Schedules

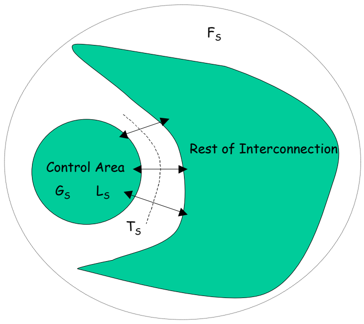
Explicit actual schedules: resources are scheduled individually in transparent fashion. E.g., wind generators participating in the California ISO intermittent resources protocol will have explicit hour-ahead schedules.

Implicit simulated schedules have to be used whenever the explicit schedules are not available, e.g. when the analyzed resource is a part of an aggregated schedule, or when an explicit schedule is not available at all.

A resource is directly separable when it has both actual hour-ahead and real-time schedules explicitly available.

If the expected individual generation is only available through an aggregate schedule, it becomes a directly non-separable resource. The separation of its contribution becomes artificial and approximate. It can be done by simulating the implicit schedules, or by determining a “fair share” of each individual resource in an aggregate based on convention or rule.

The approach suggested in this presentation is flexible enough to accommodate all type of schedules described above.

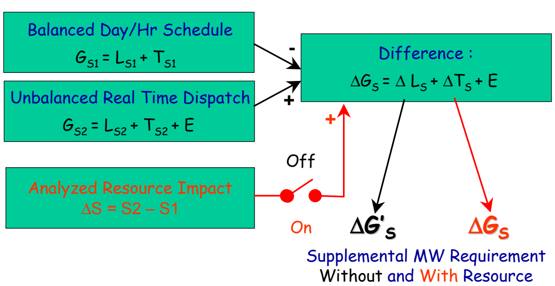


Scheduled Parameters:

- F_S Frequency, Hz
- T_S Net Interchange, MW
- G_S Generation, MW
- L_S Load, MW

Balanced Schedule:

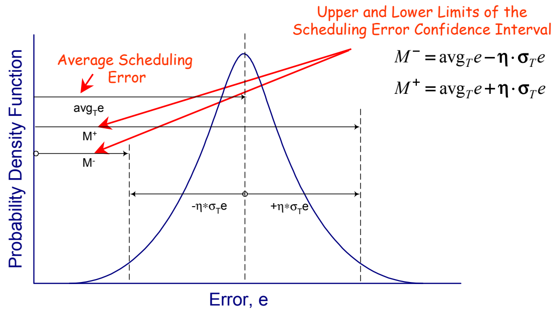
$$G_S = L_S + T_S$$



Supplemental requirements $\Delta G'_S$ and ΔG_S are processes in time (scheduling errors) that can be analyzed and compared statistically!

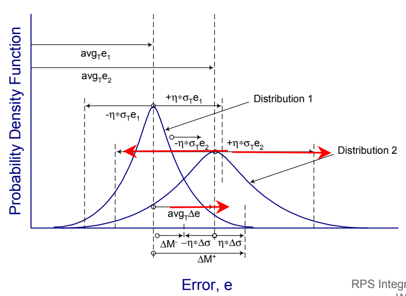
2. Measuring the Unscheduled Impacts

Variability Metrics of Unscheduled Impacts



Incremental Variability Metrics of Unscheduled Impacts

Supplemental requirements $\Delta G'_S$ and ΔG_S are scheduling errors which influence the position and boundaries of the confidence interval M-, M+



Incremental Variability Metrics of Unscheduled Impacts

Supplemental requirements $\Delta G'_S$ and ΔG_S are scheduling errors which influence the position and boundaries of the confidence interval M-, M+

$$\Delta M^{\pm} = avg_T \Delta e \pm \eta \cdot \Delta\sigma$$

Increment of Average Supplemental Reserve Requirement

Increment of Variance of Supplemental Reserve Requirement

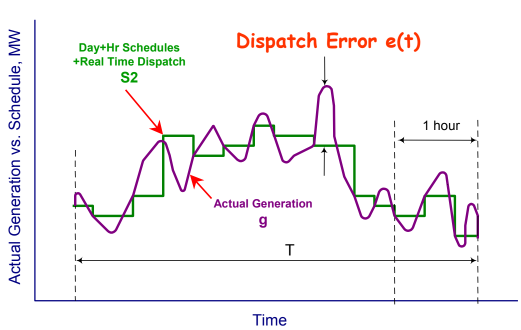
$$\Delta M^{+}_{SUP} = -\text{avg}_T \Delta s(t) + \eta \cdot \sigma_T \left[E(t) + \Delta L_S(t) + \Delta T_S(t) - \Delta s(t)\right] - \eta \cdot \sigma_T \left[E(t) + \Delta L_S(t) + \Delta T_S(t)\right]$$

$$\Delta M^{-}_{SUP} = -\text{avg}_T \Delta s(t) - \eta \cdot \sigma_T \left[E(t) + \Delta L_S(t) + \Delta T_S(t) - \Delta s(t)\right] + \eta \cdot \sigma_T \left[E(t) + \Delta L_S(t) + \Delta T_S(t)\right]$$

Features of the Proposed Metric:

- The approach determines the upper and lower statistical limits of the additional supplemental energy reserves.
- It allows assigning asymmetric quantities for the required incremental and decremental reserves.
- The approach is capable of determining the intervals, where the resource variations help to reduce the required amount of regulation.

3. Impact on Regulation Reserve Requirement

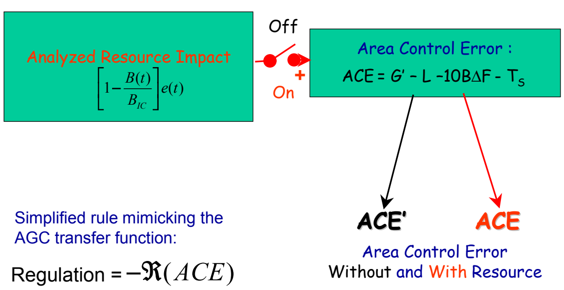


Area Control Error & Regulation Reserve Requirement

- Analysis of the real-time dispatch by itself does not account for possible correlations with random variations of load, generation, area interchange, and interconnection frequency.
- The actual additional regulation requirement caused by the analyzed resource can be determined through the statistical analysis of Area Control Error (ACE)

$$ACE(t) = G'(t) + e(t) - L(t) - 10B(t)\cdot\Delta F(t) - T_S = ACE'(t) + \left[1 - \frac{B(t)}{B_{IC}}\right]e(t)$$

Total Generation — Total Load — Frequency Term — Scheduled Net Interchange — Dispatch Error Impact on ACE



Simplified rule mimicking the AGC transfer function:

Regulation = $-\Re(ACE)$

Incremental Variability Metrics of Unscheduled Impacts

Stochastic processes ACE'(t) and ACE(t) are errors which influence the position and boundaries of the confidence interval M-, M+

$$\Delta M^{\pm} = avg_T \Delta e \pm \eta \cdot \Delta\sigma$$

Increment of Average ACE — Increment of Variance of ACE

$$\Delta M^{+}_{REG} = -\text{avg}_T\left[\frac{B(t)}{B_{IC}} - 1\right]\cdot e(t) + \eta\cdot\sigma_T\Re(ACE) - \eta\cdot\sigma_T\Re(ACE')$$

$$\Delta M^{-}_{REG} = -\text{avg}_T\left[\frac{B(t)}{B_{IC}} - 1\right]\cdot e(t) - \eta\cdot\sigma_T\Re(ACE) + \eta\cdot\sigma_T\Re(ACE')$$

Features of the Proposed Regulation Model:

- The technique is based on real-time dispatch and automatic generation control processes; it reflects specific practices of different Areas.
- The effect of any change or improvement can be analyzed.
- The methodology accounts for statistical correlations of renewable resources with the total system load, rest of generators, interconnection frequency, and interties.
- The assessment is based on basic quantities that actually determine the regulation reserve requirements: the Area Control Errors.

4. Assigning Supplemental & Regulation Requirement

We need an approximate rule reflecting the size (average generation) and variability of aggregated non-separable resources.

We suggest to use a RMS-based measure because the RMS value reflects both the average and variance of a random variable:

$$rms^2(x) = var(x) + avg^2(x)$$

Relative contribution of the *j*th resource is expressed as follows:

$$\gamma_j = \frac{avg\left(G \cdot g_j\right)}{rms^2(G)}$$

$$avg\left(G \cdot g_j\right) = \frac{1}{4}\left[rms^2\left(G + g_j\right) - rms^2\left(G - g_j\right)\right]$$

For individual resources which are a part of an aggregate:

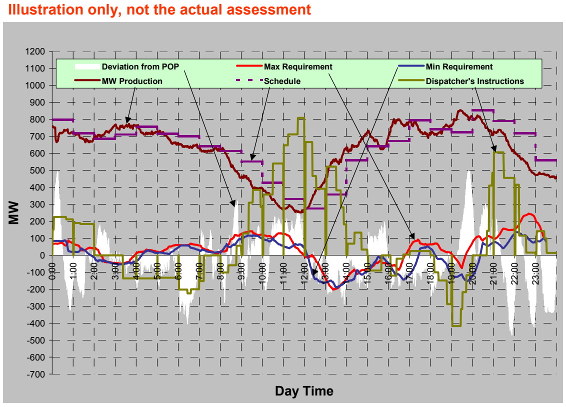
$$\Delta M^{\pm}_{SUP,j} = \gamma_j \cdot \Delta M^{\pm}_{SUP}$$

$$\Delta M^{\pm}_{REG,j} = \gamma_j \cdot \Delta M^{\pm}_{REG}$$

Features of Proposed Methodology for Assigning Individual Supplemental and Regulation Requirements:

- The technique is capable of evaluating the impacts of individual resources as well as the total impacts of their aggregates.
- The by-project participation factors are determined for each individual project/aggregate depending not only on its variance, but also on its systematic deviation from the schedule.
- This helps to distinguish the impact of generation resources equipped with advanced forecasting service from impacts of the less predictable resources.

EXAMPLE: Additional Regulation Reserve Requirement
Illustration only, not the actual assessment



Capacity Credit Analysis

Michael Milligan
National Renewable Energy Laboratory

Analysis Philosophy

- *Not Advocating:*
  - *Specific number or outcome for any generating technology – all plants are eligible*
- *An Advocate For:*
  - *Reliable systems*
  - *Economic power generation and optimal use of resources*
  - *Evaluation techniques that can discriminate between reliable and unreliable generation, regardless of the technology*
  - *Methods that provide the incentives to encourage reliable and economic ways to provide electricity*

Contract for Capacity

- *Forward market*
- *Risk of insufficient delivery*
  - *Can be handled contractually*
  - *Risk borne by generator or buyer?*
  - *Risk tolerance*
    - Generator bids according to
      - Risk tolerance and contractual coverage
      - Forecast error
- *Contracting issue, not an adequacy issue*

Effective Load Carrying Capability (ELCC)

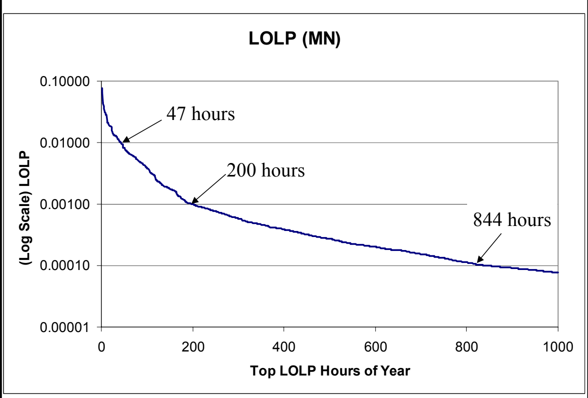
- *Reliability/adequacy required all year*
  - *Time-varying risk*
  - *Capacity that is provided during low-risk hours has relatively low value*
  - *…but during high-risk periods has value, even if not the peak hour*
  - *We often don't know in advance when the annual peak will occur*
  - *Reliability is expensive, so we want to limit the system reliability subject to LOLP criterion or other objective*
- *ELCC can finely discriminate between generators with varying reliability characteristics, size, intermittency*

Is ELCC Only for Renewables?

- *No – it is a standard metric for power system reliability and pre-dates renewables*
- *Garver's 1966 IEEE paper provides a short-cut to estimate ELCC*
- *ELCC has been used for many years to compare risk-adjusted capacity contributions from different types of power plants*
- *Capacity value (ELCC) could range from near zero to a high fraction of rated plant capacity, depending on the plant characteristics*

Examples of Reliability Calculations

- *Large study for Minnesota Department of Public Service.*
- *This is an example only.*
- *Expect differences once we are able to obtain and analyze California data.*
- *In the following graph high LOLP indicates high levels of risk (outage caused by insufficient generation).*



Why Not Choose Top Loads?

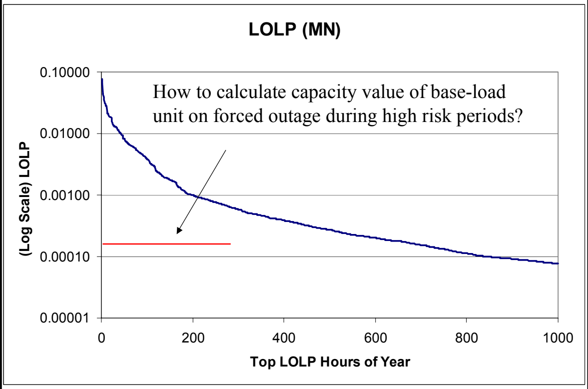
- *Usually high correlation between load and LOLP (high load vs. high LOLP)*
- *But some generation is often on maintenance during swing months (e.g. April, October)*
  - *This is captured by LOLP calculation*
- *Top LOLP equates to times of high risk, and high load periods* may be approximately *the same*
- *Depends on the data/maintenance schedules: Some systems* may *have perfect correlation between high load hours and high risk*
- *This would be picked up in the analysis*

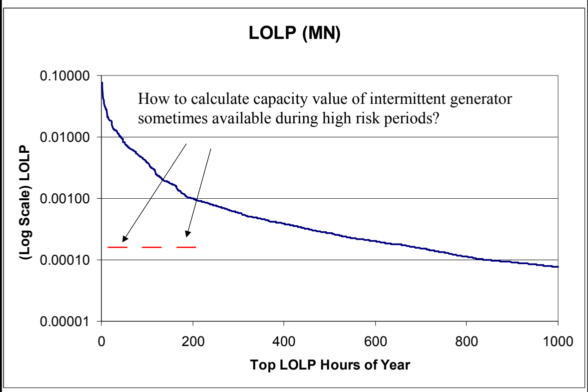
Risk Differentiation

- *Do we want to differentiate between:*
  - *Renewable always available during top risk hours only?*
  - *Renewable that is sometimes available at high risk hours?*
  - *Renewable only available during moderate risk hours?*
  - *Renewable only available during low risk hours?*

Risk Differentiation

- *Do we want to differentiate between:*
  - *Solar that is available during only top risk hours?*
  - *Base load unit?*
  - *High-reliability gas or geothermal?*
  - *Low-reliability gas or geothermal?*
  - *Wind only available during low risk hours?*
  - *Intermittent renewable vs. geothermal?*

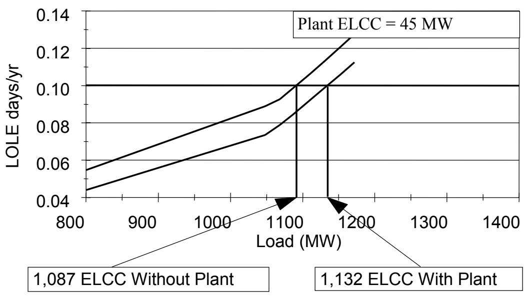




How Do We Account for These Issues?

- *Use a probabilistic method*
- *Reliability or electricity production simulation model*
- *ELCC is a measure that takes all of these issues into account*
- *Other nominated methods should also take all of these issues into account*

Example: ELCC Calculation for a small utility
Capacity credit can range from 10%-95% of rated capacity
(or less/more) and depends on the specific data and type of plant



What Can ELCC Distinguish Between?

- *Reliable vs. unreliable units*
- *Base-load units vs. intermittent units*
- *Units that can be scheduled vs. those that can't*
- *Large vs. small units*
- *Intermittent units with different time profiles*
- *Units that are available during high-risk periods vs. those that aren't*

ELCC Depends on Data

- *Conventional units' data can be updated as appropriate*
- *Intermittent renewable data can be updated as appropriate*
  - *Better forecasting technology*
  - *Newer, more efficient generating technology*

Issues

- *If ELCC is not used, how to select the number of hours and timing?*
- *If full ELCC is not counted*
  - *Generator lowers system risk with no compensation*
- *If too much is credited*
  - *Generator does not contribute the level of reliability that it is paid for*
- *Compensation (ICAP) or just count towards reserve/capacity?*
- *Can be applied to any resource*

Issues

- *How firm is firm?*
- *Should a 60%-available unit count the same as a 90%-available unit?*
- *How does the aggregation/randomness of outages benefit the system?*
  - *No direct payment is made for the aggregation benefits*
  - *But this aggregation reduces reserve requirement and costs, and enhances system reliability*

Other Regions

- *PJM Method for Wind*
  - *Based on capacity factor of plant, calculated over summer peak period*
  - *June-August, 3:00-6:00 PM*
  - *Time period corresponds to high LOLP hours*
  - *Will undertake a reliability analysis to determine ELCC after modeling issues (unrelated to wind) are resolved*

Other Regions

- *PJM (cont)*
  - *Develop a "class average" for the region*
  - *Rolling 3-year average*
  - *For immature sites, use the class average, update as new data becomes available*

Other Regions

- *Colorado: Xcel (PSCo) and PUC agreed to use ELCC as capacity measure for wind generation*

Do Intermittents Need Backing Up?

- *Operationally*
  - *This will emerge from the regulation and load following study*
  - *Individual units aren't backed up, otherwise we would have to duplicate the system*
  - *Reserves (backup) based on system-wide risk assessment, not individual units*
  - *As penetration of intermittent resources increases, may be more impact on load-following reserves*
  - *Also depends on geographic smoothing*

Do Intermittents Need Backing Up?

- *Based on capacity value*
  - *May be an impact of level of reserves that must be carried by the system*
  - *Not possible for reserve level to increase more than the ELCC value*
  - *Likely be some fraction of ELCC as contribution to system total, but must be determined by an empirical risk assessment and proper allocation method, such as the ORNL vector allocation procedure*

Recommended Approach

- *Establish the relationship between ELCC and capacity factor for existing renewable generation*
- *Evaluate whether a simplified method can do a good job of capturing ELCC*
- *Based on findings, use simplified method for bid evaluation process for each relevant generation technology*

Further information

- *Website:*
  - *http://cwec.ucdavis.edu/rpsintegration/*
- *You can subscribe to one of the following mailing lists through the website:*
  - *rpsintegration-workinggroup@cwec.ucdavis.edu*
    An open mailing list for discussion of the development of the valuation methodologies; potentially high traffic volume.
  - *rpsintegration-announcements@cwec.ucdavis.edu*
    An open mailing list announcing key events relevant to the valuation methodologies.
- *Direct general questions and discussion about the study to:*
  rpsintegration-workinggroup@cwec.ucdavis.edu
- *Submit formal questions and comments to:*
  rpsintegration-Q@cwec.ucdavis.edu
  All submissions and responses will be saved and openly posted as public record.