Research Evaluation of Wind Generation, Solar Generation, and Storage Impact on the California Grid

CEC IEPR Staff Workshop
Technologies to Support Renewable Integration
(Energy Storage and Automated Demand Response)
November 16, 2010 Sacramento, CA

Report Prepared for:
California Energy Commission
Public Interest Energy Research Program
CEC-500-2010-010, June 2010
The report describes the new analytical model that KEMA developed to analyze the minute to minute variable of wind and solar renewable resources, the ability of conventional generation resources to the variability, and the role that energy storage can fulfill to assist with the integration of large amounts of renewable resources.
Project Objectives

- Evaluate Impact of 20% and 33% Renewable Portfolios on California Grid Operations
  - AGC Performance, Load Following Ability
- Determine Ancillary Services (Regulation, Governor Response) Requirements of 20% and 33% Renewable Portfolios
- Determine Requirements for Use of Large Scale Grid Connected Storage for Ancillary Services
- Evaluate Storage Equivalent of a 100MW Combustion Turbine
- Determine Policy Issues Affecting Storage Development in California
Project Overview

- Research examined the effects of high renewable penetration on intra-hour system operations of the California Independent System Operator (California ISO) control area
- Examined how grid-connected electricity storage might be used to accommodate the effects of renewables on the system
- Utilized KEMA’s high-fidelity model (KERMIT) to analyze the effects of planned additions of renewable generation on electric system performance
- Research focused on required changes to current systems to balance generation and load second-by-second and minute-by-minute
- Study also assessed potential benefits of deploying grid-connected electricity storage to provide some of the required components—including regulation, spinning reserves, automatic governor control response, and balancing energy—necessary for integrating large amounts renewable generation.
Automatic generation control operates the generators that supply regulation services (up and down) every 4 seconds to keep system frequency and net interchange error as scheduled. The real-time dispatch buys and sells energy from generators participating in the real-time or balancing market every five minutes to adjust generator schedules to track a system’s load changes.
Study Highlights

- Model of California generators, loads and WECC regions
  - Second by second simulation for 24 hours of California system
  - Model of 4 second EMS dispatch of regulation
  - Model of Market dispatch of supplemental energy
  - Model of wind and solar variability – but limited solar data was available
- Number of days studied was very limited
  - Intensive data collection / validation effort involved
- Results clearly showed that:
  - Energy Ramps in less than 1 hour is going to be a major issue
  - Increased Renewables will Increase regulation needs significantly
  - Large amounts of regulation alone will not solve the problem
  - Energy Storage with 2 hours of capacity or more is an (expensive) solution
  - This simulation tool can be a major asset for renewable integration studies
  - AGC Algorithm development desirable for renewables integration
Time Domain, Problems, and Methods

- Harmonics
- Protection
- Stability
- Frequency Response
- Regulation
- Balancing
- Replacement Reserves
- Capacity
- Economics
- 1 ms
- 1 cycle
- 1 second
- 1 minute
- 10 minutes
- 1 hour
- 1 day
- 1 month
- 1 year

- Transient and Harmonics Analysis
- Short Circuit
- Governor Response
- Statistical Analysis of AGC and Balancing
- Spinning and Short Term Reserves
- Storage
- Replacement Reserves
- Emissions Performance
- Production Costing
- Market Simulation
- Expansion Planning
- Long Term Generation, Transmission, DSM, and DG Investments
- KEMA Simulation Tool
- Power Factory
- PSSE
- DigSilent
- KEMA Energy Ecology Model
- ProMod
- GE MAP
KEMA Simulation Tool

**Standard Inputs:**
- Load
- Plant Schedules
- Generation Portfolio
- Grid Parameters
- Market/Balancing

**Scenarios:**
- Increasing Wind
- Adding Reserves
- Storage Parameters
- Test AGC Parameters
- Trip Events

**Outputs:**
- ACE
- Power Plant MW Outputs
- Area Interchange
- Frequency Deviation

**Outputs:**
- Load Rejection
- Wind Power Forecast versus Actual
- Volatility in Renewable Resources

**KERMIT 24h Simulation**

- Generation
  - Conventional
  - Renewable
- Frequency Response
- Inter-connection
- Real Time Market

Modeled Power Areas:
1. California/Mexico Power Area
2. Arizona/New Mexico/Southern Nevada Power Area
3. Northwest Power Pool
4. Rocky Mountain Power Area
Data Summary

• We have time-series data for the following days, which are used during calibration process:
  – 06/05/2008
  – 07/09/2008
  – 10/20/2008
  – 02/09/2009
  – 04/12/2009

• For simulation of future years: Existing time series were scaled up to reflect the projected capacities in 2012 and 2020.

<table>
<thead>
<tr>
<th>Plant Capacity in Megawatts</th>
<th>2009</th>
<th>2012</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>400</td>
<td>830</td>
<td>3234</td>
<td>3234</td>
</tr>
<tr>
<td>CST</td>
<td>400</td>
<td>996</td>
<td>7297</td>
<td>10000</td>
</tr>
<tr>
<td>Wind</td>
<td>3000</td>
<td>5917</td>
<td>10972</td>
<td>13000</td>
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Wind power

- Available from CAISO as time series.
  - Time series of the past (see side graphs), were scaled up according to capacity table
- Appropriate weightings were used to reflect location of future windfarms including wind in BPA Control Area that has to be balanced by CA ISO

<table>
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<td>10972</td>
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</table>
Concentrated Solar Thermal

- Available from CAISO as time series
- Afternoon production extended two hours to reflect gas firing
- Scaled up to reflect capacity table
  - Belief is that geographic diversity will be minimal

### Plant Capacity in Megawatts

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Photovoltaic

- Lacking measurements, we will use simulated time series.
- KERMIT has PV model:
  - Direct inputs are time series for Temperature (degC) and Solar intensity (W/m^2).
    - From NOAA site, we can get these data for selected days for a particular locations in the US.
  - Indirect inputs are related to panel characteristics (electrical and tilt), the surroundings (clouds, abedo)
- The next slide shows simulated time series for a 100MW fictitious PV farm in N. California.
- Such time series will be scaled up for 2012 and 2020, based on the capacity table below.

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July Renewables – 2020 High Penetration

- Volatility Across Peak
- Jagged Solar Ramp Up a Challenge
- Upward Blip a Challenge
- Abrupt 9000 MW Ramp Down then Reversal

Graph showing solar, wind, and total renewables over time.
July Day – ACE across renewable scenarios
Evaluating Performance - 2000 MW Storage, July 2020HI Scenario

System Area Control Error (ACE)

- No Storage
- 1 Hr Storage
- 2 Hr Storage

4 Hr works
1 Hr does not work
April Day – ACE
Adjusting Conventional Generation Schedules for the 2012 and 2020 Cases

- Some conventional plants must be decommitted in hourly schedules
  - Each MW from renewables would mean 1MW less from conventional plants
  - Plan A: use results from CAISO/Nexant production costs study. (not available in study time frame)
  - Plan B: “Poor Man’s Decommit”
    - Of the 250 plants modeled, we have ranked them by age and by type.
    - Plants are decommitted based on the priority list. (“Least efficient” units would go first.)
  - Some plants will be retired anyway. (per preliminary list of scheduled retirements)
  - Different cases / scenarios “re-commit” Combustion Turbines (or any other class of unit selectively) to provide ramping / regulation at specified level
  - New schedules “sanity checked” against scheduled imports, renewables, and load to ensure balance

Comment: Scheduling / De-commitment process is NOT for best economics but to study system dynamics; precise economics not a requirement for this study
Major Conclusions

• System Requirements for “Normal” (non-ramping) periods
  – > 800 MW regulation in 2012
  – Approximately 1,600 MW in 2020
  – Storage more effective in smaller incremental amounts

• In the 2020 33% High Renewable Capacity Case the System may Require 3000 – 4000 MW of Regulation & Reserves
  – Even so, performance will not be acceptable by today’s standards
  – Requires further investigation of renewable scheduling for certainty
  – System appears to have adequate ramping capability in CT & Hydro but wind / solar scheduling vs. conventional generation is a major difficulty
  – Performance will be sensitive to 15 – 30 minute errors in renewable forecasting

• 3000 MW / 6000 MW of Storage will Suffice (except possibly for the April day studied)
  – Preserves current levels of performance with respect to ACE, Frequency, CPS1

• Storage Requires an Aggregate Ramping Capability of 0 – 100% in 5 minutes in the 33% scenario
  – May indicate limited effectiveness of pumped hydro and CAES
Major Conclusions (2)

- Storage equivalent to 110 MW Combustion Turbine appears to range between 30 – 50 MW of storage
  - Varies with other system conditions especially how much regulation is present
- Use of Combustion Turbines for increased regulation (forced commitment) increases overall system emissions by approximately 3% vs. using storage
System performance with storage and increased regulation during non-ramping hours

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Added Amount (MW)</th>
<th>Worst Maximum Area Control Error (MW)</th>
<th>Worst Frequency Deviation (Hz)</th>
<th>Worst Control Performance Standard 1 (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regulation</td>
<td>Storage</td>
<td>Regulation</td>
<td>Storage</td>
</tr>
<tr>
<td>20% RPS*</td>
<td>400</td>
<td>200</td>
<td>477</td>
<td>311</td>
</tr>
<tr>
<td>33% RPS* Low</td>
<td>800</td>
<td>400</td>
<td>480</td>
<td>493</td>
</tr>
<tr>
<td>33% RPS* High</td>
<td>1,600</td>
<td>1,200</td>
<td>480</td>
<td>344</td>
</tr>
</tbody>
</table>
ACE maximums for July 2020HI

Day|DAY07-09-2008|Scenario|2020HI|CT|0.2|Hydro|0.2

Sum of ACE_Max

Storage Capacity
- 0
- 1000
- 2000
- 3000

KEMA

AGC BW
# Adding Storage for Normal Operations

## Performance Across Regulation Levels With No Storage

<table>
<thead>
<tr>
<th>Year</th>
<th>Regulation</th>
<th>Worst max ACE</th>
<th>Worst dF</th>
<th>Worst CPS1</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>400</td>
<td>477</td>
<td>0.047</td>
<td>184</td>
</tr>
<tr>
<td>2012</td>
<td>800</td>
<td>325</td>
<td>0.0425</td>
<td>195</td>
</tr>
<tr>
<td>2012</td>
<td>1600</td>
<td>316</td>
<td>0.0424</td>
<td>196</td>
</tr>
<tr>
<td>2020 LO</td>
<td>400</td>
<td>690</td>
<td>0.063</td>
<td>173</td>
</tr>
<tr>
<td>2020 LO</td>
<td>800</td>
<td>480</td>
<td>0.061</td>
<td>190</td>
</tr>
<tr>
<td>2020 LO</td>
<td>1600</td>
<td>480</td>
<td>0.061</td>
<td>194</td>
</tr>
<tr>
<td>2020 LO</td>
<td>2400</td>
<td>480</td>
<td>0.061</td>
<td>194</td>
</tr>
<tr>
<td>2020 HI</td>
<td>400</td>
<td>950</td>
<td>0.062</td>
<td>141</td>
</tr>
<tr>
<td>2020 HI</td>
<td>800</td>
<td>662</td>
<td>0.061</td>
<td>172</td>
</tr>
<tr>
<td>2020 HI</td>
<td>1600</td>
<td>480</td>
<td>0.061</td>
<td>191</td>
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## Storage Added to 400 MW Regulation

<table>
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<tr>
<th>Year</th>
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<th>Worst max ACE</th>
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<th>Worst CPS1</th>
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</thead>
<tbody>
<tr>
<td>200</td>
<td>311</td>
<td>0.0438</td>
<td>195</td>
<td></td>
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<tr>
<td>400</td>
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<td>0.0609</td>
<td>190</td>
<td></td>
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<tr>
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<td>344</td>
<td>0.059</td>
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- **200 MW Storage > 400 MW Regulation**
- **400 MW Storage = 400 MW Regulation**
- **1200 MW Storage > 2400 MW Regulation**
Evaluating Storage

2000 MW of storage with 4 hours of energy solves the problem.

2000 MW with 2 hours of energy helps

2000 MW of storage with only 1 Hr of energy does not control the ACE problem.
Policy Recommendations

- Use fast storage for regulation, balancing, and ramping either as a system resource to address aggregate system variability or as a resource used by renewable resource operators to address individual resource variability and ramping characteristics
- Procurement of increased regulation, balancing, and reserves by the California ISO
- Consider possible imposition of requirements on renewable resources to accommodate their effects on grid operation, such as ramp rate limits on renewable resources, more accurate short-term forecasting, sub-hourly scheduling, and other possibilities
- Pursue changes to the market system to encourage fast ramping by conventional generation resources
- Use demand response as a ramping/load following resource, not just a resource for hourly energy in the day-ahead market or for emergencies
Study Strengths & Weaknesses

Strengths:
- Detailed High Fidelity System Dynamic Model
- Calibration to CA ISO Data
- Ability to investigate the interaction of renewables, scheduling, dispatch, regulation, droop
- Development of algorithms for renewables and storage integration
- Runs 24 Hrs in approx 15 minutes
- Extensive post processing analysis capabilities

Weaknesses:
- Only a few representative days studied
- Real Time Dispatch / Balancing was old BEEP rather than MRTU
  - Some look-ahead embedded
- Conventional Unit response capabilities “optimistic”
  - Follow dispatch at rate limit promptly; regulation through full range
- “Perfect” Renewables Forecasts
- Concentrating Thermal Solar data based on two existing plants
Goal – Understand Renewables’ Impact on Grid Operations

- Understand variability and volatility of Renewables – esp CST and PV
- Understand characteristics and potential of ADR
- How to forecast better – day ahead, hour ahead, intra hour
- How to factor renewable variability/volatility in dispatch and how to use storage and ADR
- What resource capabilities (storage, ADR) are needed to manage renewables
- How to distribute volatility management across time frames and products
- Understand Requirements of AGC to manage Renewables and Use ADR and Storage
- Develop and test AGC Algorithms
- What monitoring, command, and control over new resources is required?
- Understand requirements of AGC to manage Renewables and use ADR and storage
- Develop and test AGC algorithms
- What monitoring, command, and control over new resources is required?
What are Priorities for Future Work?

<table>
<thead>
<tr>
<th>Develop dynamic models of CST and CSP / utility scale PV</th>
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<tbody>
<tr>
<td>Develop statistical description of variability with temporal and spatial correlations</td>
</tr>
<tr>
<td>Develop consensus forecast</td>
</tr>
<tr>
<td>Develop models of distributed PV and ADR for use in load disaggregation</td>
</tr>
</tbody>
</table>

| Incorporate Renewable Variability, Storage characterizations, and ADR characteristics in Day Ahead Scheduling and Real Time Dispatch |

| Develop realistic scenarios of conventional unit performance for simulation |
| Integrate ADR, updated renewables and storage models |
| Install KERMIT at CA ISO and deliver training |
| Develop AGC Algorithms and Test |
| Identify “scenarios” for future portfolio and use in 2012 and 2020 studies |

| Integrate production cost / market simulations as inputs to KERMIT |
| Use KERMIT to iterate with production and market simulations around ancillaries requirements |
| Study impacts of forecasting accuracies |
Conclusions

• Frequency Responsive Load (or Storage / Autonomous DR) is of benefit
  – Will be of greatest benefit in an island situation
• Using fast resources in response to ACE is better than response to frequency (assuming similar time constants and control/communications) especially in terms of controlling tie flows resulting from generation/load imbalance
• Best choice of control will depend upon the situation and the problem being addressed
  – Autonomous frequency response has the virtue of requiring no control / communications