Coordinated Ramping Product and Regulation Reserve Procurements Using Probabilistic Solar Power Forecasts

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Project Motivation: Efficient System Operations

- Increasing variable renewable penetration → Ramping and regulation issues →

- **Current reserve procurement practice:** based on historical data and offline analysis
  → Requirements that are *too conservative* for most conditions but *inadequate* or risky for other conditions.

Procurement needs **up-to-date information on energy forecasts and their uncertainties** to result in appropriate reserves that reflect the risks of imbalances.

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**Ramp Events Analysis**

<table>
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<tr>
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<th>Load</th>
<th>Net Load</th>
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<tbody>
<tr>
<td>Up</td>
<td>313</td>
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Project Summary

Objective: Integrate probabilistic short-term (0–6 hours ahead) and midterm (day-ahead) solar power forecasts into operations of two ISOs:

- CAISO
- MISO.

Approach:
1. Advanced big data-driven “probabilistic” solar power forecasting technology
   - IBM Watt-Sun and PAIRS: Big data information processing
   - Machine learning approaches to blend outputs from multiple models.

2. Integrate probabilistic forecasts into ISO operations for ramp product and regulation requirements.

3. Provide situational awareness via visualizations of probabilistic ramp forecasts and alerts.
Flexible Ramping Product?

• Introduced to ensure load-following flexibility in market clearing
  – Ensure sufficient ramping capability in the current binding interval to meet the forecasted net load ramps (and their upward and downward uncertainties) in the future advisory intervals.
  – Insure against insufficient ramp capability in real-time markets that might result in extreme prices.

• Not spinning reserves, deployed after a contingency event.
• Not regulation reserves, used to meet fine-grained fluctuations.

Flexible Ramping Product for Market Efficiency

Scenario 1
Generation scarcity (ramp-limited) event $\rightarrow$ real-time price spikes $\rightarrow$ unplanned quick starts ($+$ regulation services to offset area control error)

Regulation and contingency reserves: “MW reserved” unavailable to the market when needed and results in real-time price spikes. (Make whole or uplift payments for unplanned starts.)

Scenario 2
Market efficiency improves if future flexibility/ramping needs explicitly modeled.

Gain in market efficiency and the consequent savings (reduced price spikes, unplanned quick starts, uplift payments) much greater than slight increase in energy market locational marginal price + ramp product payment.

Note: The cited examples in this slide assumes single-period dispatches without (Scenario 1) and with (Scenario 2) flexible ramping product (FRP). Multiperiod dispatches will help mitigate the ramping issues to a certain extent (as in NYISO and CAISO), but uncertainties in forecasted net-load ramps are still an issue that requires procuring FRP.
Flexible Ramping Product: Implementation

**MISO:** May 2016 in day-ahead market (24-h, foresight) and real-time economic dispatch (5-min)

**CAISO³:** Nov. 2016 in real-time market (unit commitment, 15-min, foresight) and economic dispatch (5-min)

(Latest developments, to be included in the day-ahead market at 15-min. intervals.)

**ISO-New England⁴** and **Southwest Power Pool** are also looking to implement ramp products.

Note: Though the overarching objective of ramping product is the same, implementing entities have differences in the way ramping products are procured. Refer to the respective resources.

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Current Practice: Flexible Ramping Product Procurement Process

Ramp Up $\text{Req}_t = \max \{0, \text{Netload}_{\text{forecast}}(t+5\text{min}) - \text{Netload}_t + \text{up} - \text{forecast error}\}$

Ramp Down $\text{Req}_t = \max\{0, \text{Netload}_t - \text{Netload}_{\text{forecast}}(t+5\text{min}) + \text{down} - \text{forecast error}\}$

Step 1

Note: Refer to Footnote 3 in previous slide for details and nuances of each step in the ISO process. This slide shows a high-level summary only.


Step 2

- For each hour, assess last 30–40 days of historical data for “advisory interval” forecast errors.
- Introduce bias for weather events based on forecasts.

7 Figure source: CAISO, “Market Performance and Planning Forum,” presentation slides, Feb. 20, 2018.

Step 3

Probability of X MW forecast error * Penalty (price spike) = $/MWh price for procuring X MW flexibility (risk index)
Use of Probabilistic Forecasts

For a selected hour (4–5 p.m.), we have four 15-min. upward forecast errors.

15-min. solar forecast errors (historical data analysis of upward errors)

Improvement over current practice: Robust, dynamic FRP procurements using latest probabilistic forecasts \(\rightarrow\) avoid costly over-procurement and risky under-procurement.
Big Data-Driven Probabilistic Forecasting System

Situation-dependent blending of forecast models:

- Apply multi-expert deep machine learning with historical forecasts and weather data.
- Learn which model is better, when and where.

Leverage “big” data platform and advanced machine learning-based analytics to complement NWP models \(\rightarrow\) high-fidelity probabilistic forecasts and adaptive and more accurate forecasts.
PAIRS Big Data Platform
Physical Analytics Integrated Data Repository and Services (PAIRS)

Harmonized data curation: aligned to a global spatio-temporal reference and indexing system

<table>
<thead>
<tr>
<th>Models</th>
<th>Lagrangian</th>
<th>Weather Forecast Models</th>
<th>Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RAP</td>
<td>HRRR</td>
</tr>
<tr>
<td>Spatial Res. &amp; Coverage</td>
<td></td>
<td>U.S. 13 km</td>
<td>U.S. 3 km</td>
</tr>
<tr>
<td>Temporal Resolution</td>
<td></td>
<td>15 min 2D, 1 h 3D</td>
<td>15 min 2D, 1 h 3D</td>
</tr>
<tr>
<td>Forecasting Horizon</td>
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<td>10 min</td>
<td>18 h</td>
</tr>
<tr>
<td>Ensemble Forecast</td>
<td></td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

- **GOES-R/16 satellite** can generate up to 16 GB/d.
- GOES-R will be used with deep convolutional neural network for next-generation solar forecast models.
IBM Watt-Sun Output via IBM PAIRS Geoscope

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Market Impact Assessment

• Ramping procurement passed on to ISO scheduling procedures
  • Align process with well-documented ISO procedures.

• ~July 2019: **Test 1** on modified IEEE 118-bus test system with high solar penetration
  • Resource mix, load, and solar profiles that mimic ISOs.

• ~April/July 2020: **Test 2** on Western Electricity Coordinating Council system, with CAISO as focus area.

• Metrics:
  • *Economic*: Production costs, prices (average and real-time spikes), make-whole payments, procurement vs. actual deployment
  • *Reliability*: Quick starts, area control error, and Control Performance Standard 2.
Visualization of Probabilistic Ramp Forecasts for Situational Awareness

Will provide:
1) Forecasted net-load ramps and their uncertainties
2) “Ramp alerts” at shorter timescales, when ramp forecast > available capability.

Regional solar power ramp forecasts: may identify economic output control options in event of ramping alerts.
Ramp Visualization for Situational Awareness (RaViS): User Interface

Features:
- Forecast data from IBM integrated
- Probabilistic and deterministic values
- RaViS refresh rate of 60 s
- User interface is implemented as a single-page Web application
- Open-source libraries
- Shows site-specific metadata via hover
- Highly flexible and easily configurable
- Adaptable to other kinds of events: outage/trip, cyber threats.

Contact: Venkat.Krishnan@nrel.gov or Paul.Edwards@nrel.gov, or Haiku.Sky@nrel.gov
Summary: Impact and Significance

• Probabilistic forecasting approach will significantly transform the forecasting software (for solar power, load, and wind).

• Enhance existing ISO optimizations by supplying probabilistic forecasts in the form of reserve procurement targets and visualization aids.
  
  ❑ Has the ability to create a better way for markets to optimize the uncertainty embedded with renewable resources into market products.

• Future work:
  
  ❑ Data-driven dynamic regulation requirements, a) finer resolution forecasts and error characterization, b) using deployed regulation and area control error historical data.
EXTRA SLIDES
CAISO Baseline Market Simulation

Flexible Energy Scheduling Tool for Integrating Variable Generation (FESTIV)

- TD-2 18:00
  - Day-ahead market
  - Regulation requirements posted
- TD-1 10:00
  - Bids submitted (incl. renewables)
- TH-75
  - Real-time unit commitment
  - Bids submitted
  - Demand frequency update: 30 min.
- <TH-7.5
  - Real-time dispatch
  - Renewable forecast frequency update: 5 min. (private)

Resolution
- Hourly
- 24 hours
- 15-min.
- 5-min.

Horizon
- 24 hours
- 65-min.

Commit
- Fast- to long-start units
- Fast- and short-cycle time if <3 h
- + medium start
- Fixed: 3 h

Market power mitigation and reliability runs not included.
(No virtual bids, single forecast across market participants, no reliability must-run units.)
Ramp Visualization for Situational Awareness (RaViS): Design

The user interface is implemented as a single page Web application in which all user interaction takes place within a customizable dashboard. This is achieved via a modular architecture (using open-source libraries) in which each functional aspect is contained in a set of files constituting a single component.
Can Solar Resources Provide Flexible Ramping Product?

California load and net load ramp event characterization

Solar (other renewable energy) resources contribute to increase in the frequency of ramp events ...

Ramp Magnitude: Load and Net Load

... but also decrease large ramp magnitudes in some hours.

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<table>
<thead>
<tr>
<th>Load (MW)</th>
<th>Net Load (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up</td>
<td>Down</td>
</tr>
<tr>
<td>Max</td>
<td>21,704</td>
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<tr>
<td>Min</td>
<td>2,566</td>
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<tr>
<td>Mean</td>
<td>5,406</td>
</tr>
<tr>
<td>Std</td>
<td>5,077</td>
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“Implicit ramp product” from renewable energy resources? Solar explicit ramp product?

Solar Ramping Product Taxonomy

Quadrant 1: Natural ramp up
- Net load up
- Solar down

Quadrant 2: Natural ramp down
- Net load down
- Solar up

Quadrant 3: Control/curtail
- Net load down
- Solar up
- Curtail (control ramp rate or store) and provide D-FRP
- When D-FRP $ > $ from energy and PTC?

Quadrant 4: Control/storage
- Net load up
- Solar down
- Least likely?
- Controls or complementary tech will enable? For example, ramp rate control, storage integration?

Implicit FRP

Storage

Ways solar resources can provide FRP and regulation, possible coordination with storage technologies

Impact of solar FRP on total FRP procurements (i.e., net load estimations), use of site-specific solar forecasts.
Example of Evolving CAISO Regulation Requirements

Examples: December Regulation Required
Solid – Sunny Weather Conditions
Dotted – Partly Cloudy/Cloudy weather conditions

• Use of historical data to set regulation requirements based on probabilistic criterion (automatic generation control needs)

• Opportunity to condition forecast of distribution on most recent weather.