Reduced Network Modeling of WECC as a Market Design Prototype

James E. Price, *Member*, *IEEE*, and John Goodin

Abstract —California's administration, legislature, and energy regulators have adopted aggressive targets for renewable energy, which will result in profound changes in markets and system operations as the resource portfolio shifts from heavy reliance on natural gas as a fuel for electric generation to intermittent, often remote resources. As part of determining workable modeling approaches as changes in market design are considered, this paper examines the necessary level of detail for modeling unit commitment. This study utilizes a 240-bus model as a realistic test system for the California and WECC market. Demand response and energy storage technologies are important contributors to the flexibility that will be needed in future markets, and provide an illustration of this analysis.

***Index Terms*—market model, renewable energy, demand response, unit commitment**

I. Introduction

CALIFORNIA'S Renewables Portfolio Standard and other policies promote the development of environmentally friendly power, including the procurement of 20 percent of energy from renewable resources in the 2010 to 2012 timeframe, and then increasing to 33% renewables by 2020. The now-existing renewable resources within the California Independent System Operator (CAISO) balancing authority area include wind, solar, geothermal, biomass and small hydroelectric generation, and have previously represented approximately 11 percent of the total energy delivered to California electric customers. Additional energy from renewable resources located outside the CAISO balancing authority area is imported into the CAISO from adjacent areas. The CAISO projects its wind resources to increase from 2648 MW in 2006 to 6688 MW in 2012, solar generation to increase from 420 to 2246 MW from 2006 to 2012, and geothermal generation from 1101 to 2341 MW over this period, along with an existing 701 MW of biomass and biogas, and 614 MW of small hydroelectric generation. [1] By 2020, the overall renewable resources would increase from a historical level under 6000 MW to more than 25,000 MW. [2]

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As analyzed in detail in [1] and [2], these changes in resource portfolios will have significant impacts on the CAISO's operations, including increases in regulation and ramping capability that is available for dispatch, and ability to decrease scheduled non-renewable generation during hours of low demand and high output of renewable resources. As a result, the CAISO is exploring a variety of changes in market design that would increase the flexibility of its operations. [3] The production cost studies reported in [1], and subsequent studies that are currently in progress, have used inputs that maintain a considerable amount of detail on resource characteristics to ensure that the studies have a high degree of confidence in their reported results, as a foundation for considering potential changes in market design. An issue to be faced in pursuing future modeling of potential market changes is that maintaining detail in modeling inputs has a cost in model performance (execution time), and there can be a tradeoff between the level of detail in modeling and the timeliness of modeling results as alternatives in market design are considered. In addition, as a test model for research studies, some research-oriented software may impose limitations on the number of generators that can be modeled, as the base case for this paper includes 150 generators, and adding generators just in the Southern California area to examine unit commitment for large generation adds 25 generators. This paper explores one aspect of modeling detail, which is the number of generators for which explicit decisions are considered for unit commitment, and applies this question to examples of resources that can provide flexibility in the CAISO's operations, which are additions of storage capacity and management of electric vehicle charging.

The following discussion first describes the model used for these illustrations, then describes the role of storage and demand response in meeting the anticipated operational challenges, and concludes with illustrations of modeling results.

II. Development of 240-bus WECC Model

The comparisons reported herein concerning the tradeoff between maintaining detail in modeling inputs and model performance (execution time, which can affect the timeliness of modeling results in considering alternatives in market design) are based on modeling using a realistic 240-bus model of the CAISO and WECC. The model's network topology and other inputs have evolved as a previous 225-bus model that supported research reported in [4] had first extended a pre-existing 179-bus model, which was used in [5], but overcame limitations of the 179-bus model by conforming its topology for the CAISO area to that shown in CAISO transmission planning studies [6]. Reference [7] advanced the accuracy of the 225-bus model by similarly conforming the topology of areas outside the CAISO to that shown in other transmission planning organizations' planning studies, and the study reported herein has further refined it by adding transmission wheeling charges as a "hurdle rate" to recognize economic limitations on energy transactions within the WECC region, and adjusting a limited number if transmission line impedances to produce flow patterns that better reflect those shown in transmission planning study reports. It must be recognized that actual regional market transactions are much more complex than has been represented in this initial analysis. Parts of the WECC region (CAISO and Alberta, Canada) have organized, central markets, while the rest of WECC is based on bilateral transactions. Each balancing authority within WECC has a primarily responsibility to maintain reliable conditions within its area, with inter-area transactions typically being secondary to serving native load, whereas this study necessarily assumes a regional economic dispatch while being unable to model all operating constraints within the region.

The resulting network topology is shown in Attachment 1. In this system block diagram, blocks with thick dashed outlines represent load and generation pockets, and thick solid lines represent interties between the CAISO and neighboring areas, and significant transmission constraints (e.g., flowgates) within the CAISO, as used in [7].

Resource characteristics have been derived from published CAISO transmission study data and WECC's Transmission Expansion Planning Policy Committee (TEPPC) to form resource models for existing system conditions (represented as the year 2004) and future conditions in the 2015 timeframe, as follows:

- Hourly time-varying loads for 11 areas within the CAISO were developed for reference [11], and were obtained from TEPPC studies for sub-regions outside the CAISO.
- Hourly time-varying profiles for wind and solar resources, aggregated to the buses in the 240-bus model, were obtained from TEPPC studies, for both the current and future timeframes. These represent three aggregated wind areas within the CAISO, one solar resource areas within the CAISO, 13 aggregated wind resources outside the CAISO, and four solar resource areas outside the CAISO (one existing, plus three future additions).
- Hourly time-varying profiles for geothermal resources within the CAISO were derived by aggregating utility-controlled vs. non-utility-controlled geothermal resources from the results of [11], and placed in the North Bay/ Geysers area shown in Attachment 1, which is the largest concentration of geothermal resources in the CAISO. Based on average performance of these resources, the assumed output of four geothermal areas outside the CAISO is constant at 80% of maximum capacity.
- Biomass generation within the CAISO is aggregated at three buses within the CAISO, with actual aggregated hourly time-varying profiles using data from [11]. It is assumed that all biomass generation is under utility control, through contracts. Biomass generation is less prevalent outside the CAISO, and is aggregated into generic renewable resources.
- Optimization of hydroelectric generation is a complex issue, since generating capability depends on available water in storage, which varies by month. Its scheduling and dispatch can be limited by environmental requirements for minimum releases and for ramping, for reasons including fisheries management and recreation, as well as requirements for water supply deliveries. Typically, data for accurately modeling these factors are resource-specific, and are known by the resource owners but not by entities such as the CAISO. Some hydro resources have flexibility that makes them desirable to reserve as operating reserves. These issues are complicated for use in this study by the use of resource aggregation, to keep the model size manageable in research studies. Hourly output data may be analyzed to determine representative time profiles, but it must be recognized that resource owners have operated their generation based on other conditions such as load-following and scheduling of their non-hydro resources, and schedules could differ for dispatchable hydro generation when other system conditions are varied in research studies. Based on observations of more detailed time profiles that have been used in transmission planning studies, the hydro optimization used in this study in the PLEXOS software assume that each hydro resource has a maximum availability of 87% after accounting for operating reserves and limited water availability, minimum output of 20% of capacity, minimum monthly capacity factor of 40%, maximum monthly capacity factor of 49%, and maximum hourly ramping of 10% of capacity. The resulting profiles are available for use in other studies that may not have the capabilities provided by PLEXOS. It should be understood that by reflecting only a portion of the operational constraints that affect hydro generation, the resulting profiles are likely to not match actual historical outputs. Instead, the point of modeling hydro profiles in this study is to recognize that hydro resources offer at least some flexibility for dispatch to offset variations in renewable resources' output, and the purpose of modeling is to examine changes from a "base case" model rather that to fully replicate historical outputs.

- In cases other than wind and solar resources in which the total resource capacity is limited and no single renewable resource type dominates an area, the resources are modeled as a generic renewable resource with constant output at 80% of maximum capacity (one aggregated resource in the CAISO, and 10 outside the CAISO).
- Gas fired generation is a significant fraction of generation throughout the WECC, and is modeled as dispatchable, using heat rates from published CAISO transmission study data and published TEPPC data. The ability to simulate unit commitment is limited by the aggregation of resources into the 240-bus model, but is approximated within the CAISO by assuming that an aggregation's minimum output is 5% of its maximum capacity.
- Based on observed performance of coal-fired generation throughout WECC, coal generation at 17 aggregated sites outside the CAISO is modeled with a constant output at 85% of maximum capacity. Although some California utilities have ownership shares of out-of-state coal generation, there is almost no coal generation within the state, and a coal gasification-fired generator is modeled as gas-fired for purposes of this study.
- Since nuclear generation is base-loaded within WECC, two nuclear sites within the CAISO and two outside the CAISO are modeled at 100% of capacity, but may be reduced to 90% if needed for congestion management.

To provide insights into the issues examined here, the CAISO has used the PLEXOS software (commercial desktop with extensive capabilities for market modeling and transmission planning – see www.energyexemplar.com) to simulate the potential for change in the volatility of regional flows across the CAISO's interties with neighboring areas and through the CAISO, and the potential for demand response and storage to moderate such impacts.

III. Application of Modeling to Development of Flexible resources

The issue of significant increases in regulation requirements and needs for flexibility in ramping to match variations in intermittent resources such as wind and solar generation presents increased opportunities for demand response to add to the CAISO's available resources for meeting these changes in resource needs. Demand response and storage are among the ways to add flexibility in operations.

Enhanced Demand Response

The CAISO is implementing new programs in 2010 and 2011 to provide flexible bidding options to Participating Loads and other demand response programs to participate on the CAISO markets, to effectively provide demand resources with fully comparable functionality to that of a generator in the CAISO's market software and systems. This design allows Participating Loads to (1) simply bid into the CAISO Markets with an energy bid, or (2) provide additional details about the operating characteristics of the demand resource like minimum MW of demand response, minimum and maximum load reduction time, and minimum load reduction cost in addition to the energy bid, or (3) provide capacity for daily requirements for committed capacity and/or as ancillary services including non-spinning reserve, spinning reserve, and regulation. The CAISO sees benefits of providing these options to market participants, as additional resources that participate in the CAISO markets, in making the markets more liquid, addressing market power concerns, and improving congestion management by having resources bid at their local locations instead of at large load aggregations that are the default for Non-Participating Loads. [8] [9]

Integration of Storage

Other non-generation resources that the CAISO is encouraging is the integration of storage devices such as flywheels and batteries, as stand-alone installations or in conjunction with Participating Loads. An important role for non-generation resources is provision of ancillary services (including regulation reserves under automatic generation control or comparable automated control), for which the CAISO is defining requirements to recognize the new mix of market resources. [10] CAISO market participants are also exploring the construction of additional pumped storage generation.

IV. Assessment of System Impacts

This section illustrates the usefulness of this 240-bus test system of the CAISO and WECC market in exploring the tradeoff between maintaining detail in modeling inputs and model performance. One issue that is examined in this comparison is an issue that was identified in reference [7], concerning a potential for changes in regional power flows through the WECC region, conceivably having operational impacts on control, stability and response of the transmission system as intermittent resources are developed throughout the region, as well as changes in internal operational requirements including regulation and load-following resources, as noted in [2].

The impact of increasing dynamic transfers to support imports of intermittent resources can be seen against a historical backdrop that includes operational impacts of unscheduled flows through the CAISO. Reference [7] illustrated this backdrop using the data in Fig. 1, showing the existing variability (visually apparent variability and irregular pattern) of unscheduled loop flow at the California-Oregon Intertie (COI), where California imports energy from the Pacific Northwest. Over the 5-month period from May to September, 2006, during the summer containing the CAISO's record peak to date (50,270 MW on 7/24/06), the mean of the unscheduled flow of –53.6 MW and the standard deviation of 284 MW suggest that, at the historical levels, predicting the loop flow at COI can create difficult conditions for the CAISO's operators to manage.

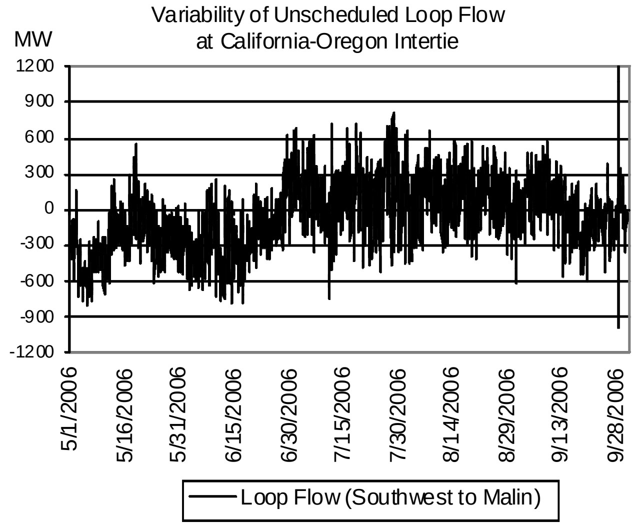

Fig. 1. Hourly Average Values for Unscheduled Loop Flow at California-Oregon Border from May 1 to September 30, 2006

The example presented here focuses on the COI intertie because this is the CAISO's single predominant interface to the Pacific Northwest, whereas the CAISO has a number of interties with Southwestern states and thus has more complex interactions of flows across its interties. The modeling results of comparing recent resource portfolios (using 2004 loads and resource data) with the portfolio that would result from the single change of increased wind and solar resources (approximately 2015 timeframe) can be seen in Fig. 2, for a representative week.

Comparing the model results for current vs. future conditions, [7] observed that its preliminary model results showed congestion at COI (flows at 100% of its limit) occurring for more hours following the growth of intermittent resources, greater variability in flows (as measured by standard deviation), and a reduction in average percentage loading. Similarly, after adding the "hurdle rate" to the model to ensure that transaction costs are considered in flows between regions, the results of this paper's initial modeling, during the week shown in Fig. 2, the hours with flows at 100% of capacity increases by 29%, and the standard deviation of hourly flows as a percentage of the limit increases 5.2%, from 24.4% to 25.7% of capacity, while the average percentage loading decreases from 86.1% to 80.6%.

The initial modeling results also suggest that flexible resources such as demand response and storage can contribute to managing the variability of renewable resources, through a 1.8% reduction in the standard deviation of COI flows, for the amount of resources that were initially modeled. Further, the initial results confirm that unit commitment does affect the results, as shown by a 6.6% increase in the standard deviation. While a more extensive analysis will be needed before specific responses can be considered, this initial analysis suggests that the growth of renewable resources may cause greater variability of regional flows, as suggested by [7]. It is important to recognize that the results here are the result of preliminary analyses, and this research is ongoing.

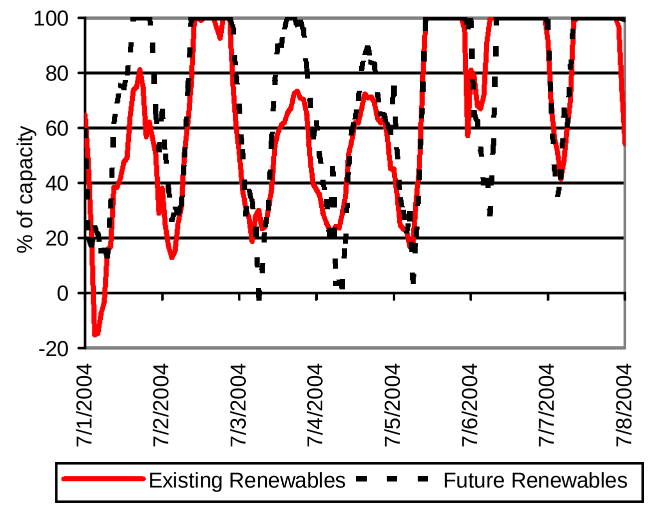

Fig. 2. Impact of Increased Intermittent Resources on Flow at COI (North to South)

ACKNOWLEDGMENT

The CAISO's work on integration of renewable energy resources extends throughout multiple departments of the CAISO, and the background information that is presented herein is the product of previous analyses presented by CAISO staff. The authors thank the CAISO staff members who have contributed to these projects.

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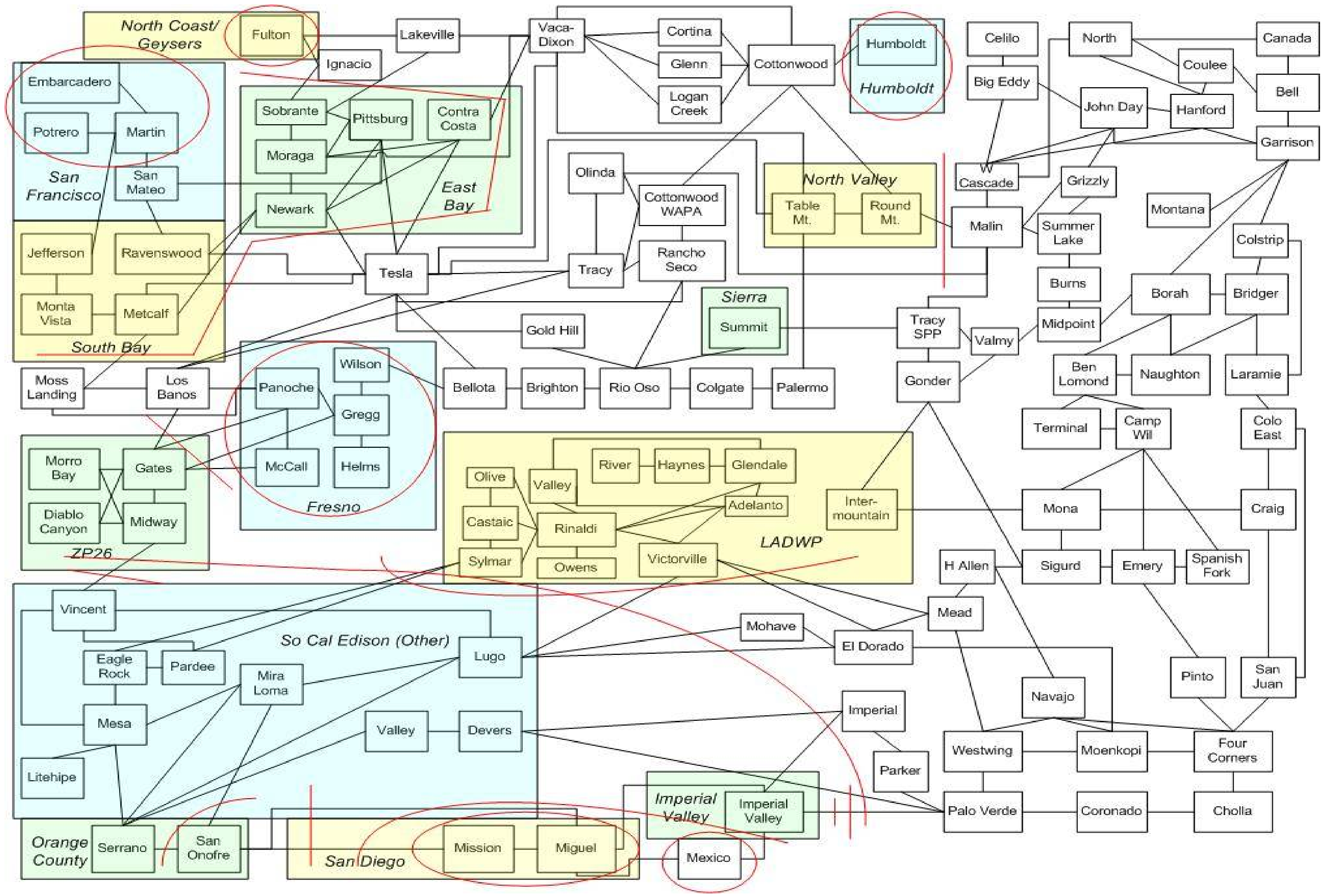
ATTACHMENT 1. TOPOLOGY OF THE 240-BUS WECC NETWORK MODEL.

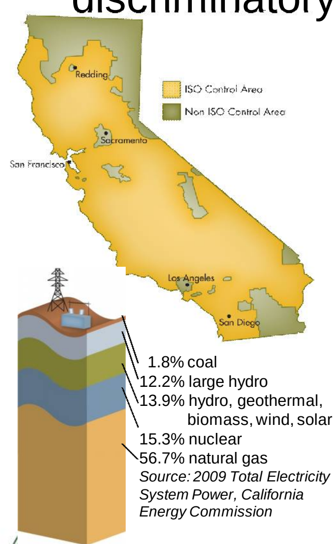


Reduced Network Modeling of WECC as a Market Design Prototype

James Price, California ISO

IEEE PES 2011 General Meeting
Paper 2011GM0942

California ISO provides open, non-discriminatory access to transmission grid



Responsibilities:

- Reliability, grid planning, outage coordination
- Market development, operations, monitoring

CAISO manages approximately 80% of California's electricity load

- 55,183 MW in-state power plant capacity
- 10,000 MW import capacity
- 50,270 MW record peak demand (7/24/2006)
- 25,526 circuit-miles of transmission lines
- 30 million people served
- 286 million annual megawatt-hours of electricity delivered annually
- 38,000 generation & transmission outages per year
- Over 30,000 day-ahead market transactions per day, similar volume for real-time market

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CAISO markets match supply & demand for reliability in day-ahead through real-time

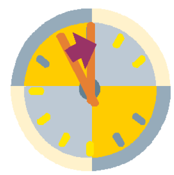
Day Ahead Market

Hourly market for 24 hours of next day

Establish energy and ancillary service schedules

Manage congestion (transmission access) using Full Network Model (FNM)

Determine residual unit commitment requirements



Hour Ahead Scheduling

Prior to real-time (RT) market, schedule energy and ancillary services for static interchange for 24 individual hours

Manage congestion using FNM

As one of 4 RT pre-dispatch processes, establish unit commitment & advisory schedules for internal & dynamic resources

Real Time Market

Manage energy flows on transmission grid with telemetry and 1-minute state estimator solutions

Update FNM for RT conditions

Dispatch balancing energy/ ancillary service

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A theme across CAISO markets is foundation on Full Network Model

- In production, full network model provides needed detail for accurate market and dispatch
- For research, simpler model can be adequate, while detail in results can hide trends.
- PSERC projects using simplified WECC models:
  - M-13: Agent Modeling for Integrated Power Systems
  - M-21: Technical & Economic Implications of Greenhouse Gas Regulation in a Transmission Constrained Restructured Electricity Market
  - M-24: Interactions of Multiple Market-based Energy and Environmental Policies in a Transmission-Constrained Competitive National Electricity Market

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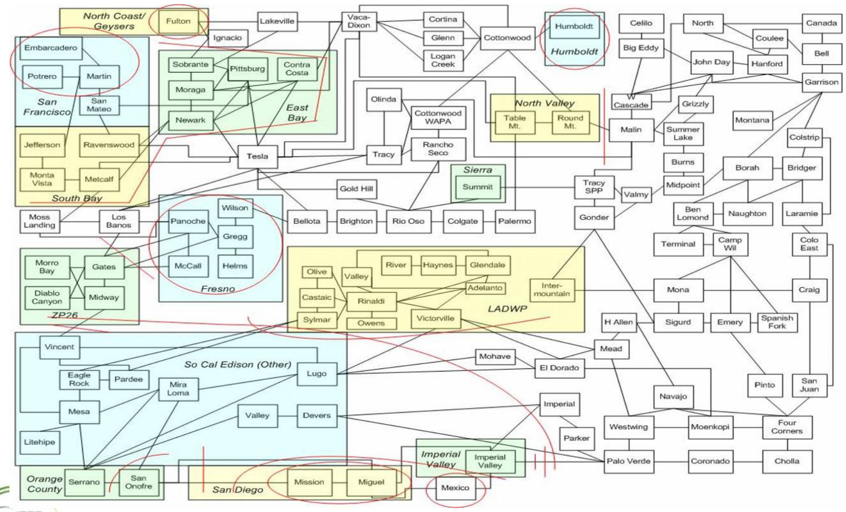
Contributing to PSERC & own research, CAISO assembled 240-bus WECC model



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Model characteristics

- Hourly loads for 11 areas within CAISO and aggregated sub-regions outside CAISO
- Hourly profiles for wind & solar resources: 3 wind areas & 1 solar area in CAISO, 13 aggregated wind & 4 solar areas outside CAISO
- Hourly geothermal & biomass aggregations in CAISO
- Hydro optimization profiles using PLEXOS software
- 23 aggregated gas-fired generators in CAISO (associated with owners) and 27 in WECC modeled as dispatchable, 17 coal plants & 4 nuclear as base-loaded

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Changes over the next 10 years present operational (and research) challenges

- Over 20,000 MW of wind and solar capacity is expected to be interconnected by 2020 – Increased supply volatility
- Approximately 18,000MW of thermal generation will be repowered or retired in next 10 years – Uncertainty surrounding thermal resources
- Potential changes to load patterns as a result distributed generation and electric vehicles – Changing less predictable load patterns

20% and 33% Renewable Portfolios Standards lead to significant new resources

	Biogas/ Biomass	Geo-thermal	Small Hydro	Solar Thermal	Solar PV	Wind
2006 Reference Case	701	1,101	614	420		2,648
Reference Case with 20% Renewables	701	2,341	614	2,246		6,688
Reference Case with 33% Renewables	1409	2,598	680	6,902	5,432	11,291

33 % solar PV includes 2,262 MW of customer side PV

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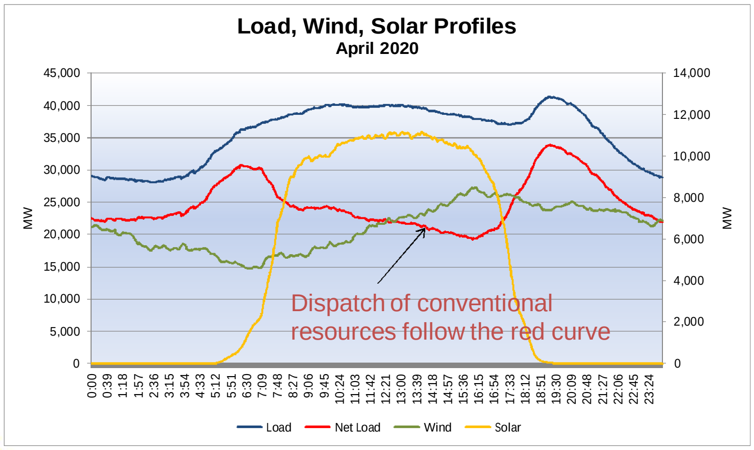
Slide 9

Dispatch of conventional resources would not follow the typical pattern – emerging trend

Source: CAISO Renewable Resource Integration Studies



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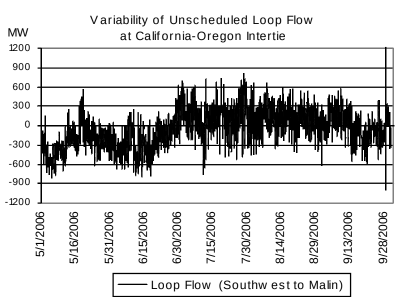
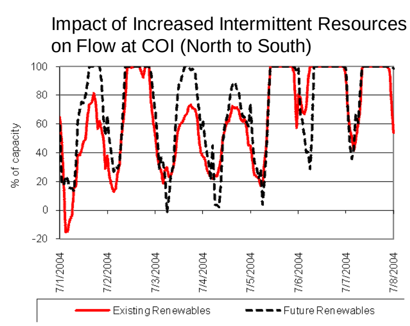
Past CAISO research using simplified WECC model identified regional flow variability

Findings in paper 2010GM0783 (2010 IEEEE General Meeting): existing issues of unscheduled flow at California-Oregon Intertie may increase as renewable resources develop throughout WECC region





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CAISO will need operational and market enhancements to support renewable integration

- Operational Enhancements
  - Wind & solar forecasting tools (output, ramping requirements)
  - More sophisticated grid monitoring systems
  - Over-generation mitigation procedures
  - Coordination with neighboring balancing areas
  - Generation interconnection standards
  - Pilot projects (includes storage, demand response)
- Market Enhancements
  - New market products & changes to market rules
  - Increased regulation and reserve requirements
  - More sophisticated day-ahead unit commitment algorithms

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Requirements for integration of renewables

Resources Required for Renewables Integration

Wind Generation

Solar Generation

"Partners in Success"

Generation Portfolio	Storage	Demand Response
Quick Start Units Fast Ramping Wider Operating Range (lower P_{min}) Regulation capability	Shift Energy from off-peak to on-peak Mitigate Over Generation Voltage Support Regulation capability	Price sensitive load Responsive to ISO dispatches Frequency Responsive Responsive to Wind Generation Production

Hydro

Geo-thermal Generation

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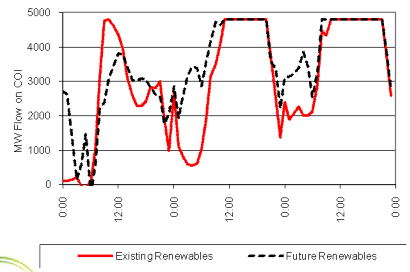
Issues to explore: How effective will various forms of storage & demand response be?

Modeling to date provides preliminary results as previous paper:

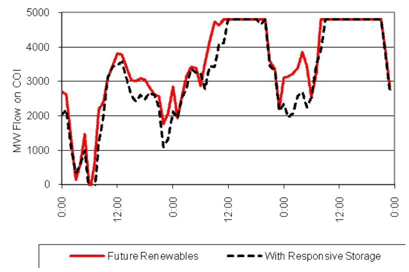
- Comparison of existing vs. future resources shows similar increases in congestion

Adding storage may stabilize flows & reduce congestion

Impact of Increased Intermittent Resources on Flow at COI (North to South)



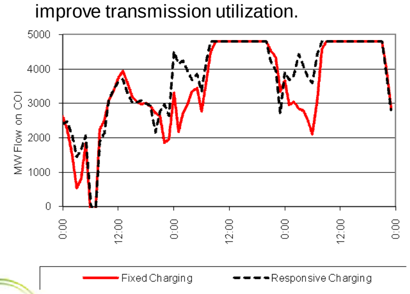
Adding storage may reduce variability & reduce congestion



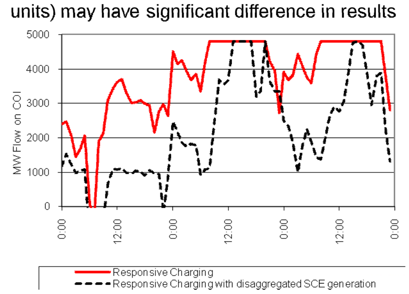
More issues remain to be explored in modeling

- Demand of electric vehicles may be added with or without coordination of charging with system conditions. Coordination may allow higher transmission utilization.
- Aggregating generators simplifies model but impacts results.

Coordinating electric vehicle charging may improve transmission utilization.



Disaggregating 4 of 166 generators (to 24 units) may have significant difference in results



Simple model as prototype for market shows potential for focusing research.

- Experience with model confirms increased ease of testing market alternatives compared to fully detailed full network model.
- As PSERC project M-24 progresses, model access will be identified through PSERC project report (to be available at www.pserc.org).
- Modeling results illustrate impacts of attention to model details, e.g., level of aggregation.