Integration of Large Scale and Distributed Variable Energy Resources: California Focus

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“All peoples everywhere should have free energy sources...Electric power is everywhere, present in unlimited quantities, and can drive the world’s machinery without the need for coal, oil, or gas.”  
Nikola Tesla
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• Concepts presented here have a California focus and may not be universally applicable
• These slides were accompanied by a verbal presentation and are not complete without the said verbal presentation
• This presentation only reflects the views of the presenter and not necessarily those of GridBright, its clients, or the California Wind Energy Association
Outline

• Changes in Electric Power Utility Industry due to increased penetration of Variable Energy Resources (VERs):
  • Planning and infrastructure development
  • System and market operation
  • Distribution level special issues
Variable Energy Resources (VERs)

Wind
- Locationally inflexible
- Unpredictable Output

Solar Thermal / Photo Voltaic
- Locationally fairly flexible in sunny geographies
- Semi – Predictable Output

Roof Top Solar
- Locationally inflexible from utility operation perspective
- Semi – Predictable Output
California Target of 50%+ Renewable Portfolio Standards by 2030

California Greenhouse Gas Reduction Goals and Historic Emissions*

- AB 32 requires California to return to 1990 levels by 2020
- SB 32 requires at least 40% below 1990 levels by 2030

California is Targeting 50% renewables by 2030

*Source: California Air Resources Board
What Is Happening in Front of the Revenue Meter

Existing and Expected Renewable Build-Out Through 2030

- **Wind**
- **Solar**
- **Geothermal**
- **Small Hydro**
- **Biofuel**

Source: CAISO
What Is Happening Behind the Revenue Meter in California

Expected to reach 15,000+ MW by 2030

Source: CAISO

Source: PG&E
Changes in Utility Practices

• Planning and infrastructure development
• System and market operation
• Special issues at distribution level
Planning and Infrastructure Development

- Resource driven planning
  - Primarily privately owned variable energy resources replacing conventional fossil resources
    - Development of resources with uncertain timing plus uncertain and inflexible locations and output
- 24X7X52 hour versus 10 minute planning
- Collaborative Integrated Resource Planning (CIRP) imperative for cost effective and environmentally benign outcome
CIRP in California

IRP Process – Conceptual Analytical Framework

1. Develop Assumptions
   - Load Forecasts
     - Energy efficiency
     - STM PV
     - Electric vehicles
   - Generation Fleet
     - Existing plants
     - Planned additions
     - Planned retirements
   - Candidate Supply & Demand Side Resources
     - Cost
     - Potential
     - Performance
   - Policy Constraints
     - APS & storage target
     - GHG planning target
     - Communities & Air Q
   - Futures
     - Key uncertain inputs
     - Input ranges

2. Evaluate Reliability Needs
   - System needs
     - LOLP modeling (CPUC)
   - Capacity expansion modeling (CPUC)
     - Flexibility needs

3. Develop Reference System Plan
   - Allocation of system & local needs
     - Other
     - PG&E
   - System and local needs identified by the CPUC will be allocated among the LSEs for inclusion in their Preferred Plans to ensure that the plans, in aggregate, meet system & local reliability criteria (flexible RA requirements may also be included here if necessary)

4. Develop Preferred LSE Plans
   - LSE Preferred Portfolio Development (LSEs)
   - The CPUC will transmit guidance on what aspects of the System Plan should be reflected within the LSE Plans and now.
   - Transmittal of System Plan guidance

5. Evaluate & Approve LSE Preferred Plans
   - Review & approval process (CPUC)
   - Each IOU, ESP, and CCA will develop its own Preferred Plan based on the Reference System Plan

Source: CPUC
Principles of CIRP in California

• Active participation by all stakeholders
• Accounting for all factors that impact the resource plan:
  • Transmission availability/development
  • Integration resources availability/development (operational and infrastructural)
  • Capacity/cost allocation among market participants
Transmission Planning & CIRP

• Provide need for resources in “Local Capacity Areas”
• Provide availability of transmission capacity as well as cost of adding transmission capacity from Competitive Renewable Energy Zones (CREZ)
  • determined from CREZ information from previous CIRP
• Selected renewable resources from CIRP from each CREZ is used to determine the “Policy Based Transmission Expansion Plan”
  • Based on the principles of “Least Regrets Planning”
Transmission Planning & CIRP

Source: CAISO
CIRP Including Transmission in California

IRP Calendar (Conceptual)

CPUC Integrated Resource Plan
- 2017 IRP
  - Preferred System Plan
- 2018/19 IRP
  - Reference System Plan
- 2020/21 IRP
  - Preferred System Plan

CAISO Transmission Plan
- 2017/18 TPP
- 2018/19 TPP
- 2019/20 TPP
- 2020/21 TPP

CEC Integrated Energy Policy Report
- IEPR 2017
- IEPR 2018 Update
- IEPR 2019
- IEPR 2020 Update

Source: CPUC
Operational Impacts

- Frequency performance
  - Primary frequency response (frequency droop)
  - Multi-hour ramp
  - Sub-minute ramp and regulation
  - Post contingency frequency response
    - Low/high frequency/voltage ride through
- Reactive power performance
  - Dynamic power factor performance requirement
- Forecast uncertainty
- Market price volatility
Other Operational Impacts

- Distribution level voltage flickers
- Protection coordination particularly at distribution level
- Harmonics performance
- Subsynchronous resonance with series compensated lines
- Special issues at distribution level
Primary Frequency Response

• Major concern with loss of primary frequency response due to proliferation of supply resources without inherent primary frequency response (e.g., inertia response)

• Requirement on all energy resources to offer a functioning governor (or equivalent) controls with the following droop characteristics
  • Maximum 5 percent droop
  • Maximum ±0.036 Hz deadband
  • Linear in the range between 59 to 61 Hz outside the deadband
Multi Hour Ramp is a Serious Concern

March 2019

- Avg Wind
- Avg Solar
- Avg Load
- Avg Net Load
Multi Hour Ramp is a Big Concern

Net Ramp in CAISO

3-hour ramp of ~15,600 MW on January 1, 2019

Minimum net load of ~6,200 MW on March 23, 2019
Monthly Minimum Net Load Trend

Negative net system load by 2021?
CAISO Monthly Ramp Trend

~20 GW of ramp by 2022?
Multi-hour Ramp: Existing Remedies

- CAISO requires multi-hour flexible capacity from Load Serving Entities (LSEs)
  - Flexible capacity offers accepted mainly from controllable resources: thermal, hydro and storage resources
- Variable energy resources curtailments used to address minimum load and limit multi-hour ramp concerns

Wind and solar curtailment totals by month

Source: CAISO
Multi-hour Ramp: Developing Remedies

• Expand market/operation footprint to include areas with different load and VER supply profiles
• Incentive for supply/load profile changes
• Promote development utilization of storage devices

Source: CAISO
Multi-hour Ramp Remedy: Balancing Area Expansion

Western Energy Imbalance benefits: $173 million

- Entities now in the implementation phase
  ~ Portland General – Fall 2017
  ~ Idaho Power – Spring 2018
  ~ BANC/SMUD & Seattle City Light – Spring 2019
  ~ Salt River Project – Spring 2020

- Entities exploring future entry
  ~ CENACE, Baja California, Mexico
  ~ Los Angeles Department of Water & Power (LADWP)
  ~ Northwestern Energy

Source: CAISO
Multi-hour Ramp Remedy: Balancing Area Expansion

Source: CAISO
Multi-hour Ramp Remedy: Rate Incentive

Source: CAISO
Storage Mandate:
580 MW by 2024 (PG&E)

Transmission 310 MW
Distribution 185 MW
Customer, Behind Meter 85 MW

Current Storage Deployments 2017

Vaca-Dixon
2 MW / 14 MWh
(Sodium Sulfur)
Participating in CAISO energy and ancillary services markets

Browns Valley
500 kW / 2 MWh
(Lithium-ion)
Distribution Peak Shaving

Yerba Buena
4 MW / 28 MWh
(Sodium Sulfur)
Testing islanding/backup + CAISO market participation
Sub-Minute Ramp

- Increased sub-minute net load variation due to cloud cover
- CAISO introduced sub-minute flexible capacity product in its forward markets in order not to dramatically increase the need for regulation reserve capacity (reserve requirement is long term basis)
Post Contingency Frequency Response

- Inverter based resources can disconnect based on vintage or poor setting during/after contingency.
- The resultant sudden jump in load is likely to significantly exacerbate supply/demand balance and lead to system instability.
  - Frequency and voltage ride through a necessity for inverter based resources.
High/Low Frequency Ride-Through
High/Low Voltage Ride-Through

Voltage Ride-Through Time Duration Curve

No Trip Zone

Return to voltage between 0.95 PU and 1.05 PU dependent on automatic or manual changes to the system.

Time (sec)

Voltage (per unit)

High Voltage Duration
Low Voltage Duration
No Momentary Cessation

CAISO order:
- No momentary cessation within the “No Trip Zone”
- During fault ride-through, inverter to provide voltage support
- Response to system event to be verified

Similar to tuning exciters and PSS for synchronous generators

Source: NERC
Reactive Power Response: CAISO Requirement

- Maintain voltage schedule within PF requirement range
- Maintain Power Factor schedule

*Note: Actual values for $V_{\text{max}}$ and $V_{\text{min}}$ will be provided by the Participating TO following final engineering and design.

Source: CAISO
Power Factor Requirement

- Maintain power delivery at the high-side of the generator substation at dynamic PF between 0.95 leading/lagging

Source: NERC
Forecast Uncertainty

- Potential serious impacts on:
  - Forward market unit commitment
  - Operations planning
  - Divergence between forward and real-time market prices

- Solutions:
  - Research in forecasting techniques
  - Create markets processes closer to real time – CAISO created a new Fifteen Minute Market (FMM) ~40 minutes before real-time
  - Add more fast start resources with low Pmin to the supply portfolio – a large number of storage MWs are being added to the California grid
  - Consider probabilistic network analysis
Market Price Volatility

Distribution of Negative Prices - March, April & May 2012 through 2016

- Increasing real-time negative energy price frequency indicates over-generation risk in the middle of the day

Source: CAISO
Market Price Volatility

• Negative prices are acting as a major disincentive for the addition or continued operation of controllable resources jeopardizing system reliability

• Potential solutions:
  • Market mechanisms and incentives for resources to keep controllable resources
  • Addition of storage devices purely on price arbitrage is starting to happen
Other Major Operational Considerations

- Voltage flicker at distribution level
  - Cloud cover clearing is a source of concern as it may lead in rapid rise in generation for larger solar projects connected at distribution level and result in voltage flicker
  - Some distribution operators place ramp control of ~10% Pmax/minute to address such concern
- Protection coordination and practices
  - Flow reversal in distribution feeders has prompted changes in protection coordination philosophy and solution (e.g., fuses replaced with breakers)
  - Low fault duty contribution by inverter based generation resources concerns some distribution operators about fault detection
- Harmonic performance
- Subsynchronous resonance in presence of series compensated lines
  - Main concern for high voltages at inverter based energy resources
Distribution Level Considerations

- Historically, VERs (and DERs) could provide generator-like services to the bulk-power transmission system.
- Emerging need for similar ‘distribution circuit level’ services. Requires -
  - Real and reactive control of VERs and DERs
  - Highly localized ‘surgical’ targeting on grid edge
  - More coordination with transmission markets to prevent conflicting commands or counter-productive side effects
VER on a PG&E feeder (aka ‘DER’), but participating in CAISO frequency market, creating power balance and quality issues

Real-world Example of Distribution Level Impacts

October 2013

October 2016

4MW Battery Output and Charging
Distribution Hosting Capacity is Approaching Physical Limits

- Large incentive to use VER & DER flexibility as a ‘non-wires alternative’ to capital intensive hosting capacity upgrades

Source: EPRI
Smart Inverters: A Key Technology Enabling DER Policy

CA began requiring Smart Inverters on all new PV interconnections beginning September 8, 2017.

- Phase 1: Autonomous Functions
- Phase 2: Communications Protocols
- Phase 3: Advanced/Market Functions

What is a smart inverter?
1. Communication capability allows for status reporting and remote control
2. Autonomous functionality that can be updated over the air

Smart Inverters are expected to make up ~50% of inverters in PG&E’s territory by 2020.
DERMs – Distributed Energy Resource Management systems

- Emerging methodology and control room systems for VER/DER situational awareness, contingency analysis, and scheduling

Distribution network contingency analysis (problem?)

Grid edge visibility

Future probabilities

Distribution network & resource optimization (solution!)

Topography flexibility

Resource flexibility

Predicted congestion

Optimal dispatch
“All peoples everywhere should have free energy sources...Electric power is everywhere, present in unlimited quantities, and can drive the world’s machinery without the need for coal, oil, or gas.”  

Nikola Tesla