Secrets of Successful Integration

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Solar Integration Workshop
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Wind and PV affect planning and operations

**System Stability**
- High penetrations of inverter-based resources (IBR)
- Essential reliability services
- Some transient stability and small signal stability issues still need to be addressed

**System Balancing**
- Wind and solar variability and uncertainty
- Reducing curtailment
- NERC standards

**Resource Adequacy**
- Seasonal mismatch of supply and demand
- Periods of low wind/solar/hydro
- 1 day in 10 years Loss of Load Expectation

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Short-term  
Medium-term  
Long-term

Graphics: EU-MIGRATE 2016  
CAISO, Fast Facts 2016  
A. Bloom, ESIG Planning WG Oct 2018
Depending on who you are, your challenges differ

**Well-connected within a larger grid**

System balancing is likely the key challenge. Make room for and fine-tune VRE output.
- Minimum generation levels
- Using forecasts to decommit conventional generators as appropriate
- 5 minute security-constrained economic dispatch of VRE
- Providing regulation/spinning reserves from curtailed VRE

**Islanded system/Loosely tied**

Frequency and grid strength are important issues. In addition previous actions:
- Increase frequency of scheduling of interties
- Fast frequency response from VRE (and other sources)
- Synchronous condenser (mode) to maintain inertia and grid strength

**Island, no interties**

In addition to previous issues:
- May need to fine-tune VRE controls
- May need stand-alone or hybridized storage
- May need grid-forming converters
Managing variability
We know how to find flexibility

• Transmission, larger markets, wider trading
• Faster trading, scheduling closer to real-time
• Forecasting
• Extract flexibility from variable resources – dispatch and ancillary services
• Extract flexibility from non-variable resources
• Storage of different durations
• Demand-side flexibility

How are different regions meeting resource adequacy?

Bigger and faster trading

Real-time energy imbalance market being transitioned to day-ahead market

By June 2019, the EIM had saved $736M and avoided 943,053 MWH of VRE curtailment (403,546 tons CO₂)

Systematic reduction of $P_{\text{min}}$ from 50% to 25% then to 10%.


ORNL, DOE 2017 Hydropower Market Report, April 2018; A. Moreno, DOE, CREPC, April 2019
Dispatching Demand

Resource Adequacy

• Portland General Electric Peak Time Rebates
  • $1/kWh peak time rebate
  • When load forecast is in top 1% of annual load hours; 3-4 hour event; day-ahead text/email
  • Typical savings $2-3 per event; estimated 12-20 events per year

• Distribution coop
  • Critical peak and high peak rebates: $1/kWh and $0.5/kWh
  • Response rate: 70% of participants

• Baltimore Gas & Electric Energy Savings Days
  • $1.25/kWh peak time rebate
  • Typical savings $5-8 per event; up to 6 events per year

APS sells cheap midday power

J. Thompson, APS, “What if Your Neighboring Utility Goes to 100% Renewables,” CREPC April 2019
Managing inverter-based resources
The grid needs essential reliability services to operate stably and reliably

- Frequency support
- Primary frequency response
- Secondary frequency regulation/Regulation
- Load following/ramping
- Contingency/spin
- Ride-through

- Voltage support
- Reactive power
- Ride-through

With fewer synchronous generators online, we need renewables to provide these services

GE Energy Consulting, 2017
How reliability services from VRE can help

A problematic day in California

ISO’s Net Load vs. Average 5-Minute Energy Prices
April 12, 2014

- Net Load
- MCP_RTD
- 5-MinPrices<Zero
- 5-MinPrices>$100

Source: Rothleder, CAISO, Testimony to FERC in Docket AD 15-4-000

How wind helps reliability in Colorado (Xcel/PSCO)

Wind Farm Metered Generation

Source: Drake Bartlett, PSCO/Xcel
Grid codes are essential – they require generators to ride-through speed bumps on the grid

- If there is a transmission fault, you want your generators to ride-through and continue to provide power to support the grid.
- Grid codes require capabilities that you may not need at low levels but will need at higher levels of renewables.
- If you are installing wind/PV capacity quickly, grid codes that require advanced capabilities are critical! Legacy (old) systems may have long lifetimes.

Misunderstandings of inverter operation, conflicting requirements, and instantaneous measurements led to Blue Cut Event with loss of 1200 MW PV

GE Energy Consulting, 2018; Graphics: NERC, 1200 MW Fault Induced Solar PV Resource Interruption Disturbance Report, June 2017
System stability

- Kauai, Hawaii – synchronous condenser mode on gas turbine
- Texas – PSCAD modeling; monitoring inertia; synchronous condensers
- Ireland – capping system non-synchronous penetration at 65%; new system services
- South Australia – reliability-must-run or out-of-merit dispatch; synchronous condensers; PSCAD modeling
- Xcel/CO
- Denmark
- Southwest Power Pool

Synchronous condensers for grid strength in ERCOT

Graphics: Fred Huang 2019; ERCOT, Dynamic Stability Assessment of High Penetration of Renewable Generation in the ERCOT Grid Version 1.0, ERCOT, 2018
Kauai uses storage and synchronous condensers

- Batteries and pumped hydro storage
- To accommodate 100% instantaneous renewables: use gas turbine as synchronous condenser to maintain inertia and use storage to provide contingency reserves
PV: accurate and fast regulation reserves

Data (left) and graphic (right) Source: Loutan, et al, “Using Renewables to Operate a Low-Carbon Grid”, CAISO, 2017
Southwest Power Pool reduced wind curtailment significantly during 2017-2018

<table>
<thead>
<tr>
<th>Year</th>
<th>Wind Curtailed MWh</th>
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<tr>
<td>2014</td>
<td>290,703</td>
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<tr>
<td>2015</td>
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<td>2016</td>
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<td>2017</td>
<td>1,800,472</td>
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<tr>
<td>2018</td>
<td>905,519</td>
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More interconnection to increase geographic diversity

Increased interconnections allows for retirement of more thermal capacity

Continuing to build out more interconnectors in the future

Source: Energinet, 2018

Well-interconnected systems


*Excludes rooftop PV
How does KIUC manage zero interconnections?

- KIUC has been and continues to build PV/battery plants
- Considering pumped hydro storage
- A fleet of fast-start diesel reciprocating engines helps manage variability and cloud events

Kauai on target to hit ~ 80% renewable electricity by 2025

Data from KIUC, 2018
System stability

Interconnections as percentage of peak demand

- KIUC
- ERCOT
- EirGrid
- Xcel/CO
- South Australia
- Energinet
- SPP

AC  DC
How do reliability services from wind/PV differ from conventional generators?

• Faster response
• Can have more aggressive droop
• Little/no wear-and-tear
• Accurate ability to follow signal
• Superior ride-through of some types of disturbances
• Can provide or absorb reactive power when it’s not sunny or not windy
• Does not contribute to grid strength (short circuit strength) today
• Mechanisms to provide headroom for underfrequency response, i.e. dispatch below 100% of available power, are different
What essential reliability services can wind/PV provide?

- Inertia/Fast Frequency Response (Quebec, Ontario)
  - Wind can provide synthetic inertia (does not require pre-curtailment)
  - Pre-curtailed PV can provide fast frequency response (down response does not require pre-curtailment)
- Primary Frequency Response (ERCOT, Quebec, Ontario)
  - Pre-curtailed wind/PV can provide PFR (down response does not require pre-curtailment)
- Secondary/Regulation/AGC (Xcel)
  - Pre-curtailed wind/PV can provide regulation (down regulation does not require pre-curtailment)
- Spinning reserves (Xcel)
  - Pre-curtailed wind can provide spinning reserves (down regulation does not require pre-curtailment)
- Ride-through (NERC PRC-024)
  - Wind/PV can ride-through voltage and frequency events
- Voltage support (NERC VAR-001 and VAR-002)
  - Wind/PV can provide or absorb reactive power when it is not windy/sunny
Arizona Public Service

- In EIM; considering EDAM
- New Trough Hour Trading product
- Added 500 MW quick start gas for capacity and ramping
- Reduced $P_{min}$ on CC and coal
- Installing 850 MW batteries
- Highest percentage use of TOU rates
- Upgrade EMS to put PV on AGC
- Forecasting of load and renewables

J. Thompson, APS, “What if Your Neighboring Utility Goes to 100% Renewables,” CREPC April 2019
TOU rates look like storage

TOU rates reduce cost of service – can we quantify that value?

Alternative rate structures can bring significant value to the system with little capital investment

Benefits of trading

By June 2019, the EIM had saved $736M