Secrets of Successful Integration

Debbie Lew
Debra Lew LLC
Solar Integration Workshop
October 17, 2019

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Wind and PV affect planning and operations

System Stability

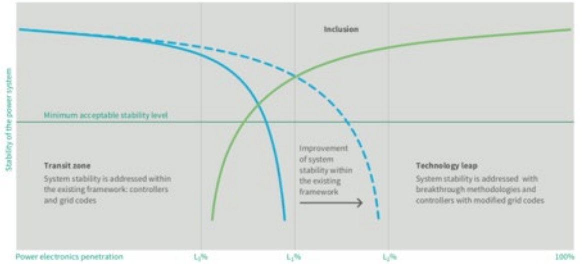
- High penetrations of inverter-based resources (IBR)
- Essential reliability services
- Some transient stability and small signal stability issues still need to be addressed

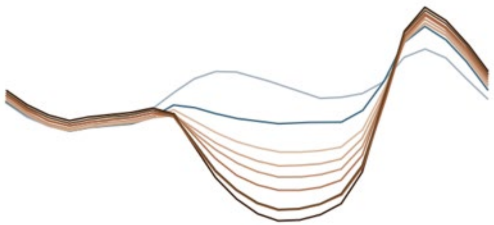
System Balancing

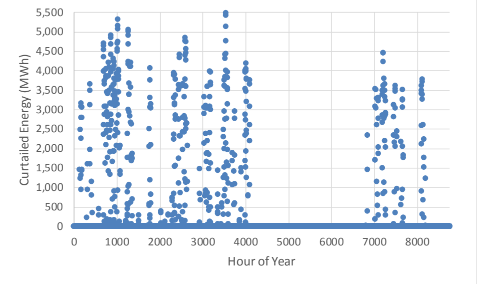
- Wind and solar variability and uncertainty
- Reducing curtailment
- NERC standards

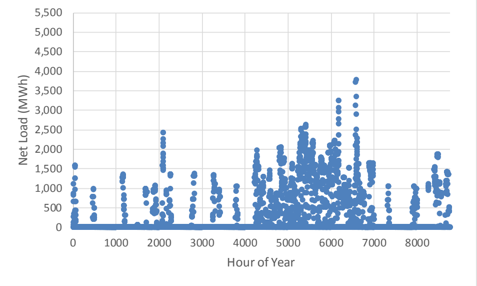
Resource Adequacy

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









Short-term → **Medium-term** → **Long-term**

Graphics: EU-MIGRATE 2016
CAISO, Fast Facts 2016
A. Bloom, ESIG Planning WG Oct 2018

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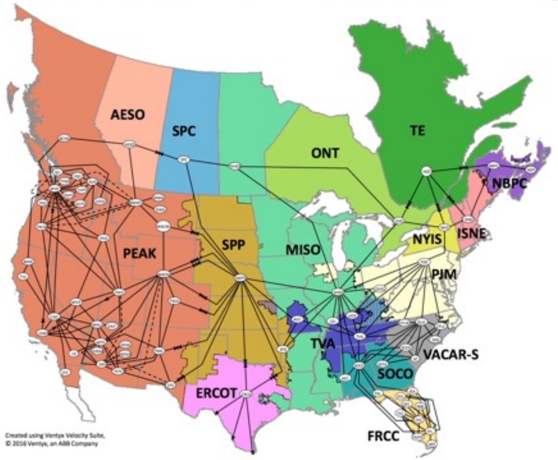
Depending on who you are, your challenges differ

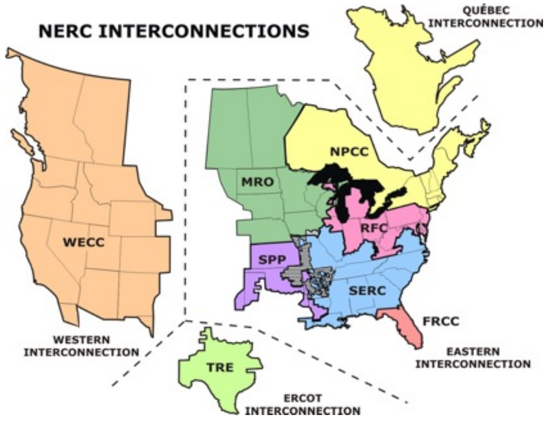
Well-connected within a larger grid



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

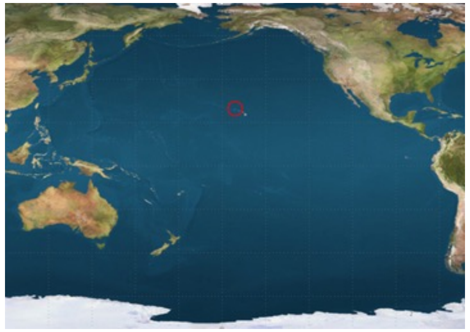
Islanded system/Loosely tied



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

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Managing variability

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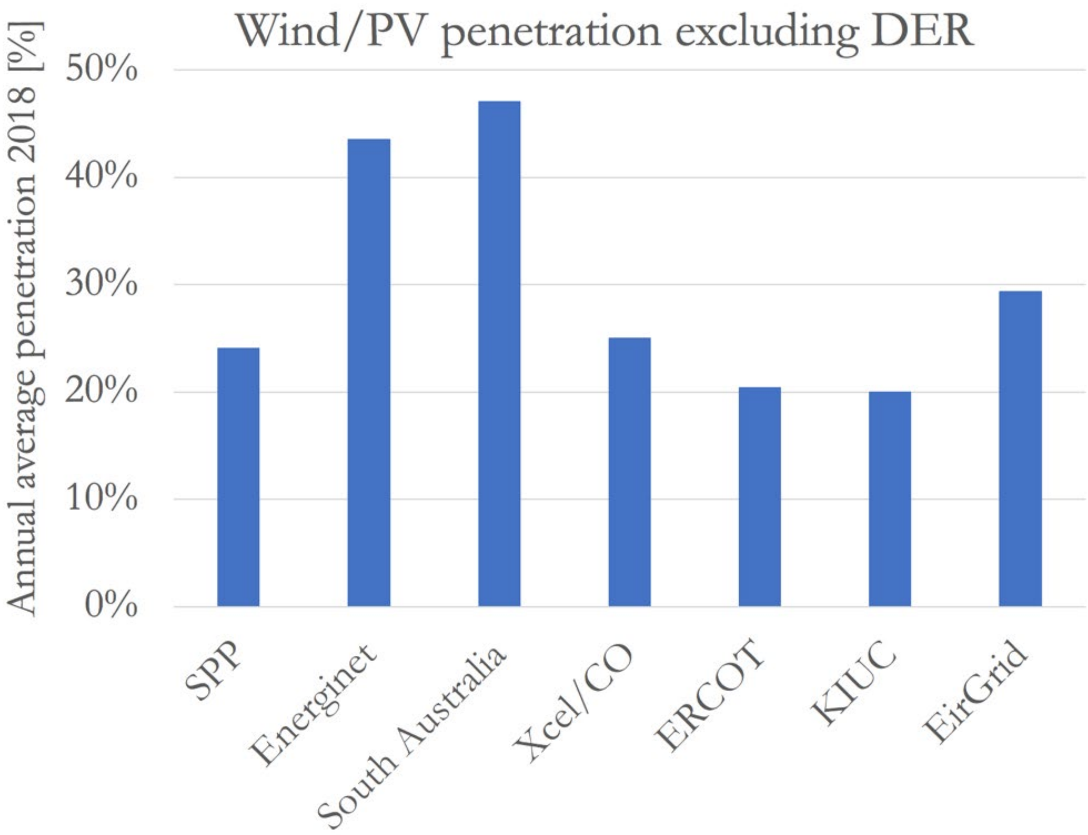
We know how to find flexibility

- 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



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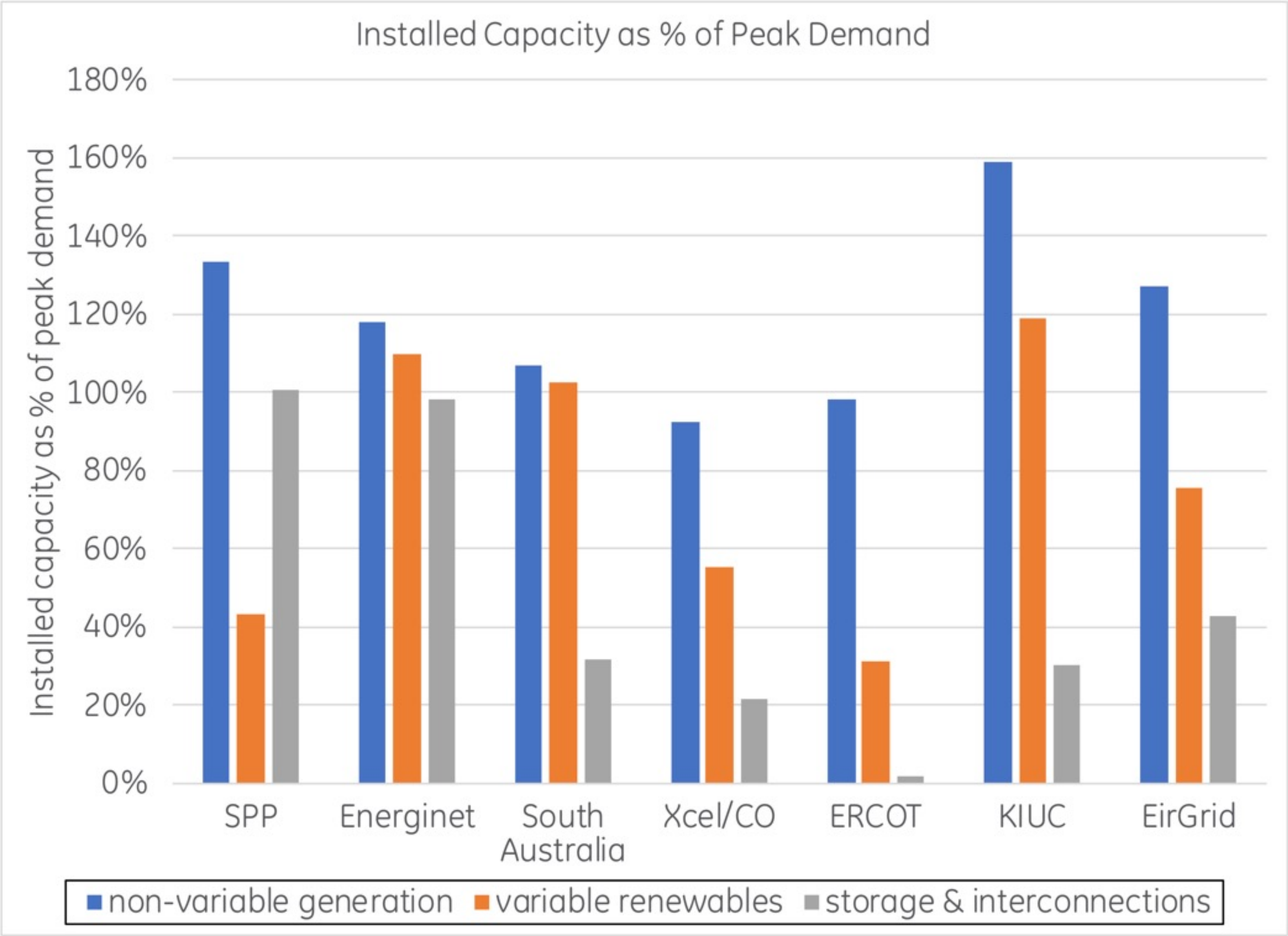
Source: Lew, et al, Secrets of Successful Integration, IEEE PES Magazine, Nov/Dec 2019

How are different regions meeting resource adequacy?



Source: Lew, et al, Secrets of Successful Integration, IEEE PES Magazine, Nov/Dec 2019

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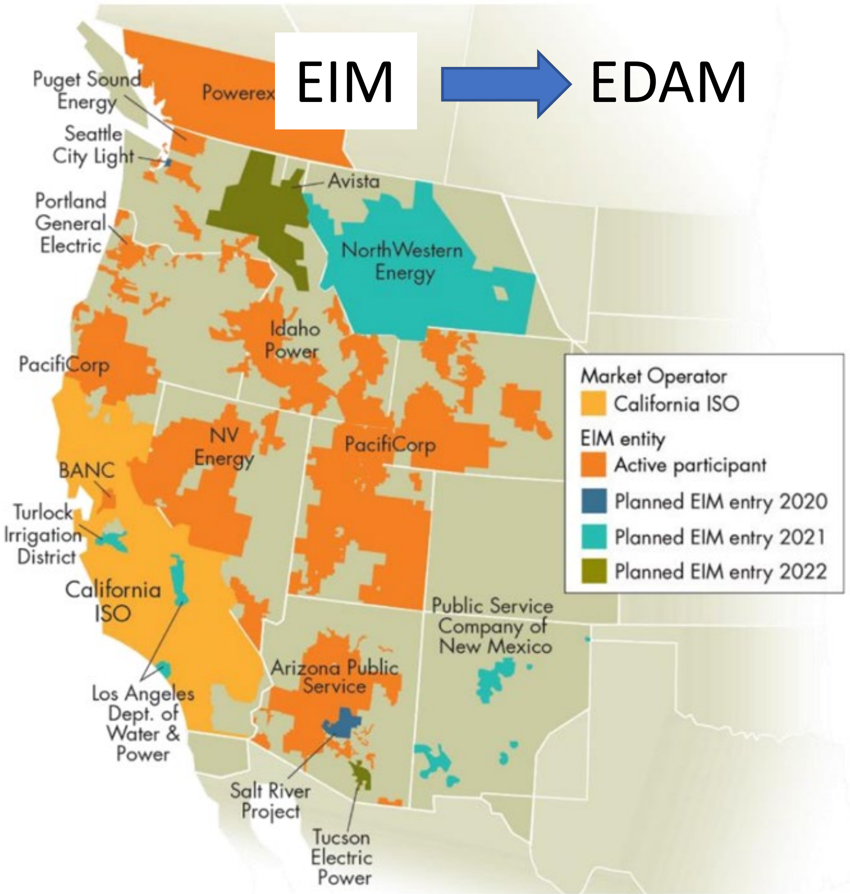
Bigger and faster trading

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 CO_2)

Year	Quarter	MWh	Eq. Tons CO2
2015	1	8,860	3,792
	2	3,629	1,553
	3	828	354
	4	17,765	7,521
2016	1	112,948	48,342
	2	158,806	67,969
	3	33,094	14,164
	4	23,390	10,011
2017	1	52,651	22,535
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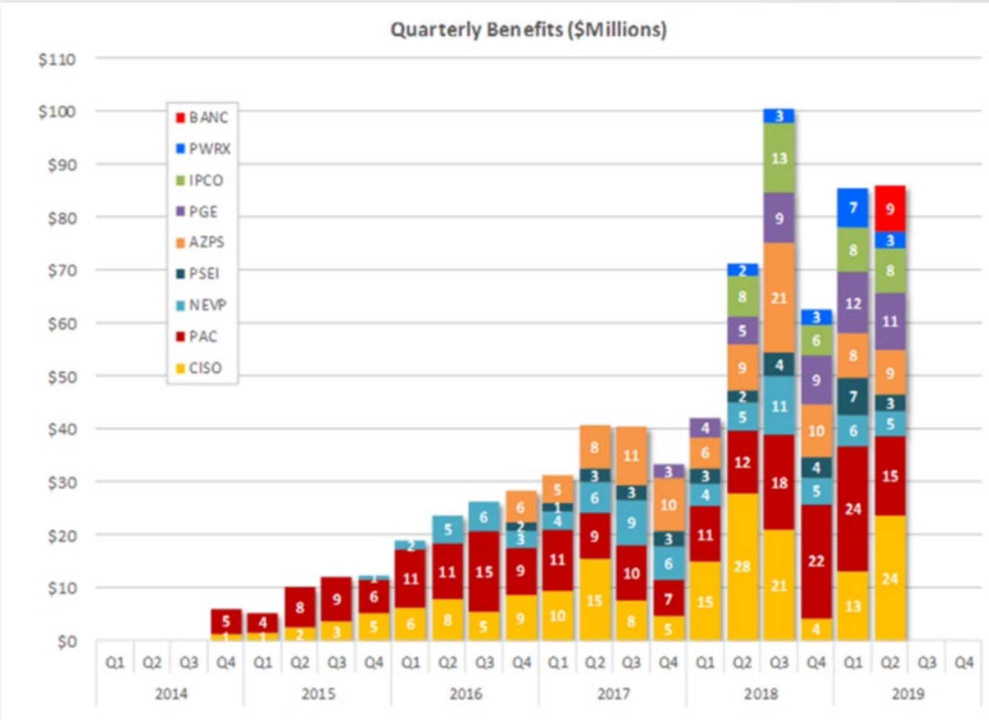
Total		943,053	403,546



https://www.westerneim.com/Documents/ISO-EIMBenefitsReportQ2-2019.pdf

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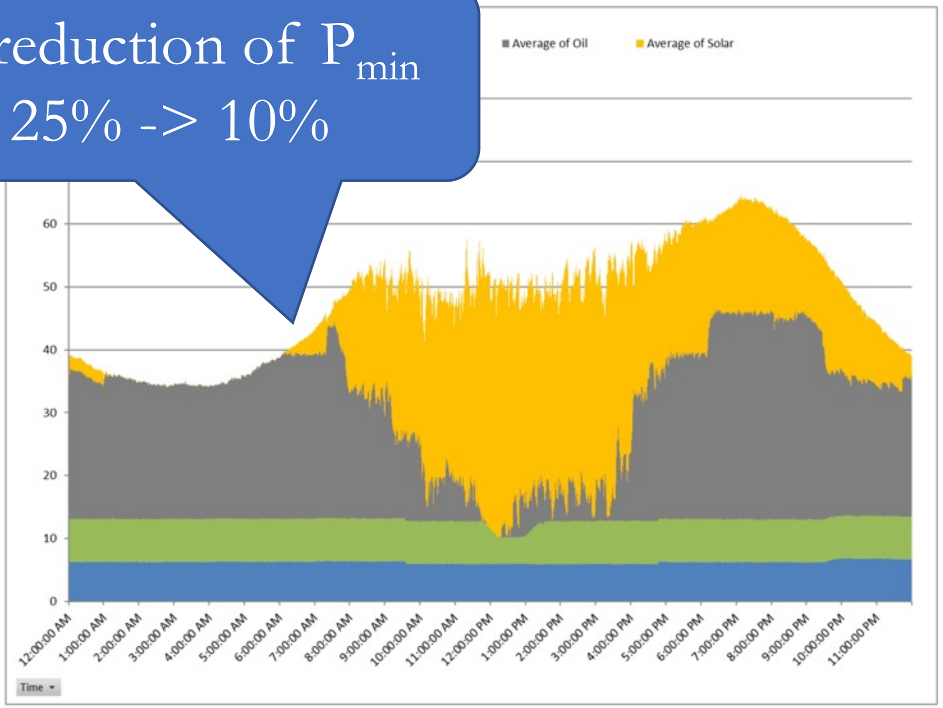
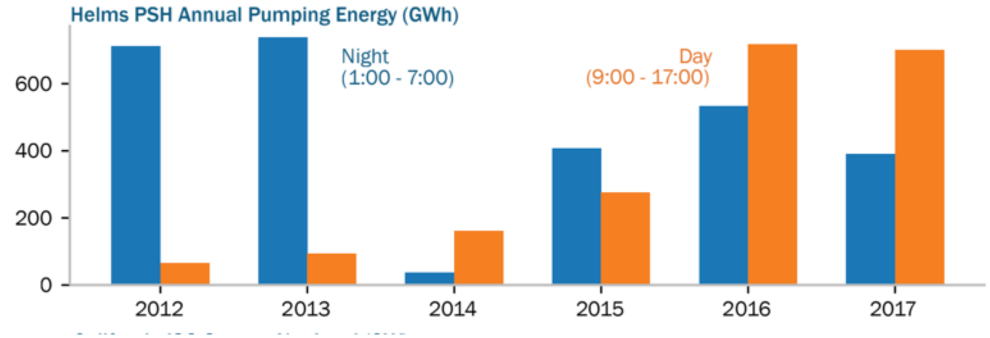
Flexibility of non-variable generators

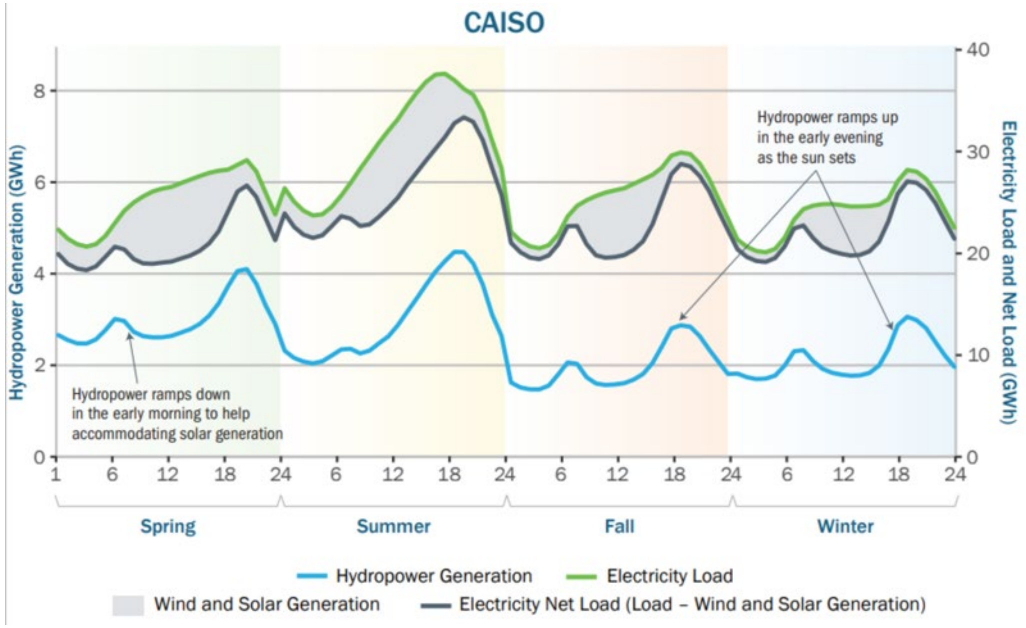
Kauai, Hawaii

Systematic reduction of P_{min}
50% -> 25% -> 10%



California





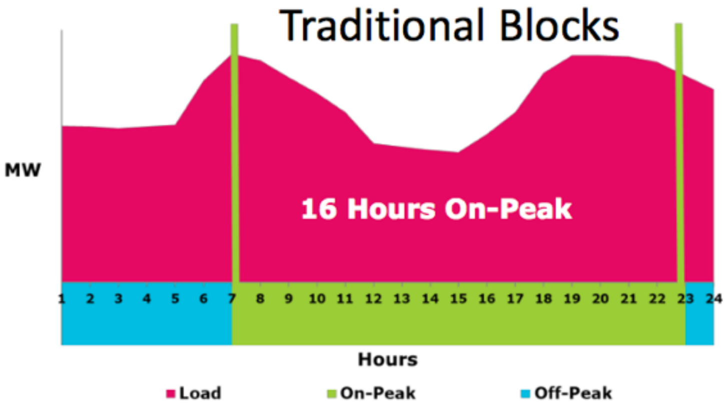
Lew, et al, "Secrets of Successful Integration: Operating Experience with High Levels of Variable, Inverter-based Generation" IEEE PES Magazine, Nov/Dec 2019

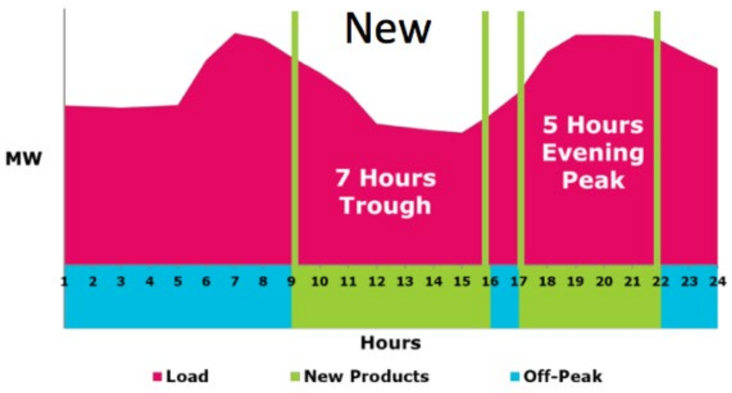
ORNL, DOE 2017 Hydropower Market Report, April 2018; A. Moreno, DOE, CREPC, April 2019

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

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Managing inverter-based resources

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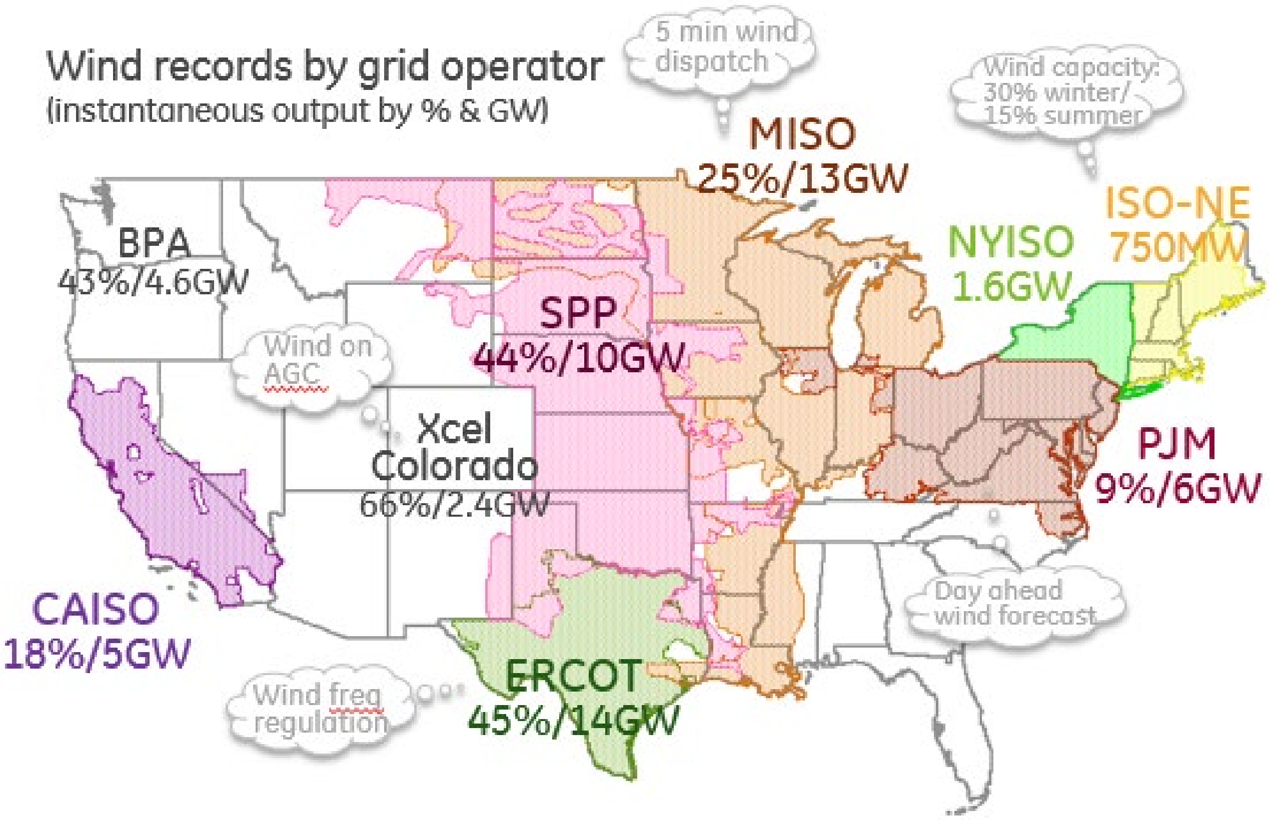
The grid needs essential reliability services to operate stably and reliably

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



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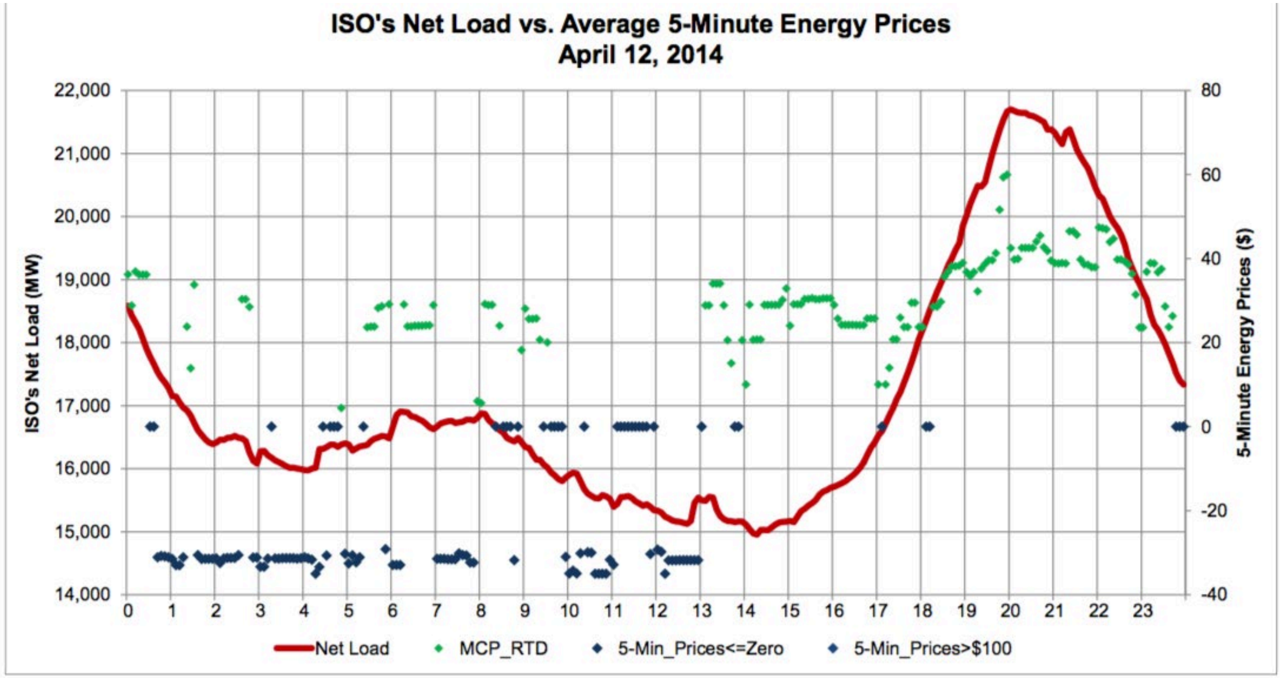
GE Energy Consulting, 2017

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

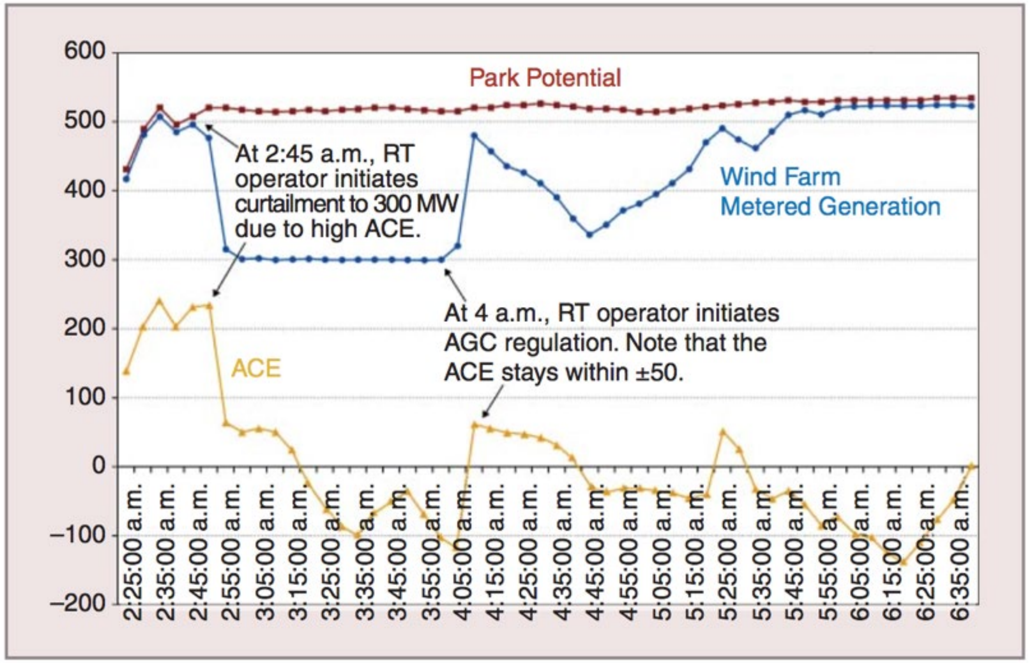
How reliability services from VRE can help

A problematic day in California



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

How wind helps reliability in Colorado (Xcel/PSCO)



Source: Drake Bartlett, PSCO/Xcel

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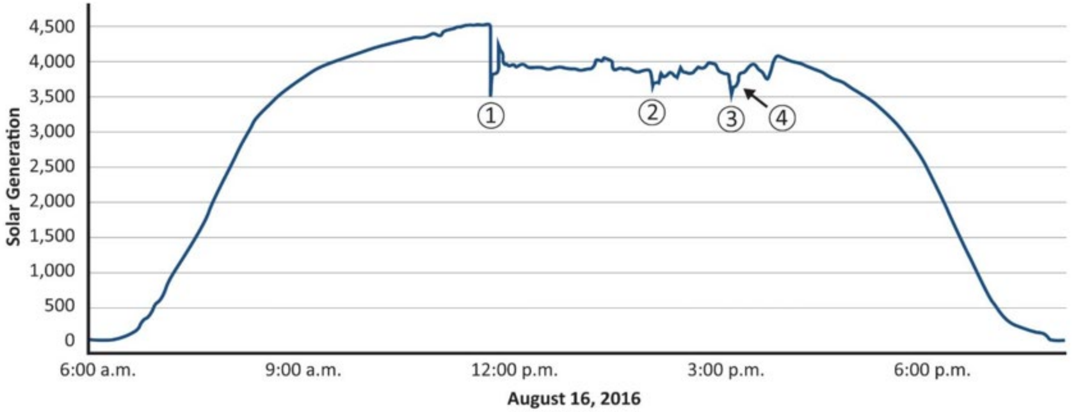
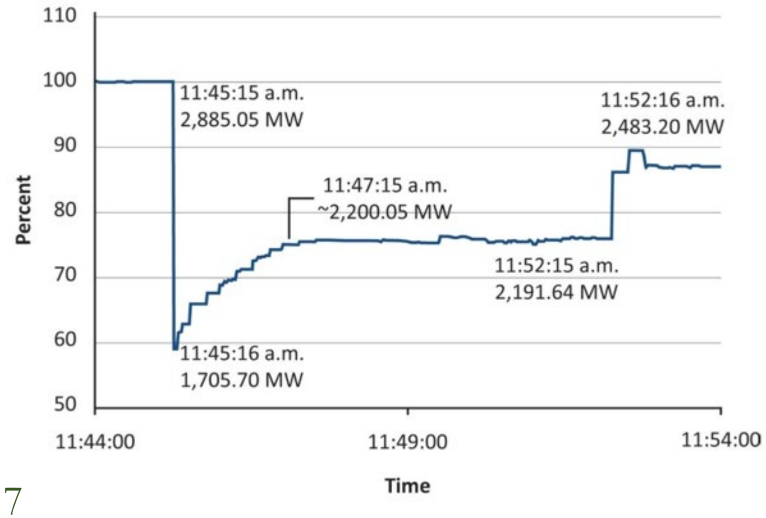
Grid codes are essential – they require generators to ride-through speed bumps on the grid

- 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





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

System stability

An actual island
- Kauai, Hawaii – synchronous condenser mode on gas turbine

Electrical islands
- Texas – PSCAD modeling; monitoring inertia; synchronous condensers
- Ireland – capping system non-synchronous penetration at 65%; new system services

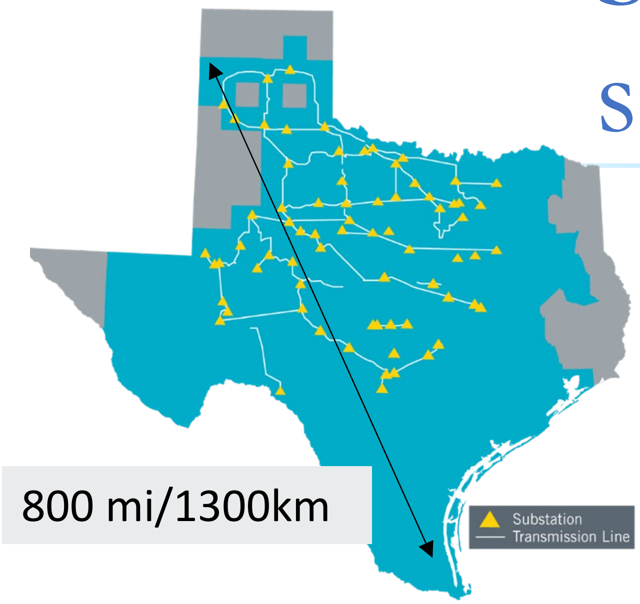
Loosely connected
- South Australia – reliability-must-run or out-of-merit dispatch; synchronous condensers; PSCAD modeling

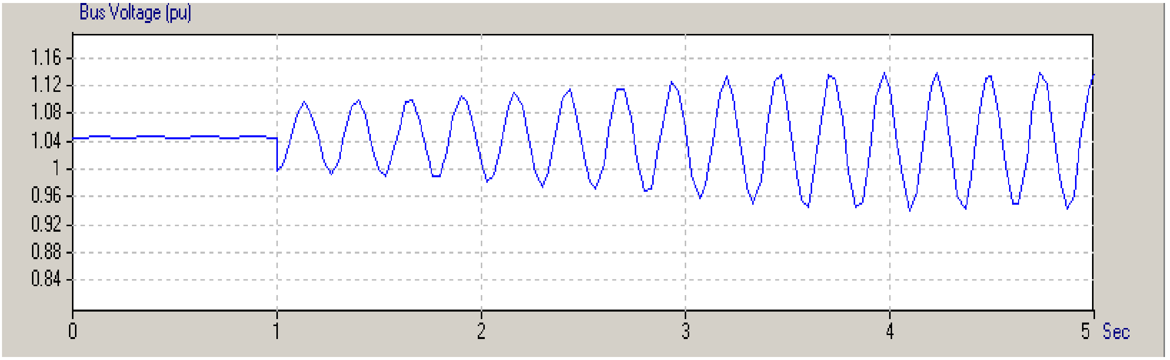
Moderately interconnected
- Xcel/CO

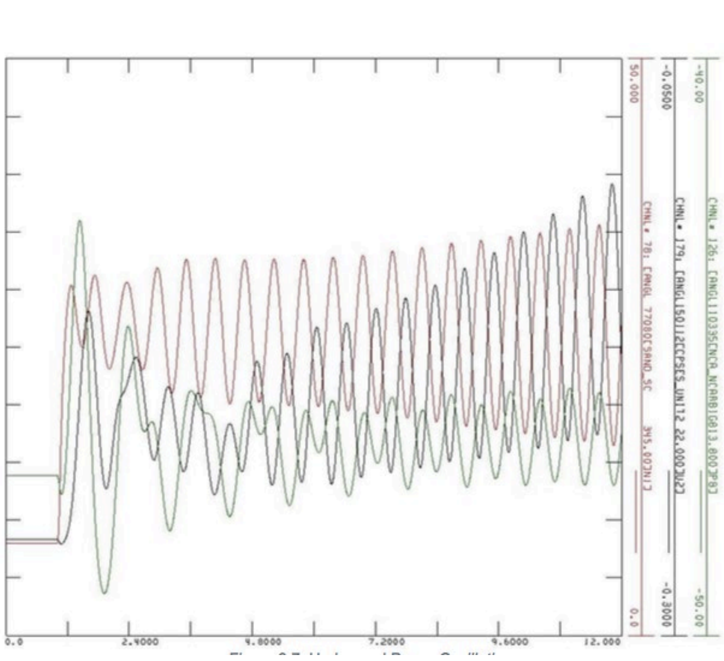
Strongly interconnected
- Denmark
- Southwest Power Pool

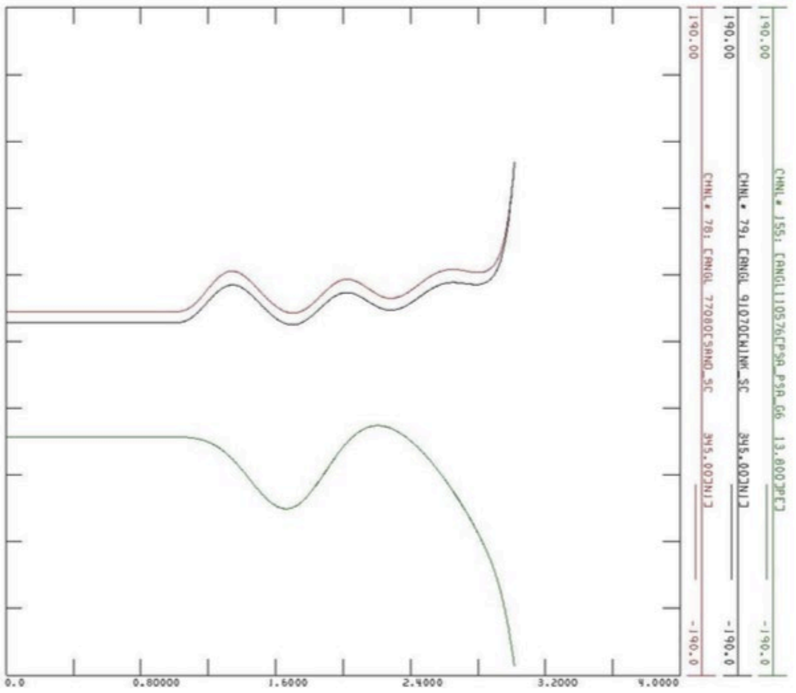
Source: Lew, et al, Secrets of Successful Integration, IEEE PES Magazine, Nov/Dec 2019

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

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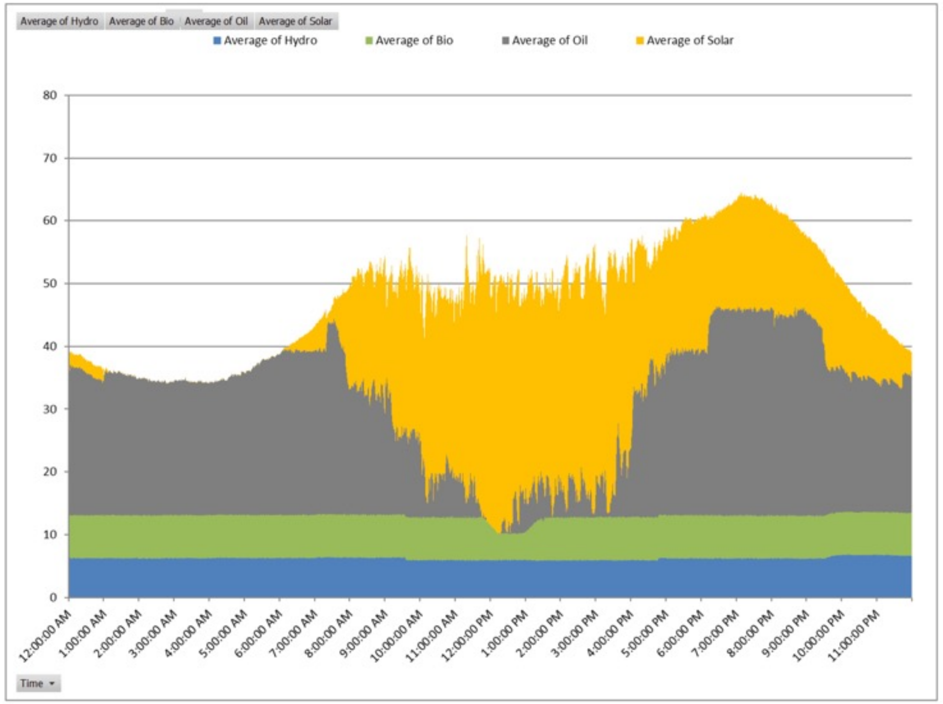
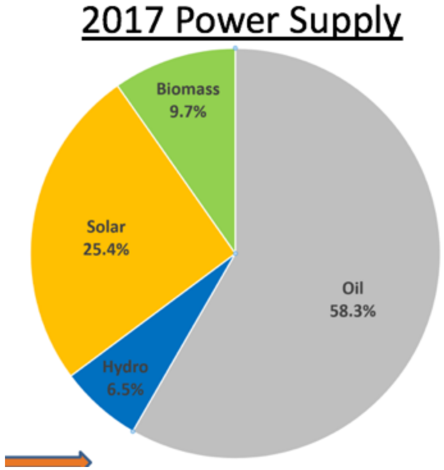
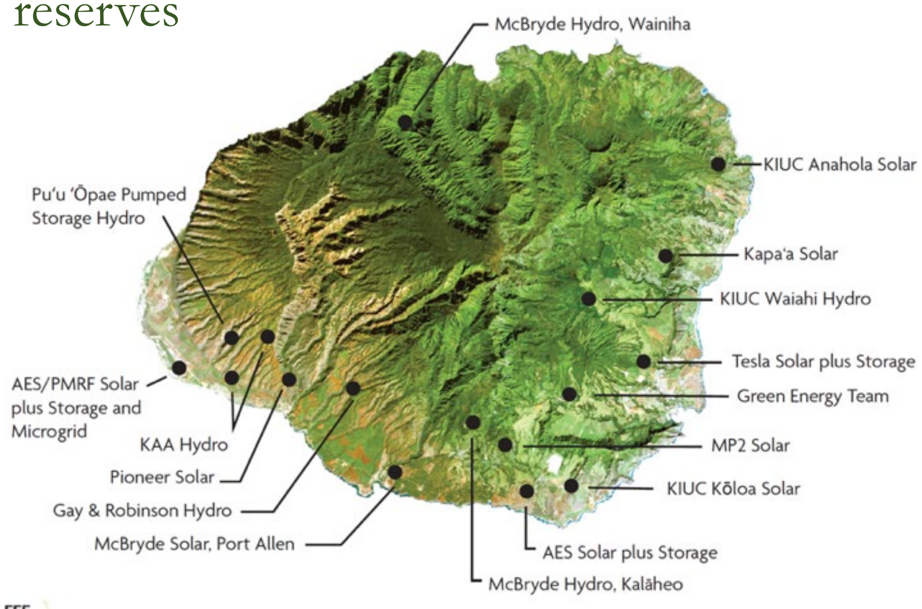
Kauai uses storage and synchronous condensers



- 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





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Lew, et al, "Secrets of Successful Integration: Operating Experience with High Levels of Variable, Inverter-based Generation" IEEE PES Magazine, Nov/Dec 2019

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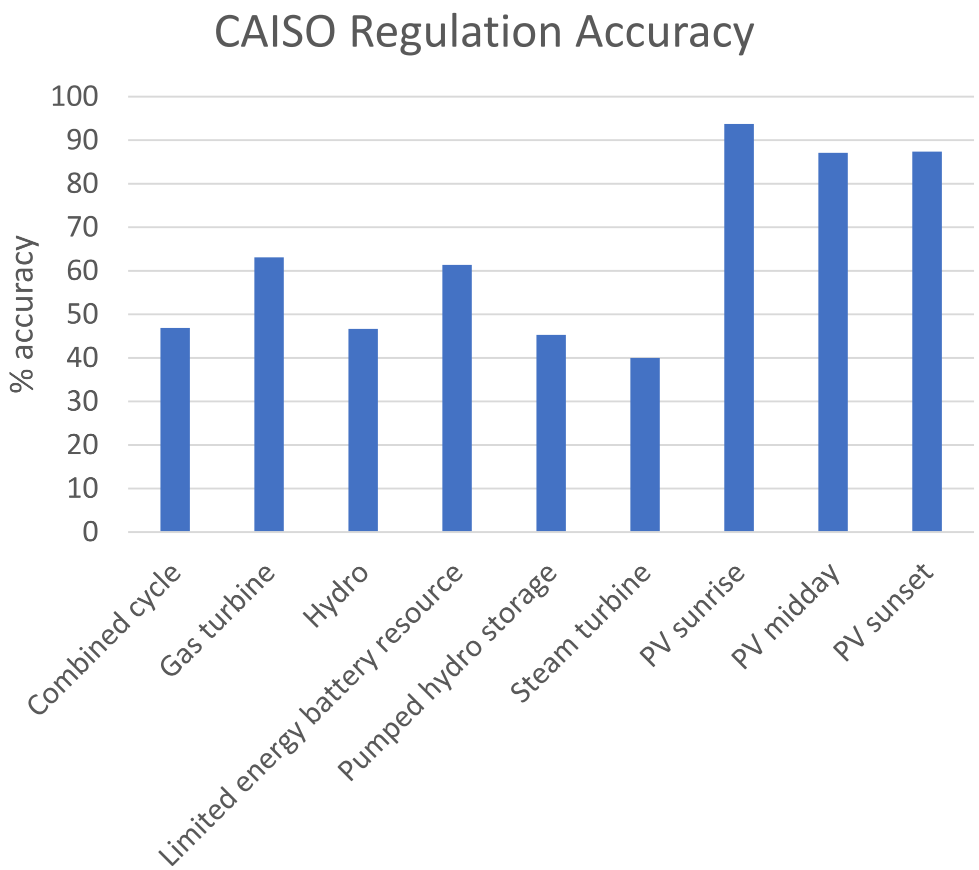
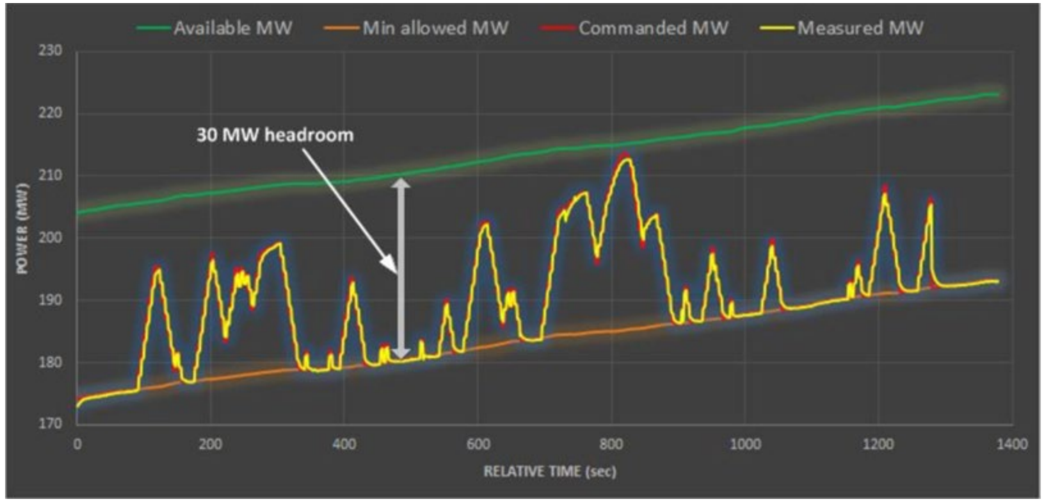
PV: accurate and fast regulation reserves





Data (left) and graphic (right) Source: Loutan, et al, "Using Renewables to Operate a Low-Carbon Grid", CAISO, 2017

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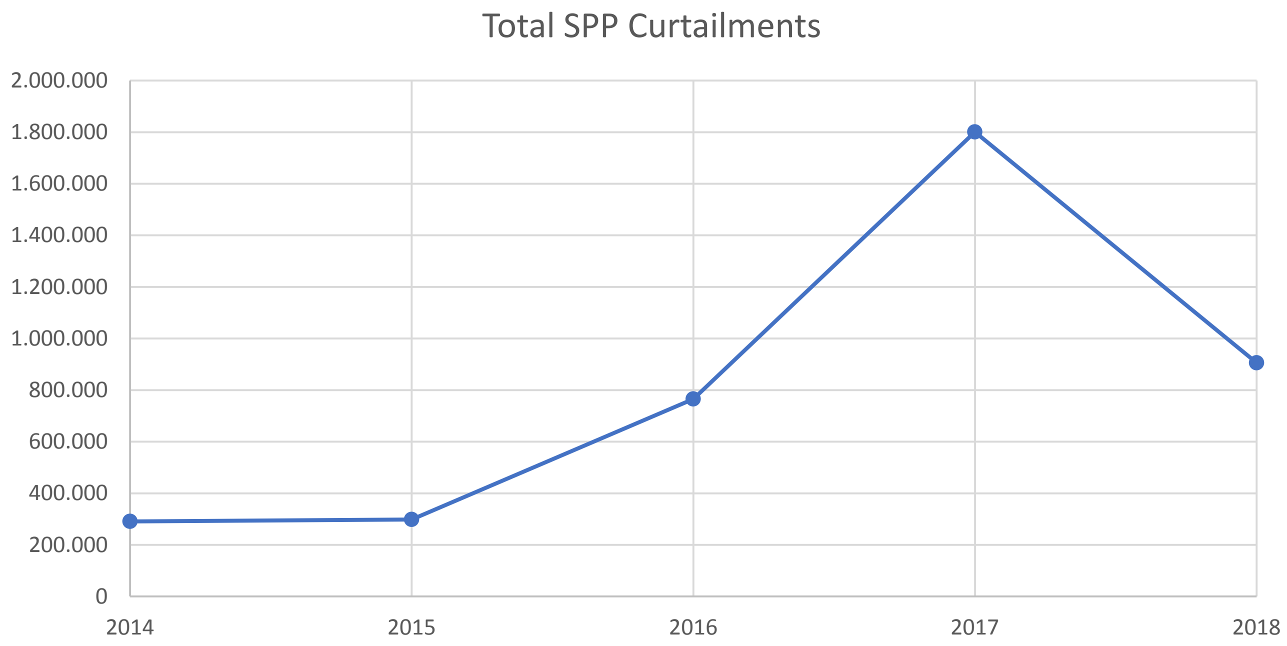
Southwest Power Pool reduced wind curtailment significantly during 2017-2018

Year	Wind Curtailed MWh
2014	290,703
2015	298,494
2016	765,676
2017	1,800,472
2018	905,519



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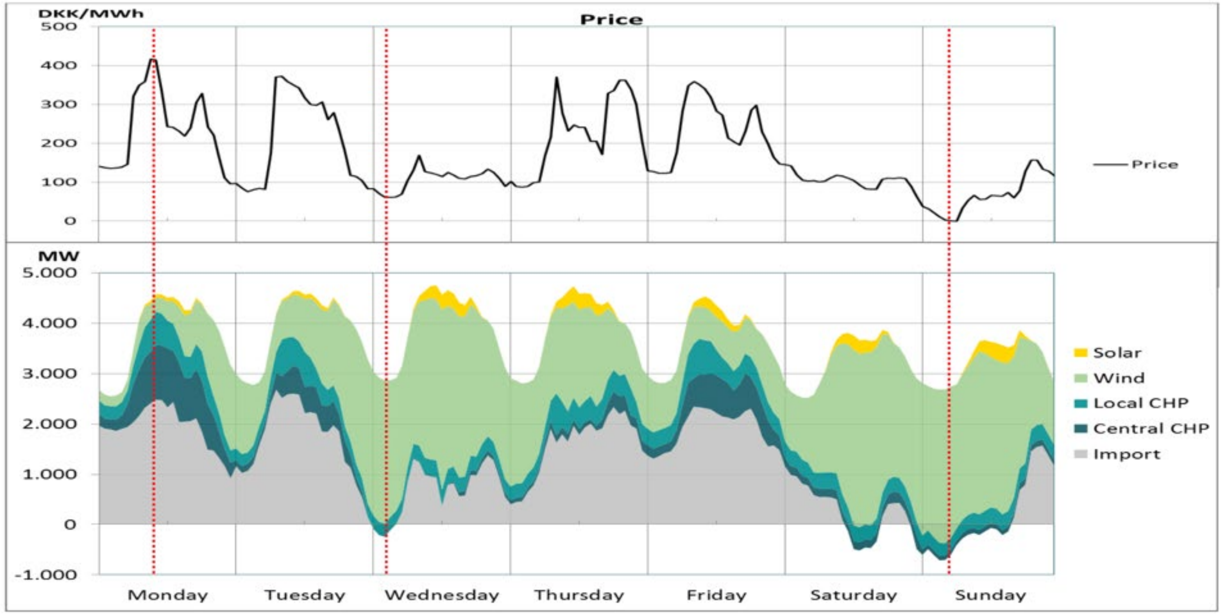
Lew et al, "Operating Experiences with High Penetrations of Variable Energy Resources," Wind Integration Workshop, Oct 2019

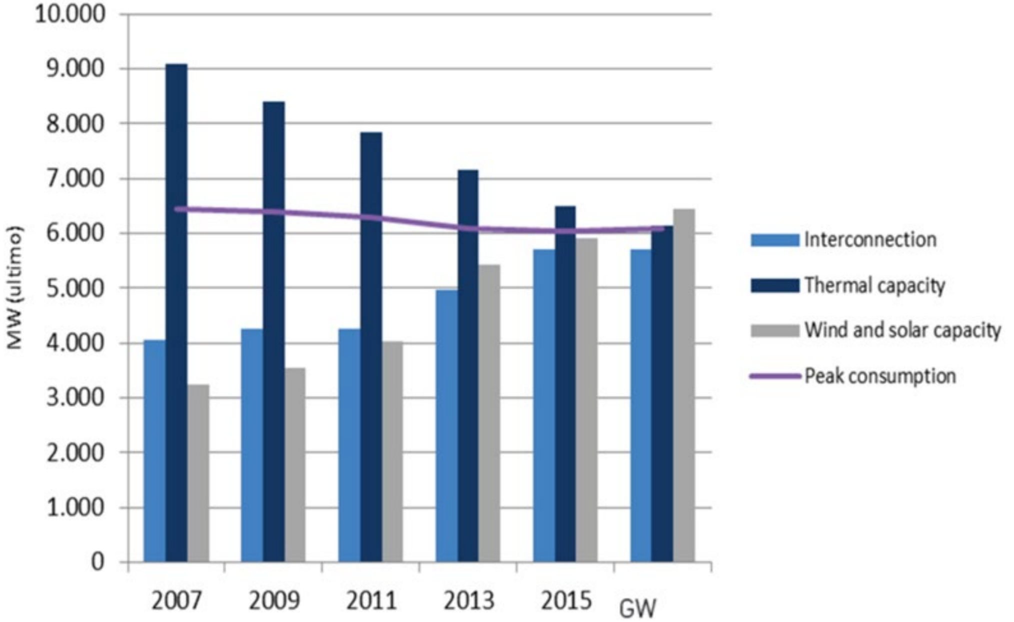
More interconnection to increase geographic diversity

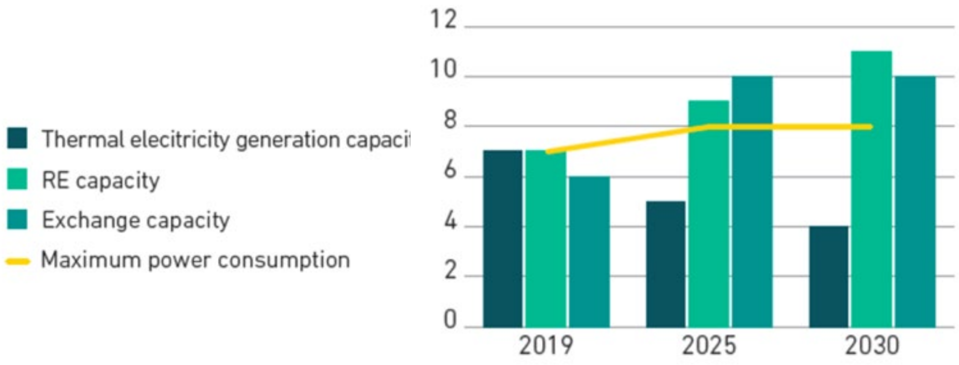
Increased interconnections allows for retirement of more thermal capacity



Jorgensen, Energinet, 2019; for Lew et al, “Operating Experiences with High Penetrations of Variable Energy Resources,” Wind Integration Workshop, Oct 2019

Continuing to build out more interconnectors in the future





Source: Energinet, 2018

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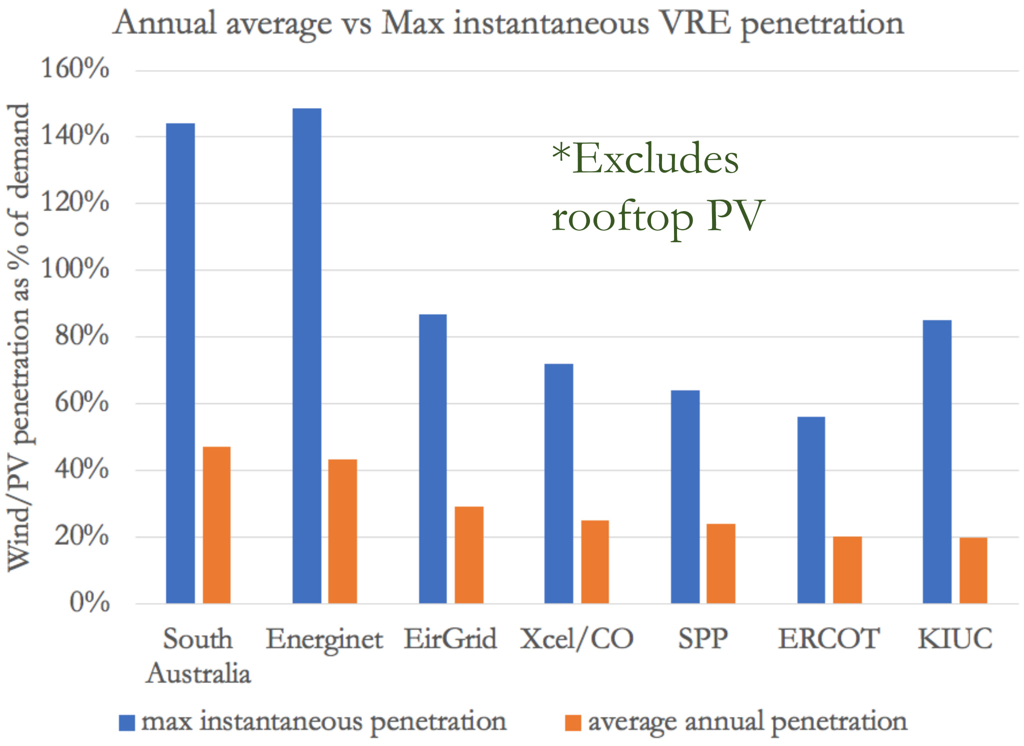
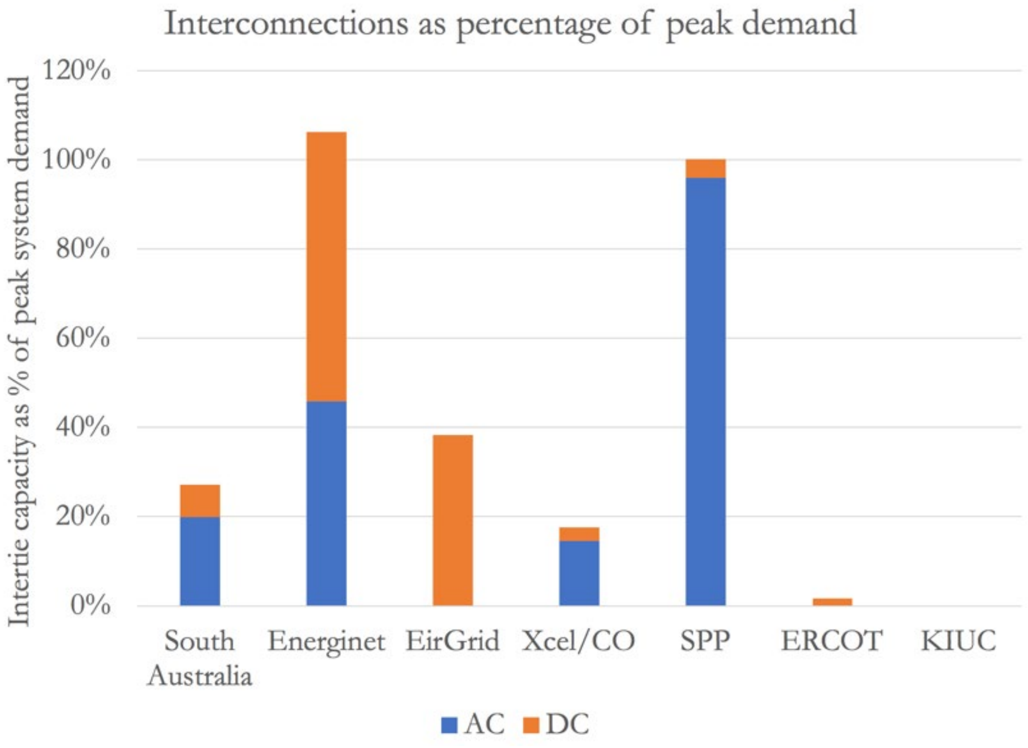
Well-interconnected systems





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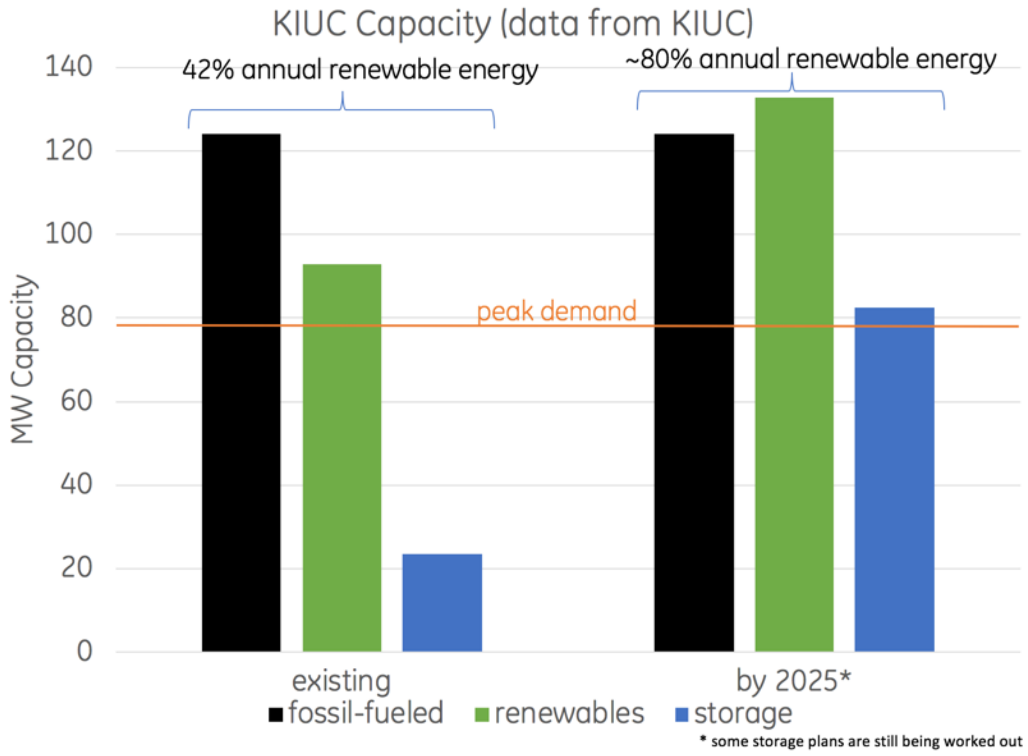
Left: Lew, et al, Secrets of Successful Integration, IEEE PES Magazine, Nov/Dec 2019. Right: same with updated interconnection data from Energinet 2019

How does KIUC manage zero interconnections?

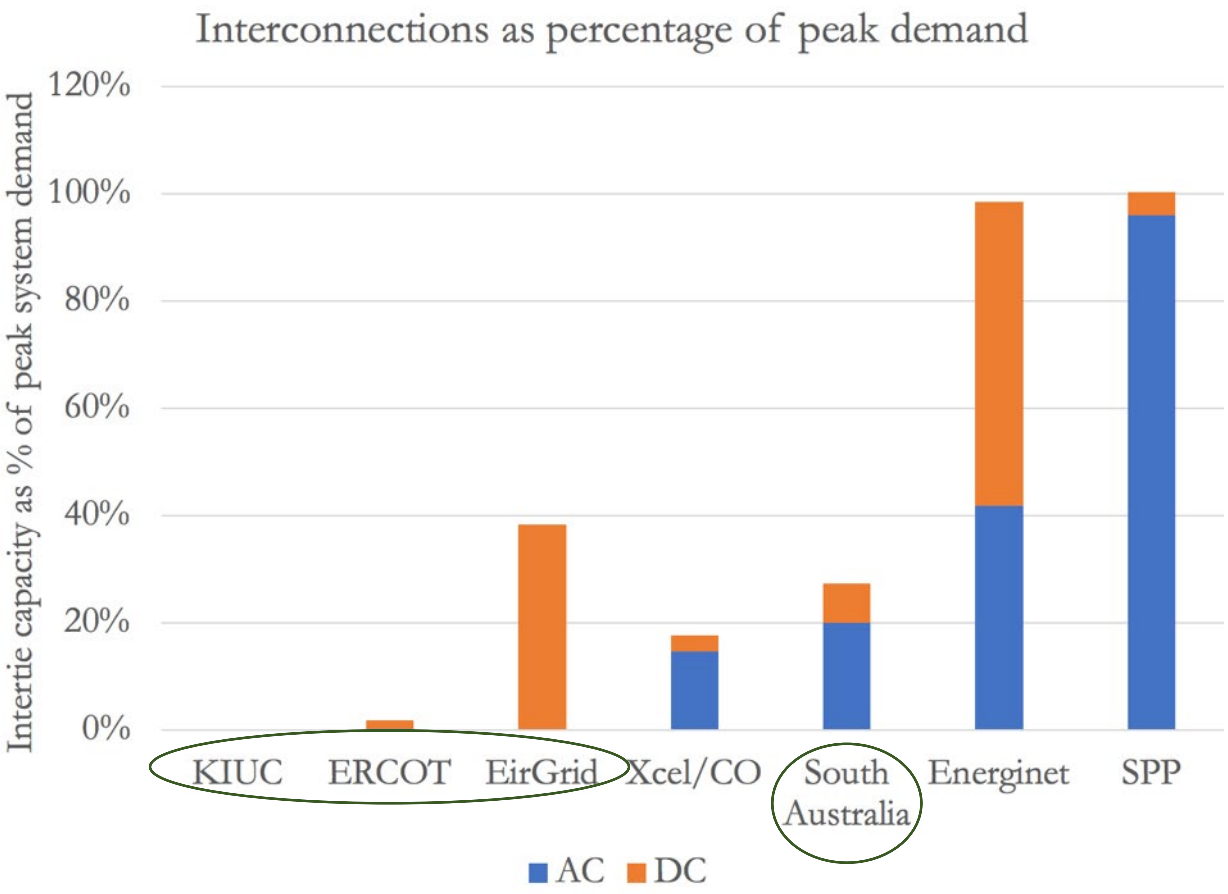
- KIUC has been and continues to build PV/battery plants
- Considering pumped hydro storage
- A fleet of fast-start diesel reciprocating engines helps manage variability and cloud events

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



Data from KIUC, 2018

System stability



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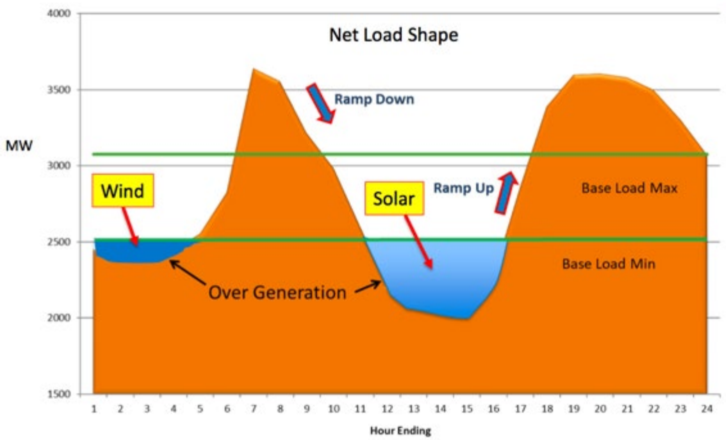
How do reliability services from wind/PV differ from conventional generators?

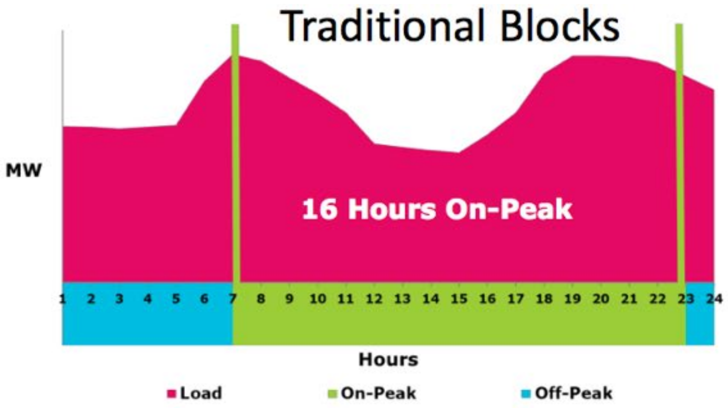
- Faster response
- Can have more aggressive droop
- Little/no wear-and-tear
- Accurate ability to follow signal
- Superior ride-through of some types of disturbances
- Can provide or absorb reactive power when it's not sunny or not windy
- Does not contribute to grid strength (short circuit strength)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

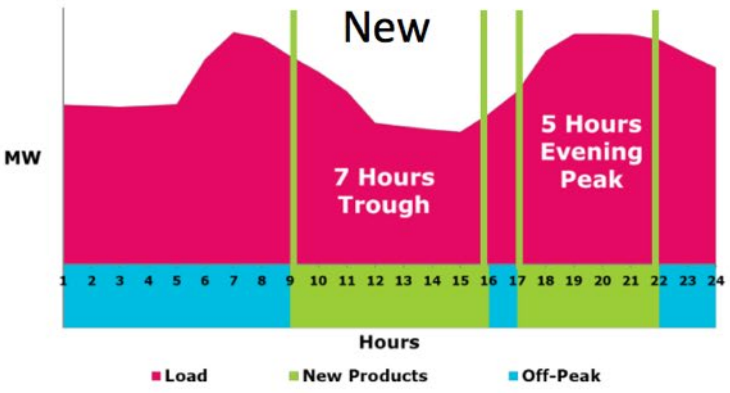
What essential reliability services can wind/PV provide?

- 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



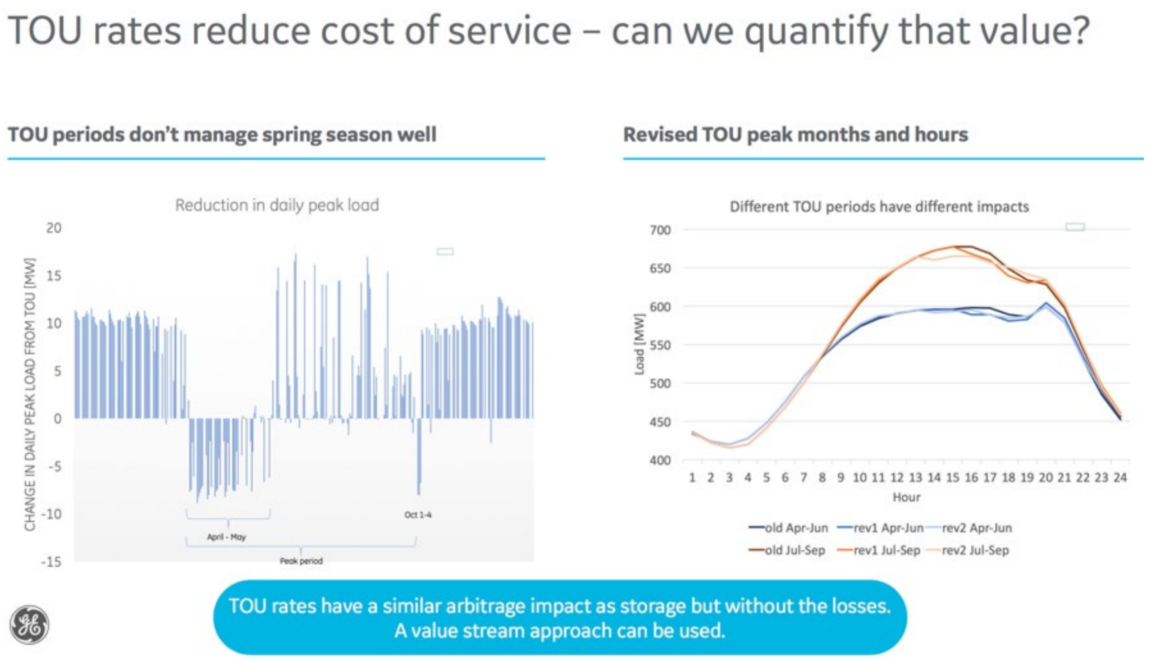


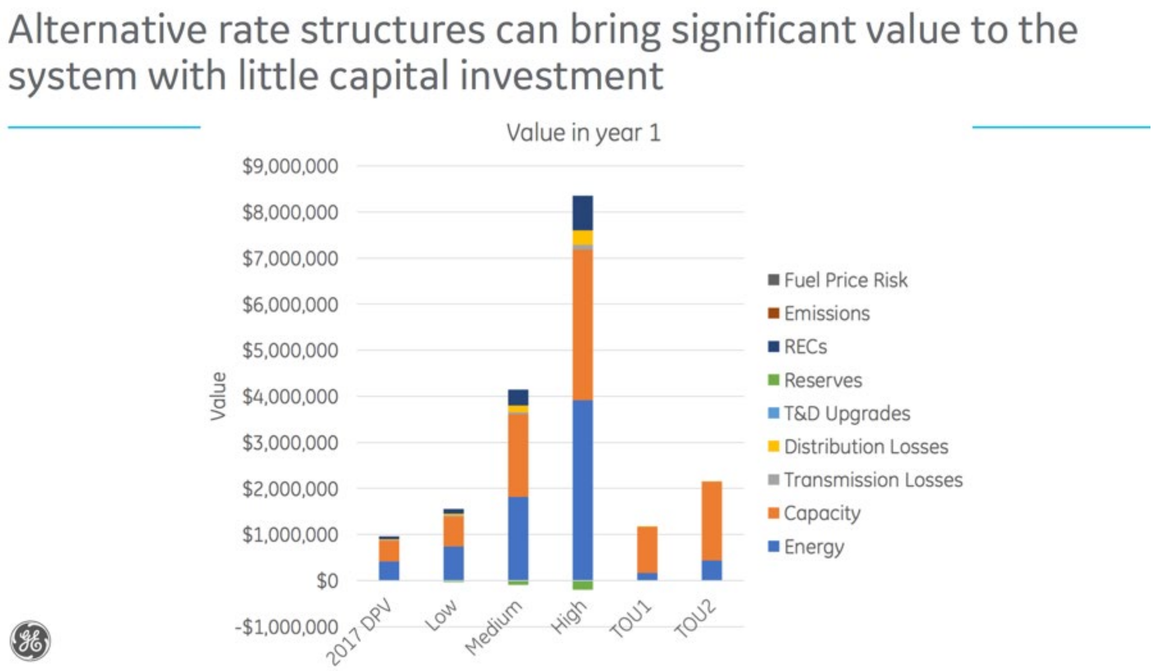


- In EIM; considering EDAM
- New Trough Hour Trading product
- Added 500 MW quick start gas for capacity and ramping
- Reduced P_{min} on CC and coal
- Installing 850 MW batteries
- Highest percentage use of TOU rates
- Upgrade EMS to put PV on AGC
- Forecasting of load and renewables

J. Thompson, APS, "What if Your Neighboring Utility Goes to 100% Renewables," CREPC April 2019

TOU rates look like storage





Lew, et al, GE Energy Consulting, "DER Compensation: Colorado Springs Utilities Solar Program Design Study," ESIG Oct 2017

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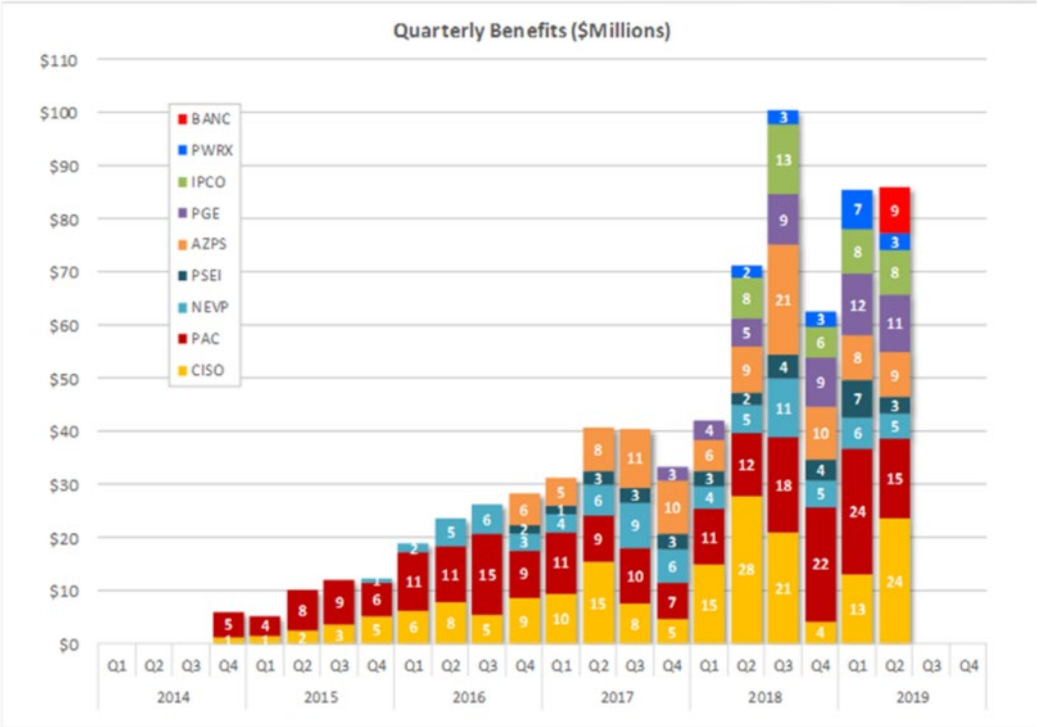
Benefits of trading

By June 2019, the EIM had saved $736M



Curtailment reductions and associated CO_2 reductions

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2015	1	8,860	3,792
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