SRP Integrated System Plan

Technical Working Session: Inverter-Based Resources Integration

February 24, 2023

Welcome

Bobby Olsen
Senior Director, Corporate Planning, Environmental Services & Innovation (SRP)

Welcome SRP Board and Council Observers

John Hoopes
SRP Association Vice President

Chris Dobson
SRP District Vice President

Anda McAfee
SRP Board Member

Jack White
SRP Board Member

Larry Rovey
SRP Board Member

Krista O’Brien
SRP Board Member

Suzanne Naylor
SRP Council Member

Rocky Shelton
SRP Council Member

Safety & Sustainability Minute

Meeting Objectives:

- Understand the power system impacts of integrating high levels of inverter-based resources (IBR) and any uncertainties
- Highlight solutions for mitigating challenges and uncertainties
- Identify improvements to long-term planning, operational readiness, and modeling processes to better account for increasing levels of IBRs in future planning processes

Agenda

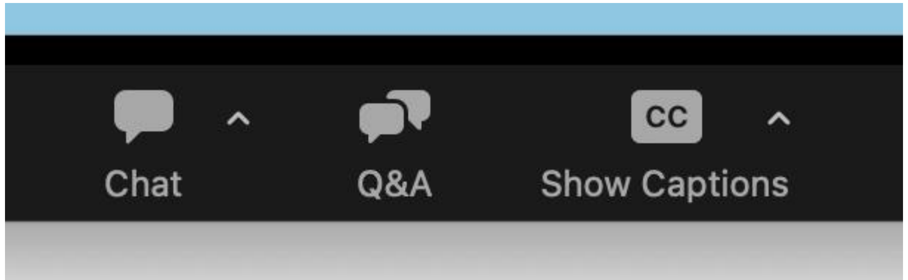
Time		Topics	Presenter
1:00-1:05	5 min	Welcome and Meeting Overview	Bobby Olsen (SRP)
1:05-1:20	15 min	SRP System: Inverter-Based Resource Penetrations & Readiness	Angie Bond-Simpson (SRP) Scott Anderson (SRP)
1:20-2:10	50 min	Presentations from panelists (10 min each)	Panelists
		(1) Research/Modeling Perspective	Nick Miller (HickoryLedge LLC)
		(2) Reliability Perspective	Ryan Quint (NERC)
		(3) Market Operations Perspective	Guillermo Alderete Bautista (CAISO)
		(4) Renewable Dispatch Perspective	Mahesh Morjaria (Terabase Energy)
		(5) Utility Perspective	Keith Parks (Xcel Energy)
2:10-2:20	10 min	Coffee Break	
2:20-3:20	60 min	Facilitated panel discussion and Q&A with participants	Panelists & SRP participants Tess Williams (Sound Grid Partners) as moderator
3:20-3:30	10 min	Wrap up and closing remarks	Angie Bond-Simpson (SRP)

How to Ask for Technical Help in the Webinar

Having technical issues during the meeting?

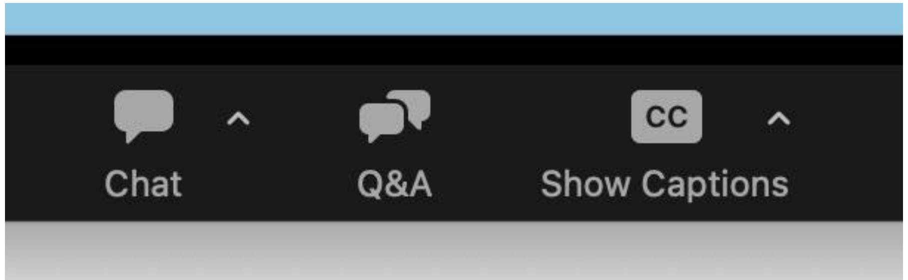
Send a message using the chat.

You can also enable captioning.



How to Ask a Question in the Webinar

Please submit questions for the panelists using the Q&A box.



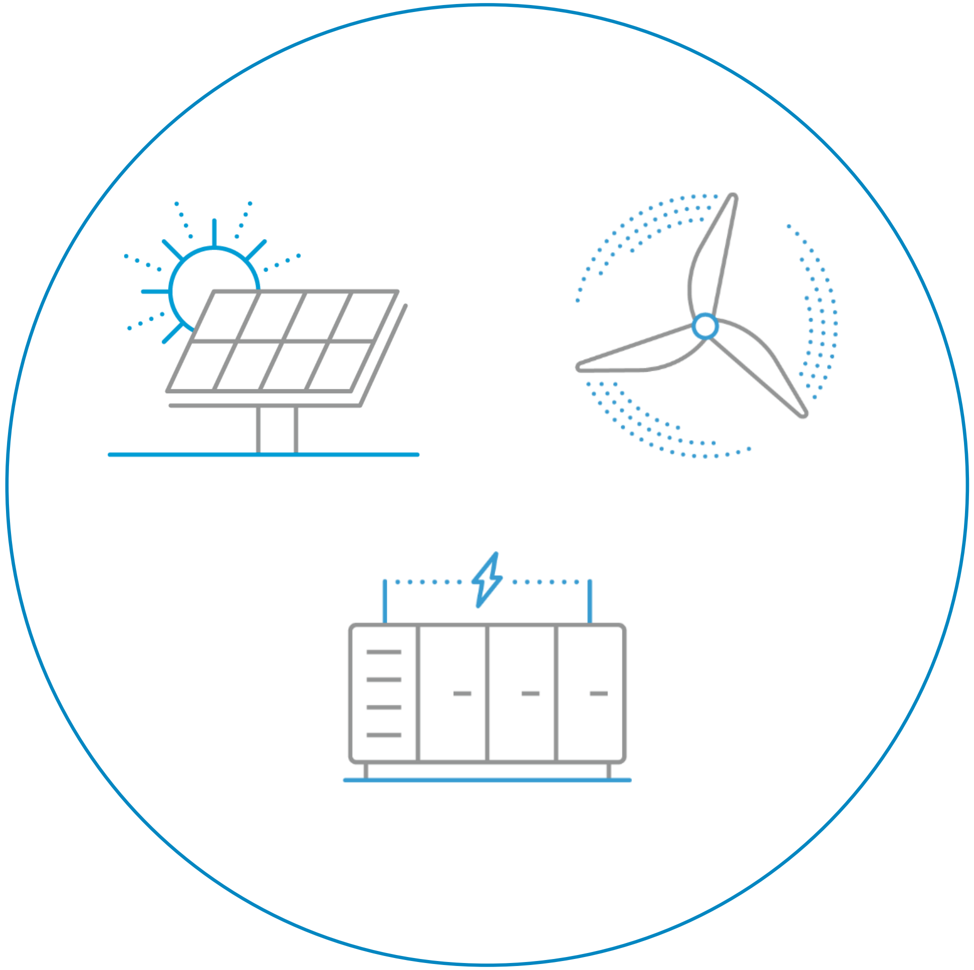
SRP System: Inverter-Based Resource Penetrations & Readiness

Angie Bond-Simpson
Director, Integrated System Planning & Support (SRP)

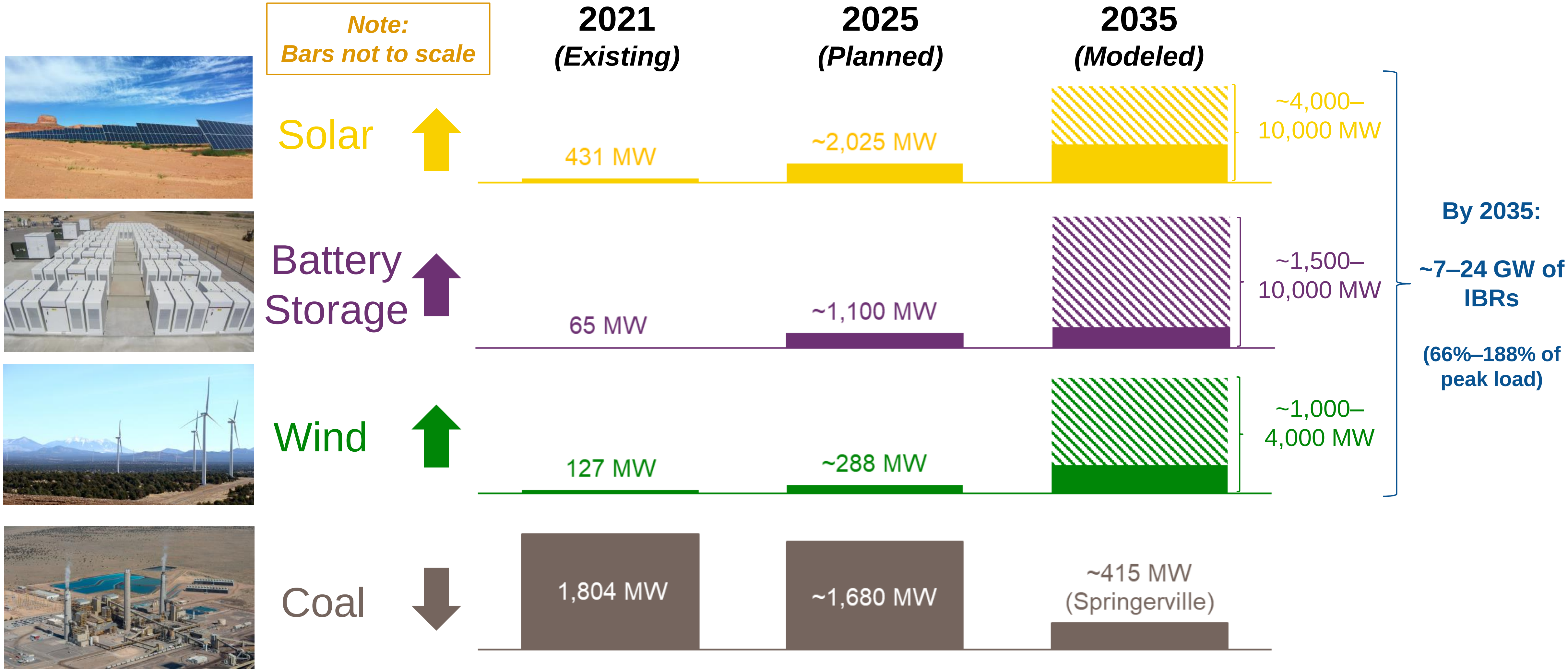
Scott Anderson
Director, Operational Readiness (SRP)

Inverter-Based Resources (IBR)

- IBRs connect to grid using inverters, or power electronics, that convert direct current (DC) to alternating current (AC).
- The most prevalent IBRs are solar photovoltaic, wind power and battery storage.
- In contrast, most power plants operating today generate power by driving a turbine that generates AC power directly.
- A transition towards IBRs reflects opportunity – growing sustainability goals and cost declines for these resources.



Integrated System Planning Outlook on IBRs



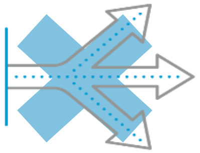
Planning and Operational Considerations of IBRs

Variability & Uncertainty in Generation

- Fluctuation in generation
- Requires generation forecasting
- More frequent and steeper net load ramps

No Spinning Mass

- Does not provide inertia
- Most renewables operating today were not designed for voltage and frequency control.
- Limitations on black-start support after outages



Operating Limitations

- Energy storage has limited duration and requires charging to operate.
- Most renewables operating today were not designed to be dispatched dynamically.

Integrating higher levels of IBRs requires intentional operational efforts to overcome challenges and realize opportunities.

Current Efforts Underway at SRP: Operational Readiness

Operational Readiness is the capability for SRP to operate the future grid **safely**, **reliably** and **cost-effectively** as renewable energy resources are added.

1. Fully Leverage New Resource Capabilities
2. Economic Dispatch with Solar + Storage
3. Risk-Adjusted Reserve Requirements
4. Advanced Forecasting Tools
5. Software and Situational Awareness

Panelist Introductions

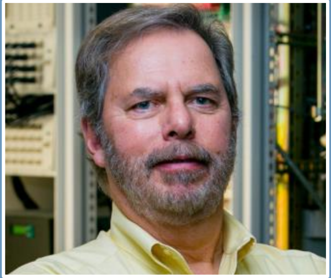
Moderator

Tess Williams, PhD

Co-Founder & Principal
Sound Grid Partners

External Panelists

Research/Modeling



Nick Miller

Principal

HickoryLedge LLC

Reliability

Ryan Quint

Director of Engineering and Security Integration

North American Electric Reliability Corporation (NERC)

Market Operations

Guillermo Alderete Bautista

Director, Market Analysis & Forecasting

California ISO (CAISO)

Renewable Dispatch

Mahesh Morjaria

EVP, Plant Operational Technology

Terabase Energy

Utility Perspective

Keith Parks

Senior Data Scientist

Xcel Energy

Research/ Modeling Perspective

Research/Modeling

Nick Miller

Principal

HickoryLedge LLC

Future Opportunity and Challenges with High Levels of Inverter-based Resources

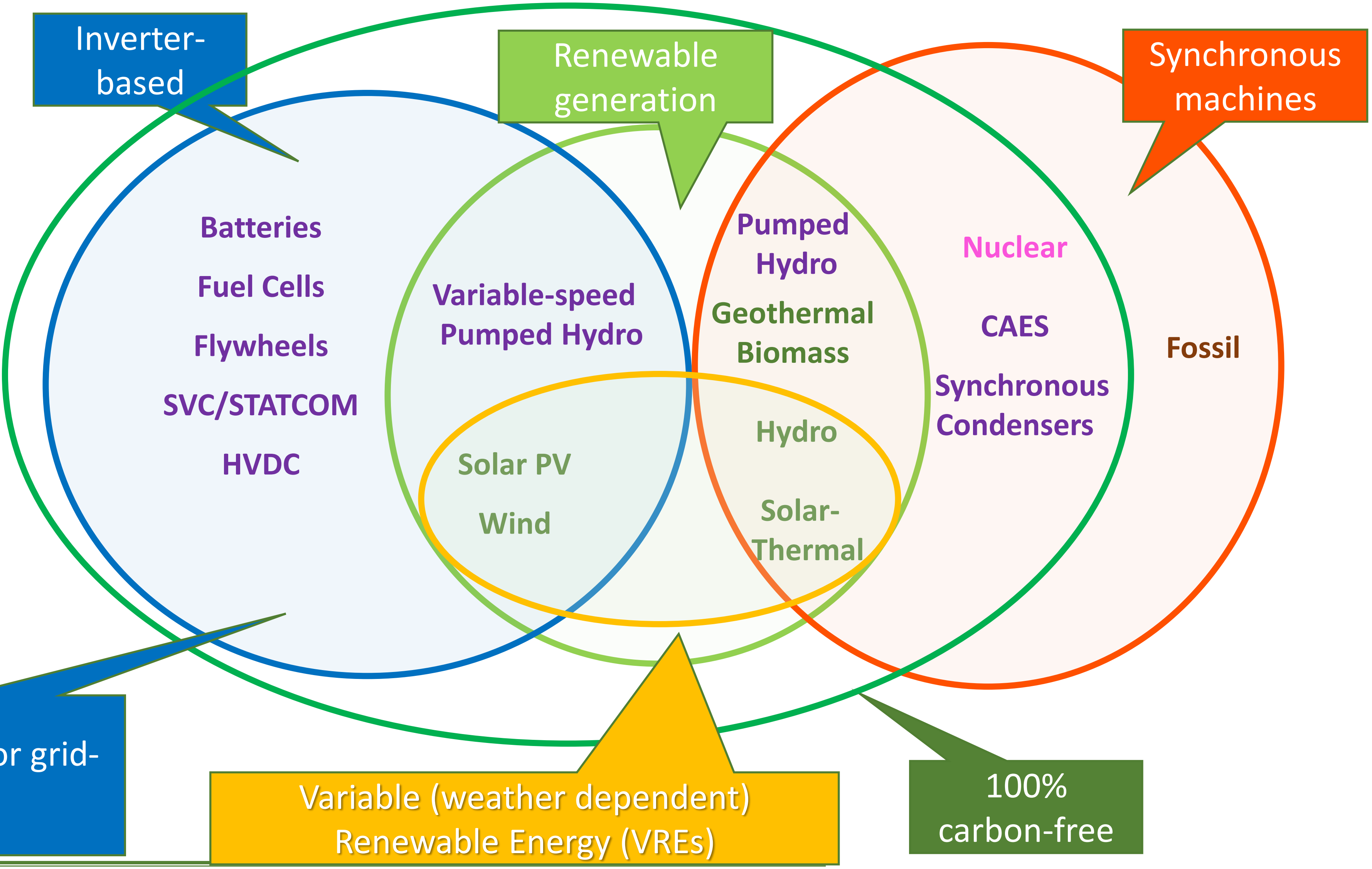
SRP
Webinar/Technical Working Session
February 24, 2023

Nick Miller

HickoryLedge

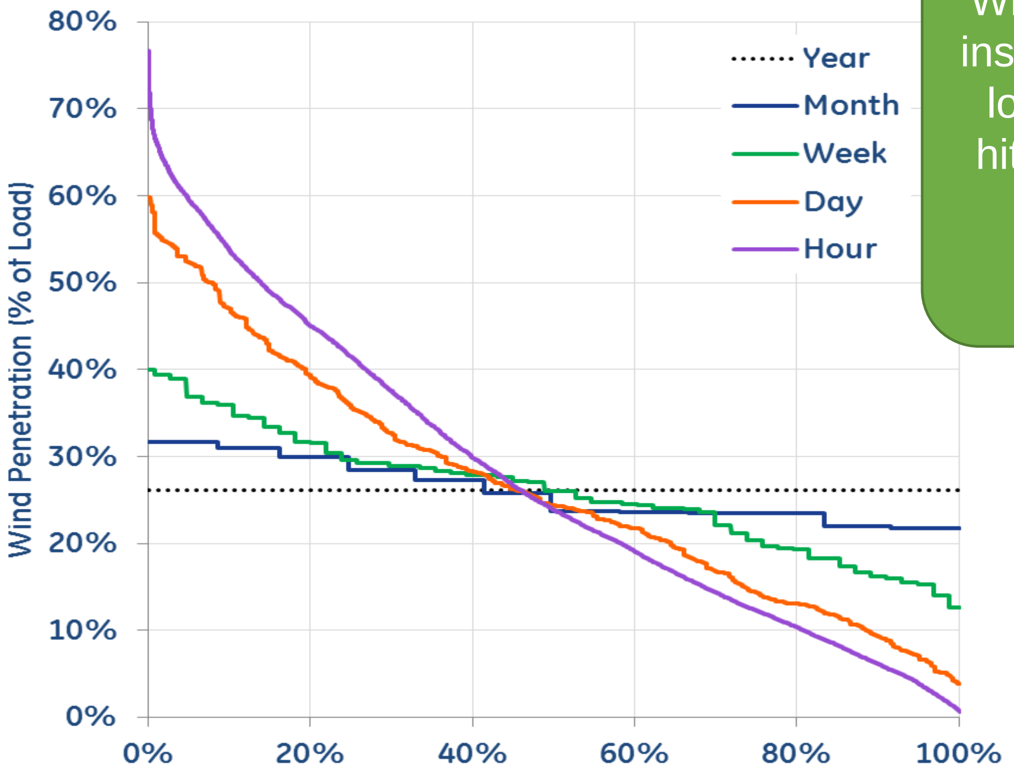
IBRs and Energy Policy: A Complicated Space

- Synchronous vs Converter-based
- Renewable Generation vs "Dynamic Enabler" vs Fossil vs Nuclear

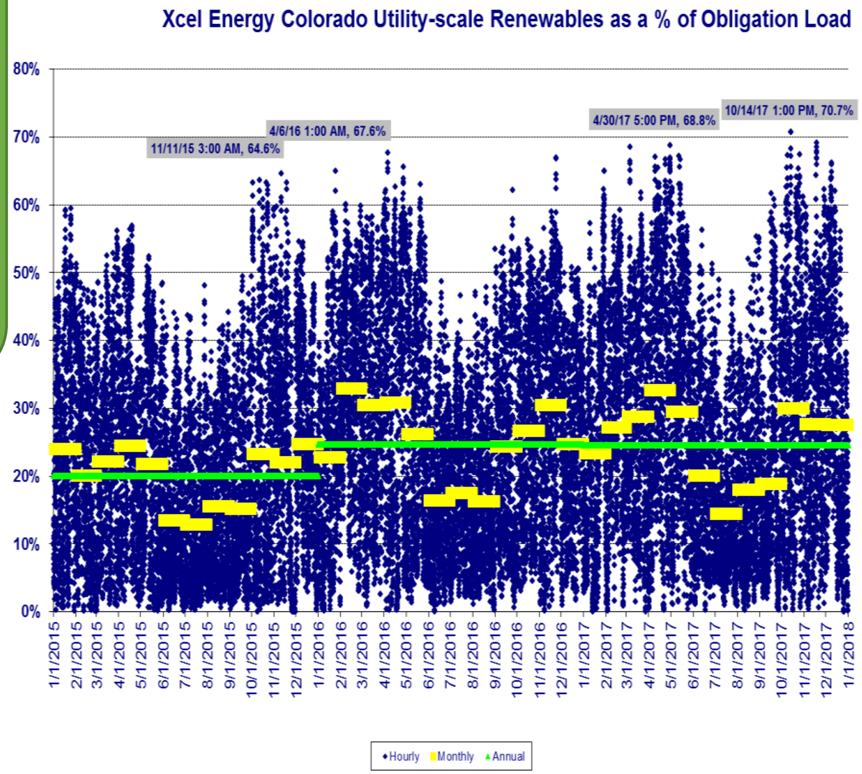


Source: A Future with Inverter-based Resources, IEEE P&E Nov/Dec 2021

VERs: Moderate annual averages can cause high instantaneous penetrations



Will hit 100% instantaneous long before hitting 100% annual average



Source: Drake Bartlett, Xcel 2018

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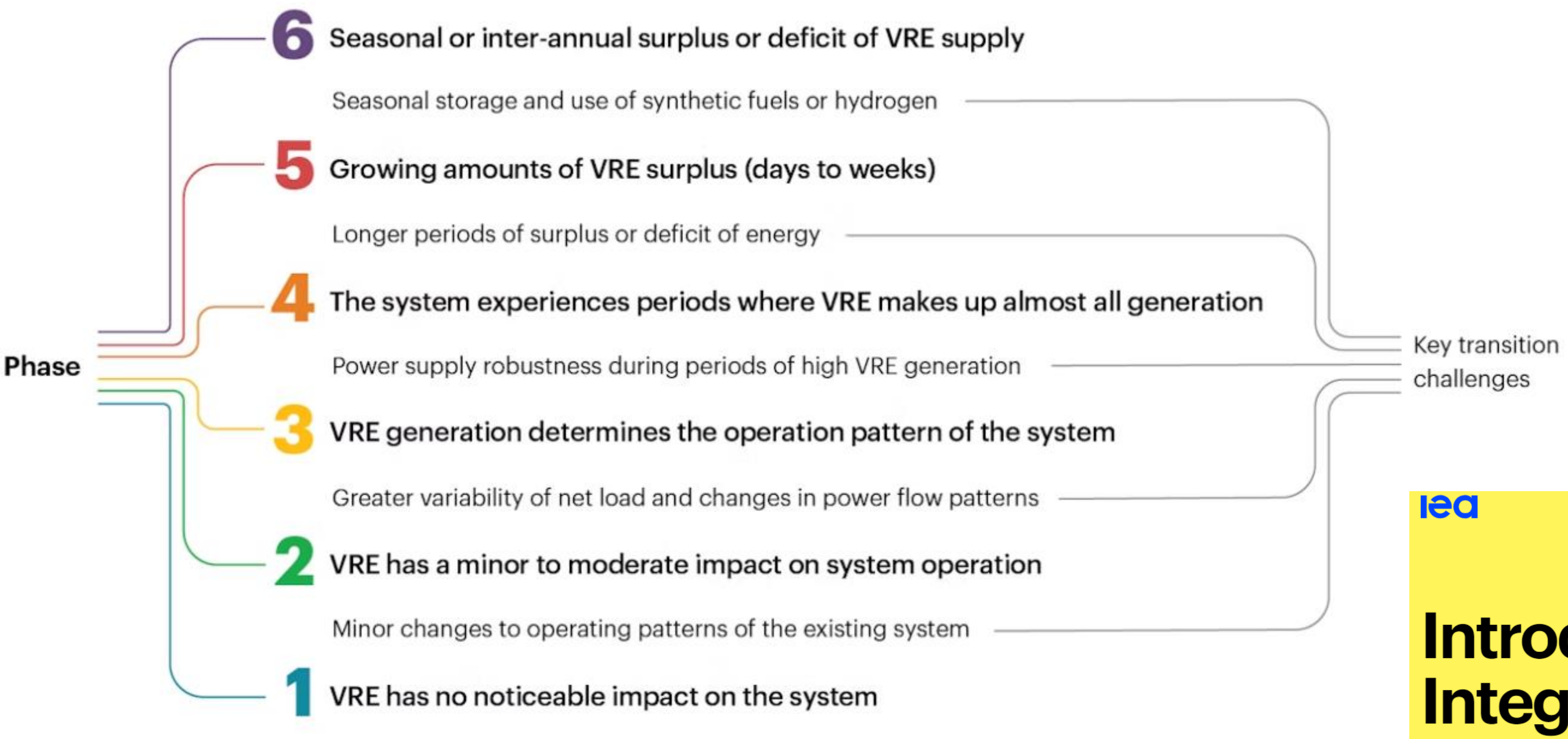
Source: N. Miller, GE, NSPI Renewable Integration Study
http://www.nspower.ca/site-nsp/media/nspower/CA%20DR-14%20SUPPLEMENTAL%20REIS%20Final%20Report%20REDACTED.pdf

Energy Transition has well understood stages

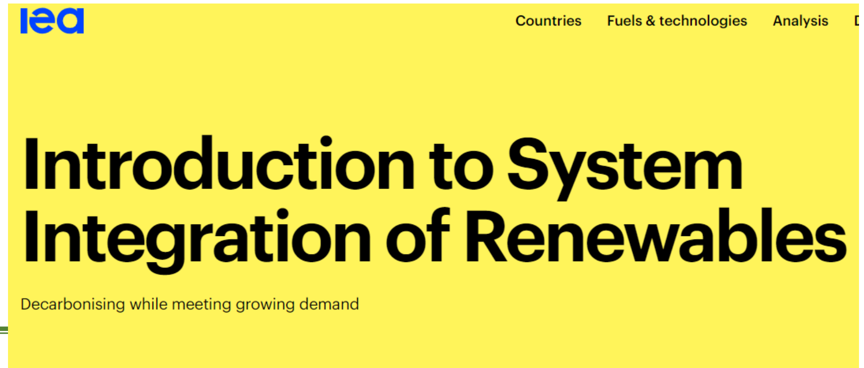
Consider the end points, but concentrate on successfully navigating to the next phase

Key characteristics and challenges in the different phases of system integration



WECC is presently mostly a Phase 3.

Increasing parts of the system moving to Phase 4



Source: https://www.iea.org/reports/introduction-to-system-integration-of-renewables

Time-scale and Penetration

Challenges have different timing and are associated with different phases of VRE integration

Issues seen at different flexibility timescales

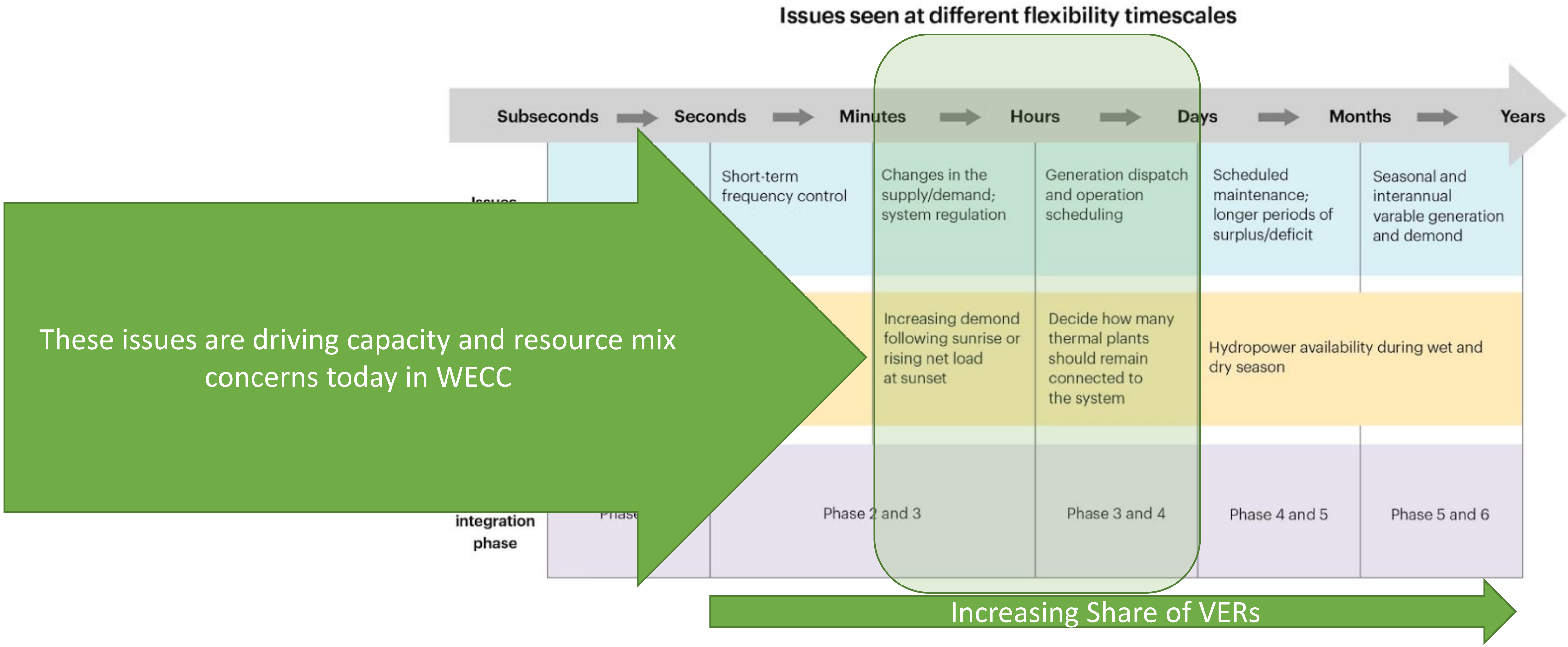
Subseconds → Seconds → Minutes → Hours → Days → Months → Years

Issues addressed	system stability	Short-term frequency control	Changes in the supply/demand; system regulation	Generation dispatch and operation scheduling	Scheduled maintenance; longer periods of surplus/deficit	Seasonal and interannual varable generation and demond
Example issue	Withstanding large disturbances such as losing a large power plant	Random fluctuations in power demand	Increasing demond following sunrise or rising net load at sunset	Decide how many thermal plants should remain connected to the system	Hydropower availability during wet and dry season	
Relevant to integration phase	Phase 4	Phase 2 and 3		Phase 3 and 4	Phase 4 and 5	Phase 5 and 6

Increasing Share of VREs →

Source: https://www.iea.org/reports/introduction-to-system-integration-of-renewables

Time-scale and Penetration



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Source: https://www.iea.org/reports/introduction-to-system-integration-of-renewables

Time-scale and Penetration

Dependence on inverters is ONLY relevant in these short time frames

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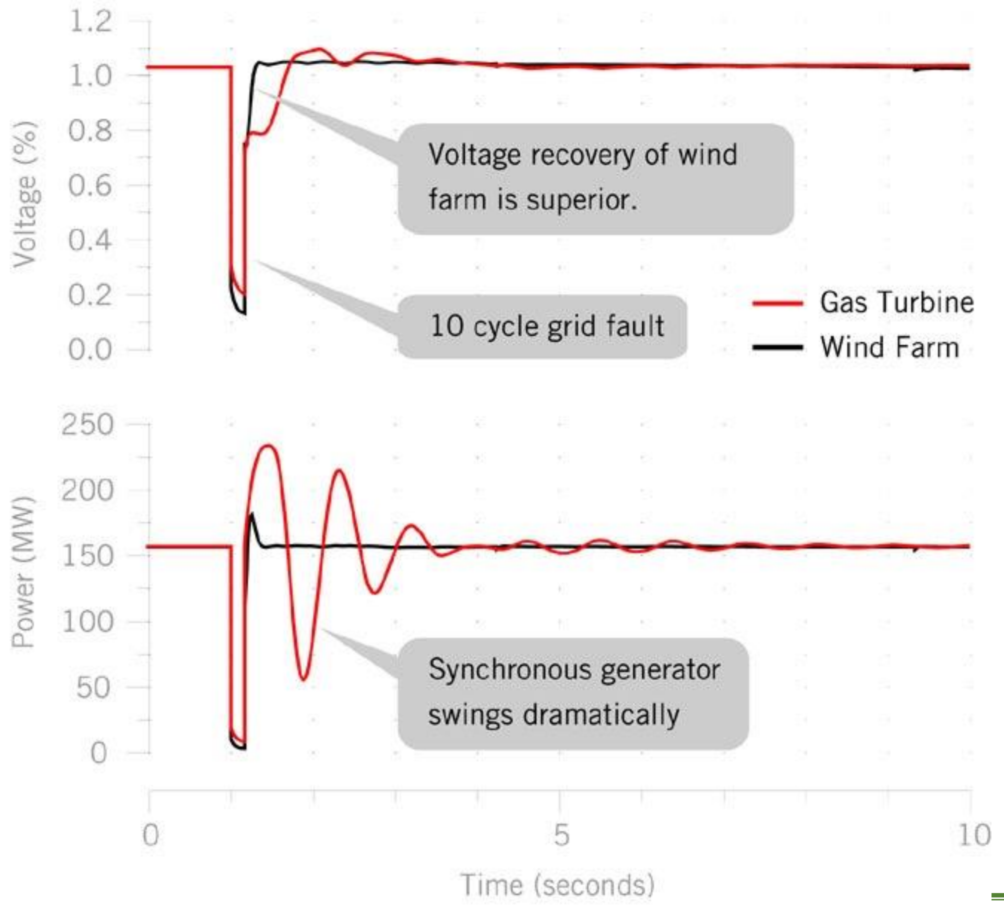
Increasing Share of VERs

HickoryLedge

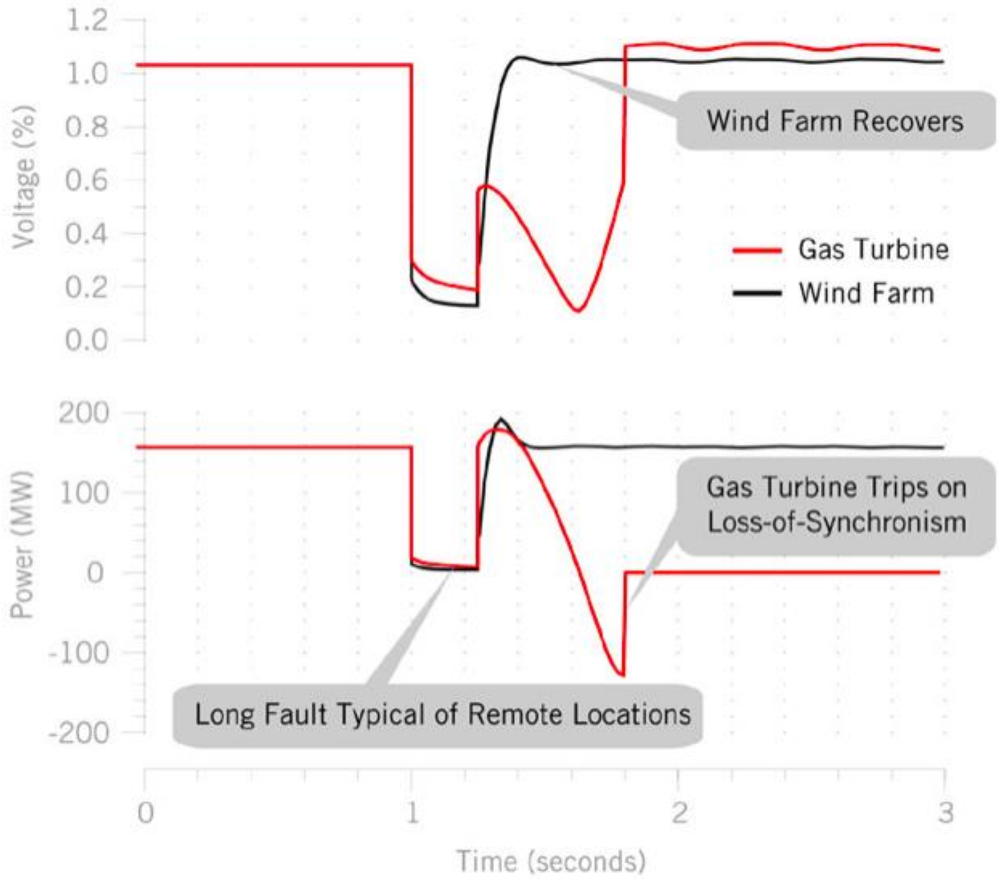
Source: https://www.iea.org/reports/introduction-to-system-integration-of-renewables

Today's IBRs can be (much) more stable

Primary Cleared Fault



Delayed Clearing Fault



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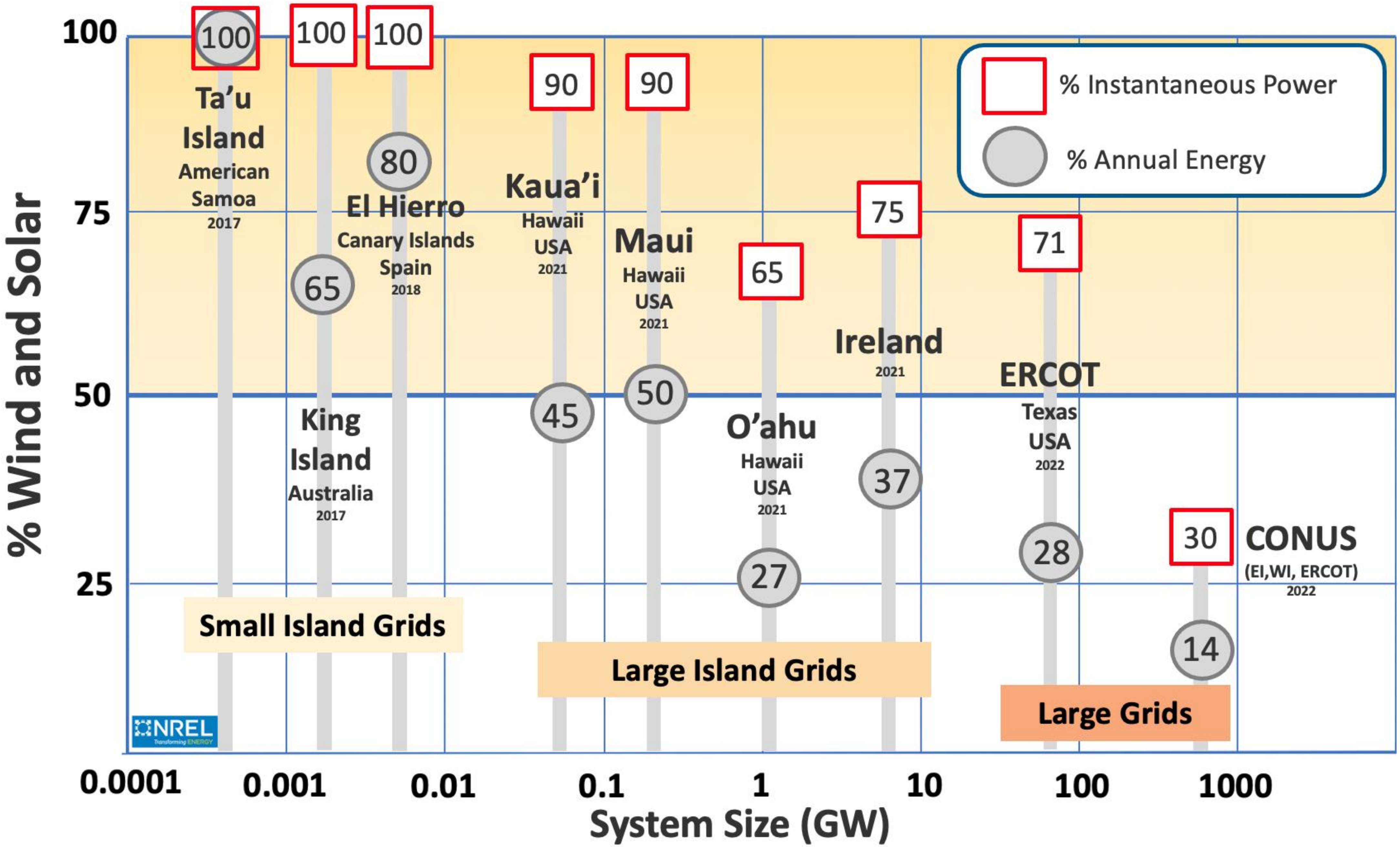
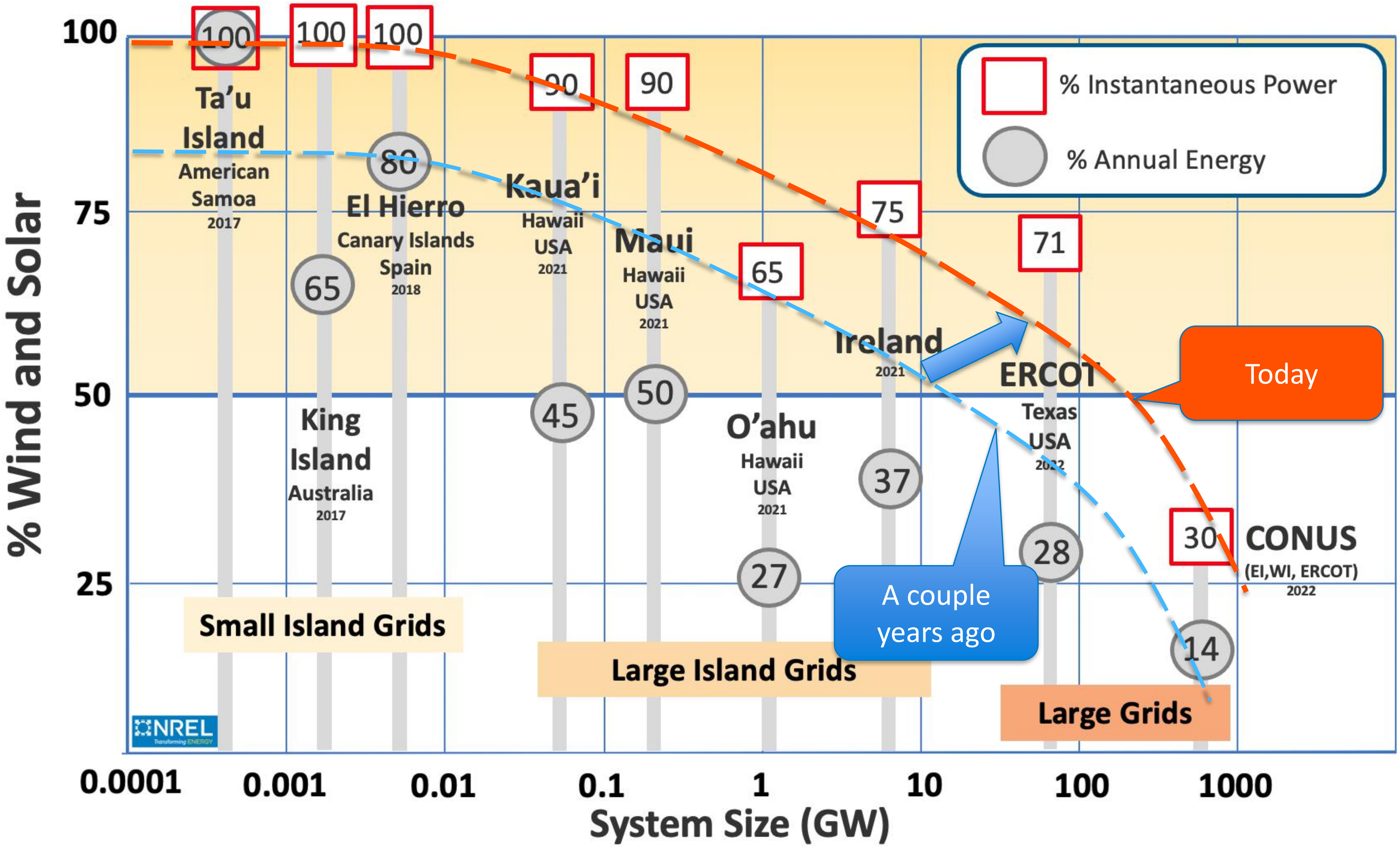
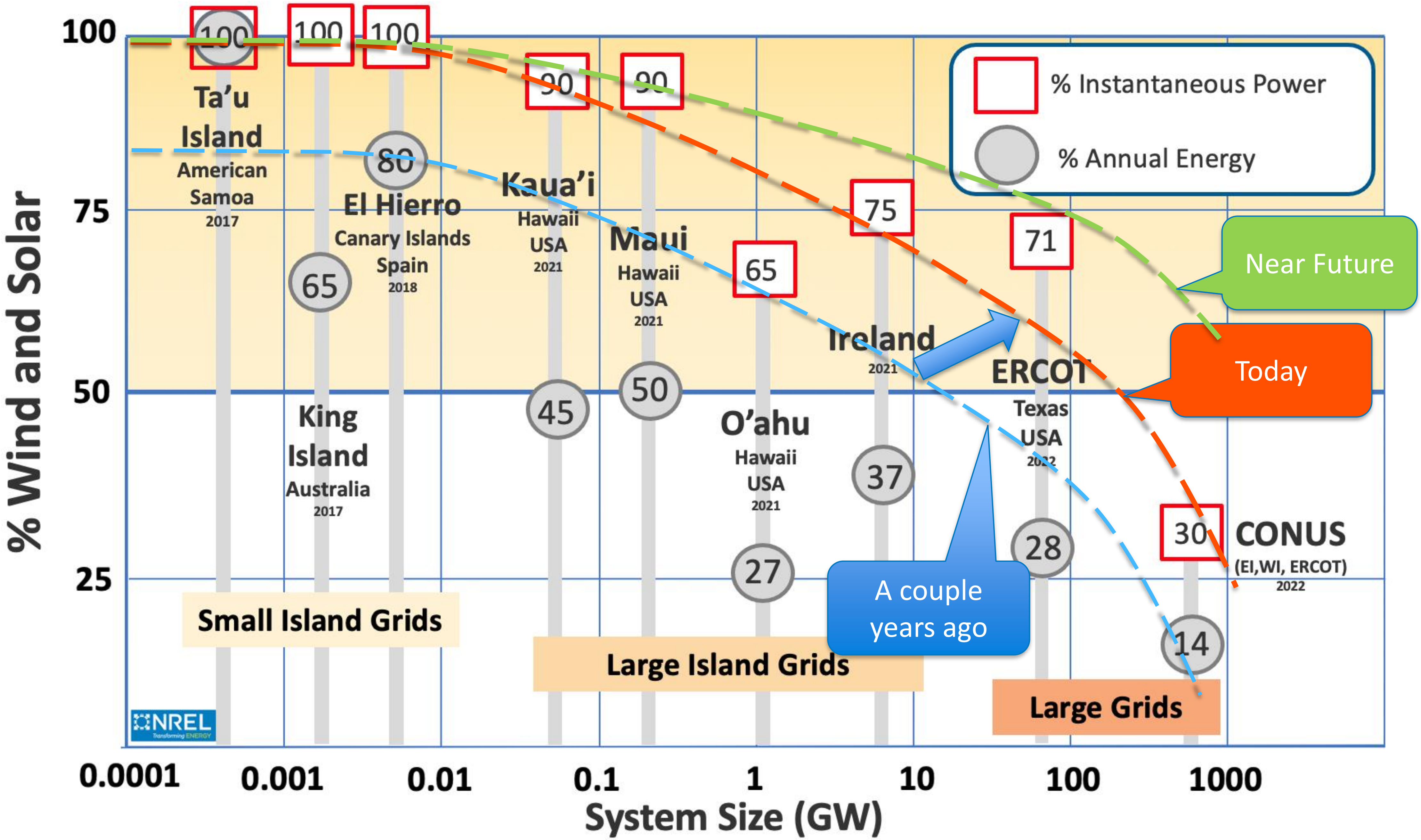
Source: GE Energy Consulting c.2005



Source: NREL UNIFI Consortium 2023



Source: NREL UNIFI Consortium 2023



Source: NREL UNIFI Consortium 2023

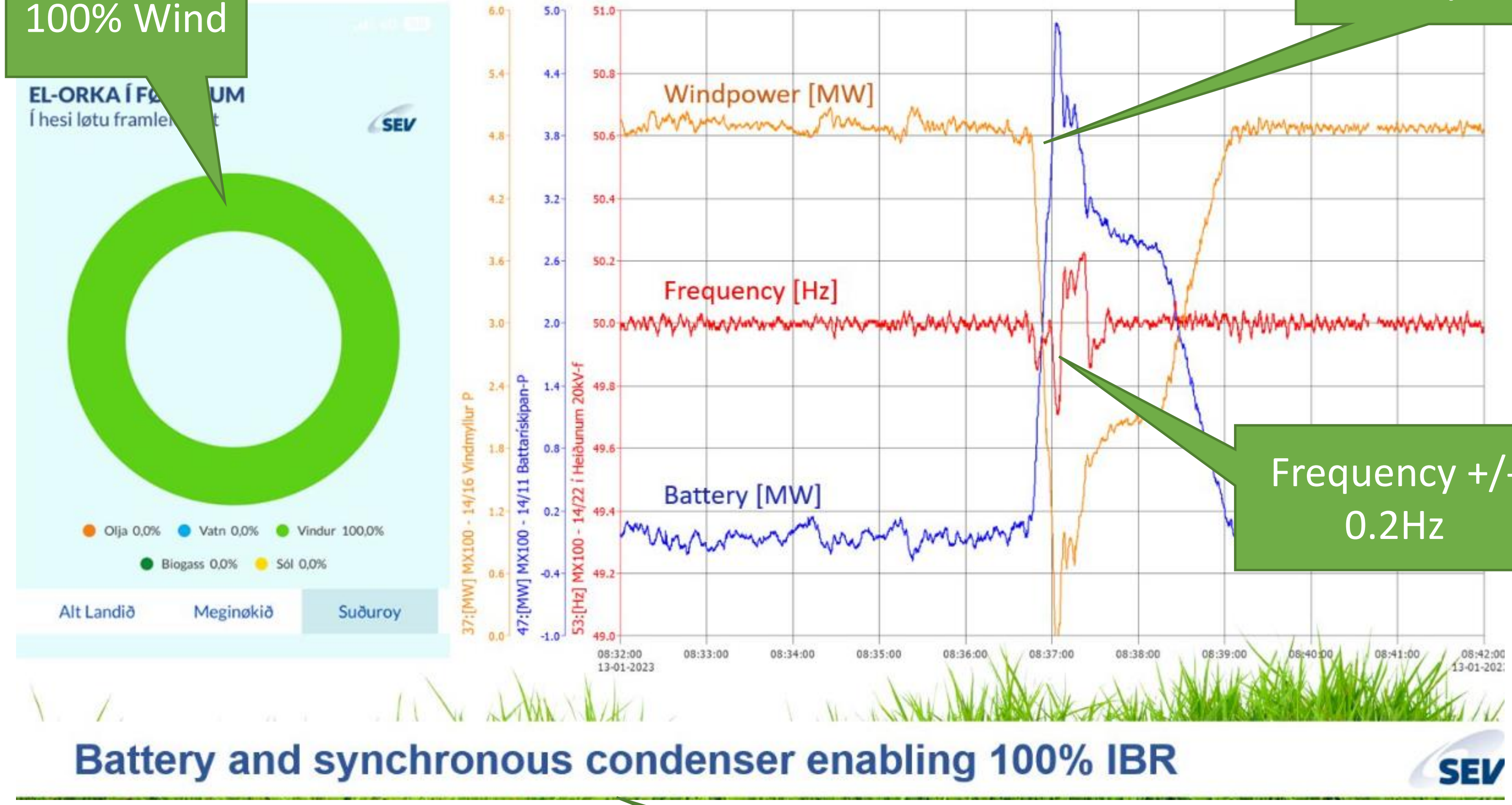
100% Wind: 1/13/23 event

SEV Faroe Islands: 50% annual VER in 2023; 100% by 2030

100% Wind

Wind cutout; Battery fills in

Frequency +/- 0.2Hz



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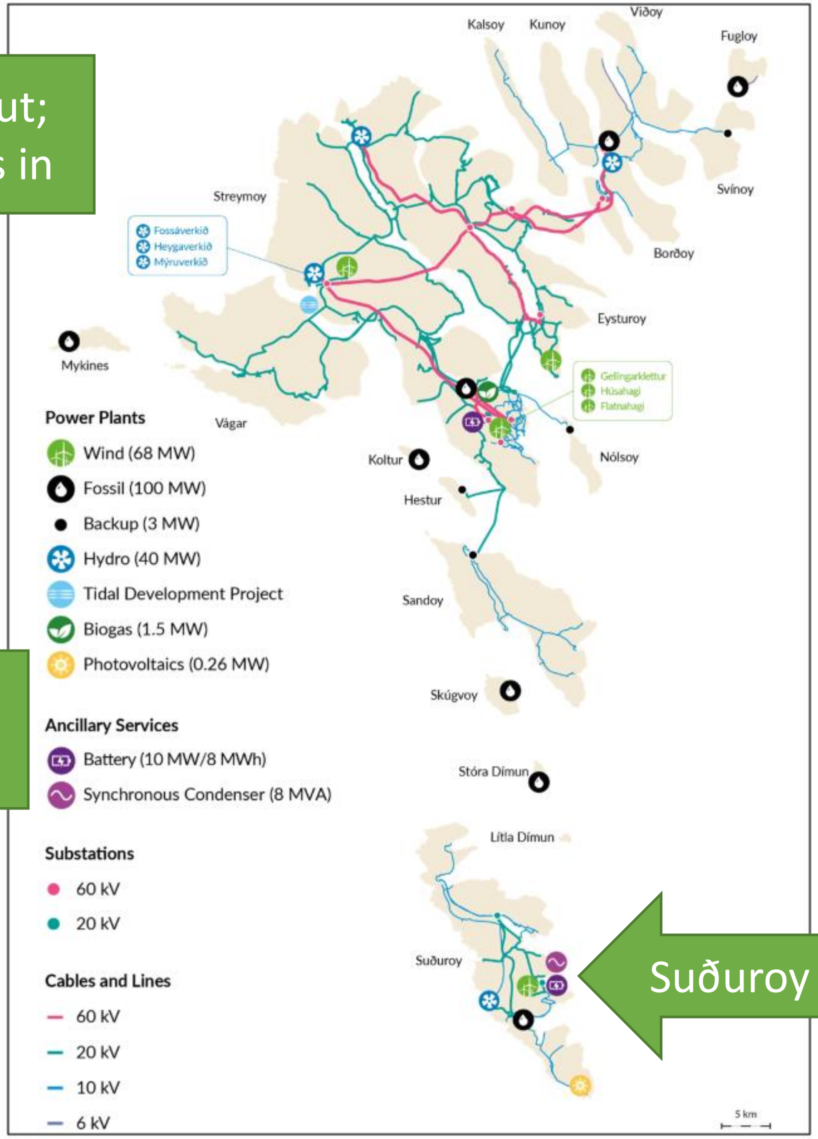


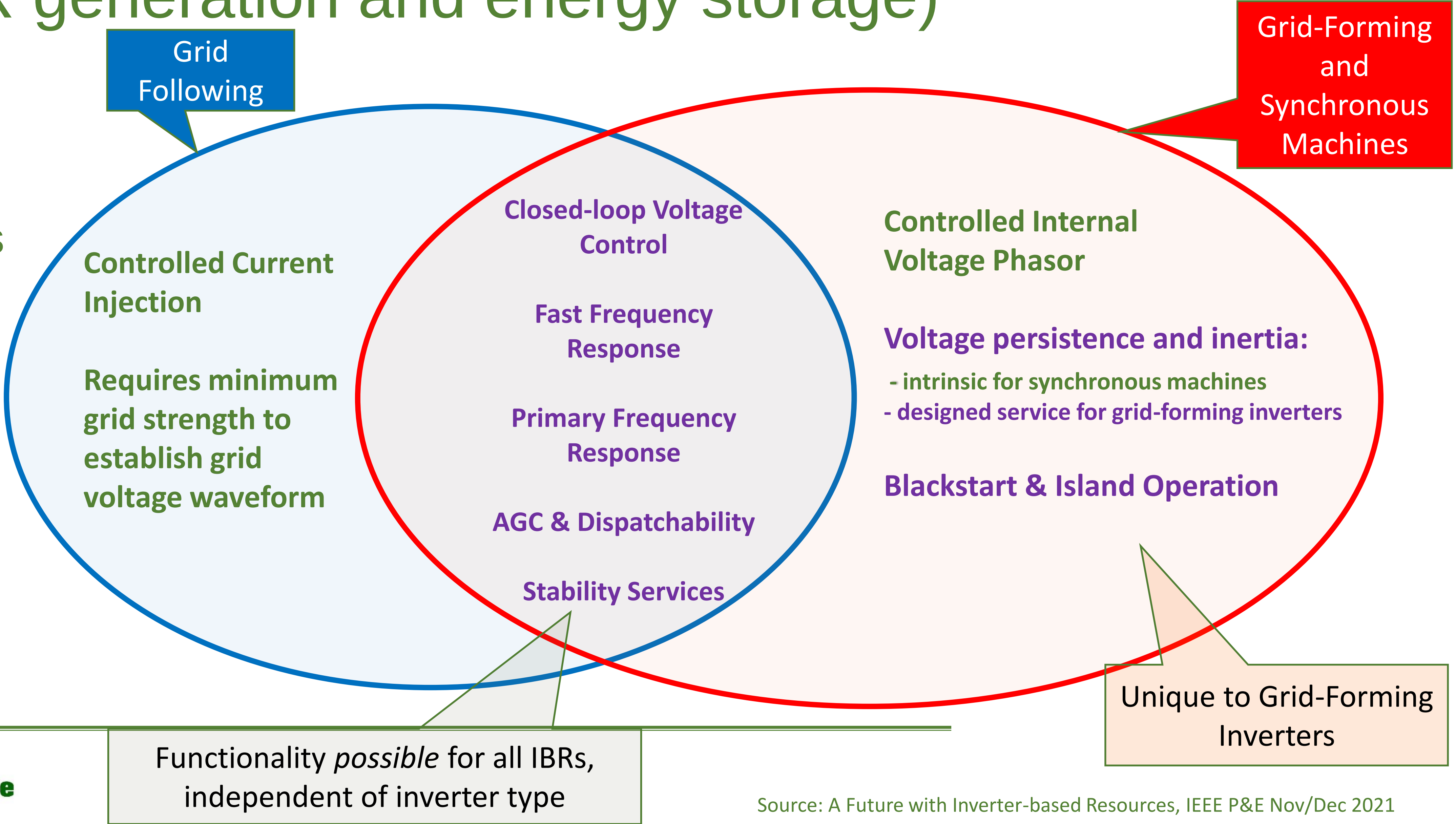
Suðuroy

HickoryLedge

Source: Terji Nielsen, SEV Faroe Islands.

Inverter Functionality (for IBR generation and energy storage)

- Grid Forming vs Grid Following
- Basic Trait vs Grid Service



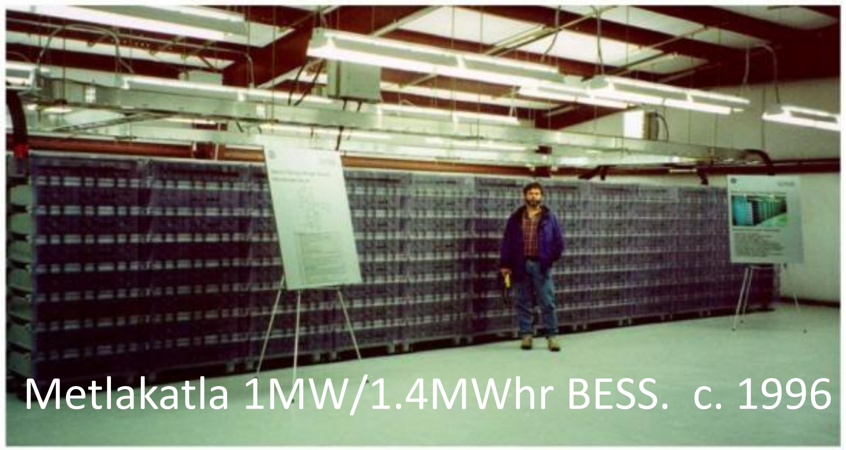
HickoryLedge

Source: A Future with Inverter-based Resources, IEEE P&E Nov/Dec 2021

Are we ready to require GFM?

Yes & No

- We're years from IEEE Stds.
- We can't wait.
- UNIFI GFM specs (and other international experience) hugely reduces uncertainty
- <u>Utility scale batteries today</u>


Metlakatla 1MW/1.4MWhr BESS. c. 1996

https://www.esig.energy/capturing-the-benefits-of-grid-forming-batteries-a-unique-window-of-opportunity/

Thanks

nicholas.miller@hickoryledge.com

Reliability Perspective

Reliability

Ryan Quint

Director of Engineering and Security Integration

North American Electric Reliability Corporation (NERC)

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Reliability Perspectives

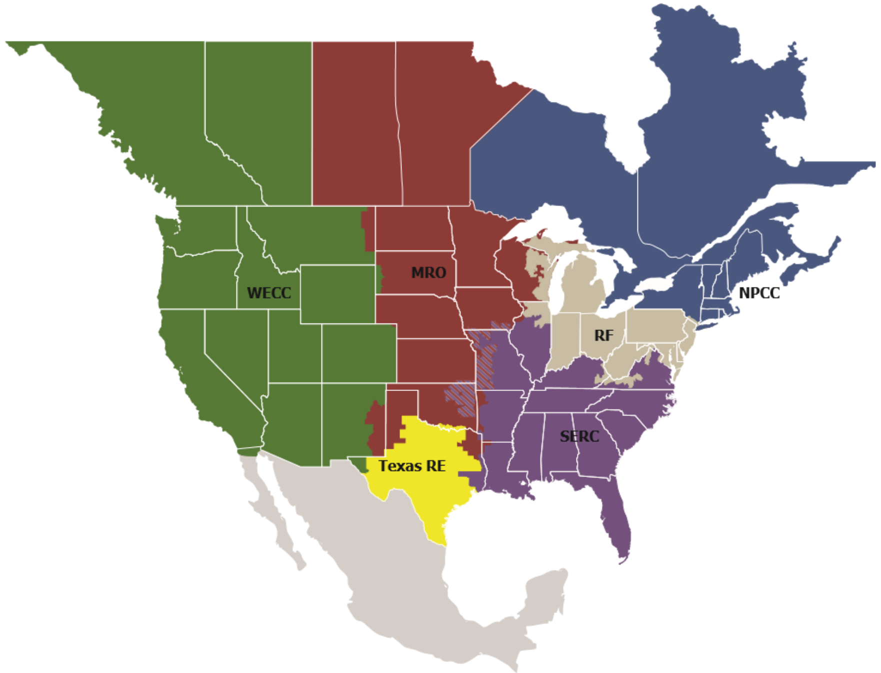
Rapid Integration of Increasing Levels of Inverter-Based Resources

Ryan D. Quint, PhD, PE
Director, Engineering and Security Integration
North American Electric Reliability Corporation
SRP IBR Technical Working Session
February 2023

RELIABILITY | RESILIENCE | SECURITY



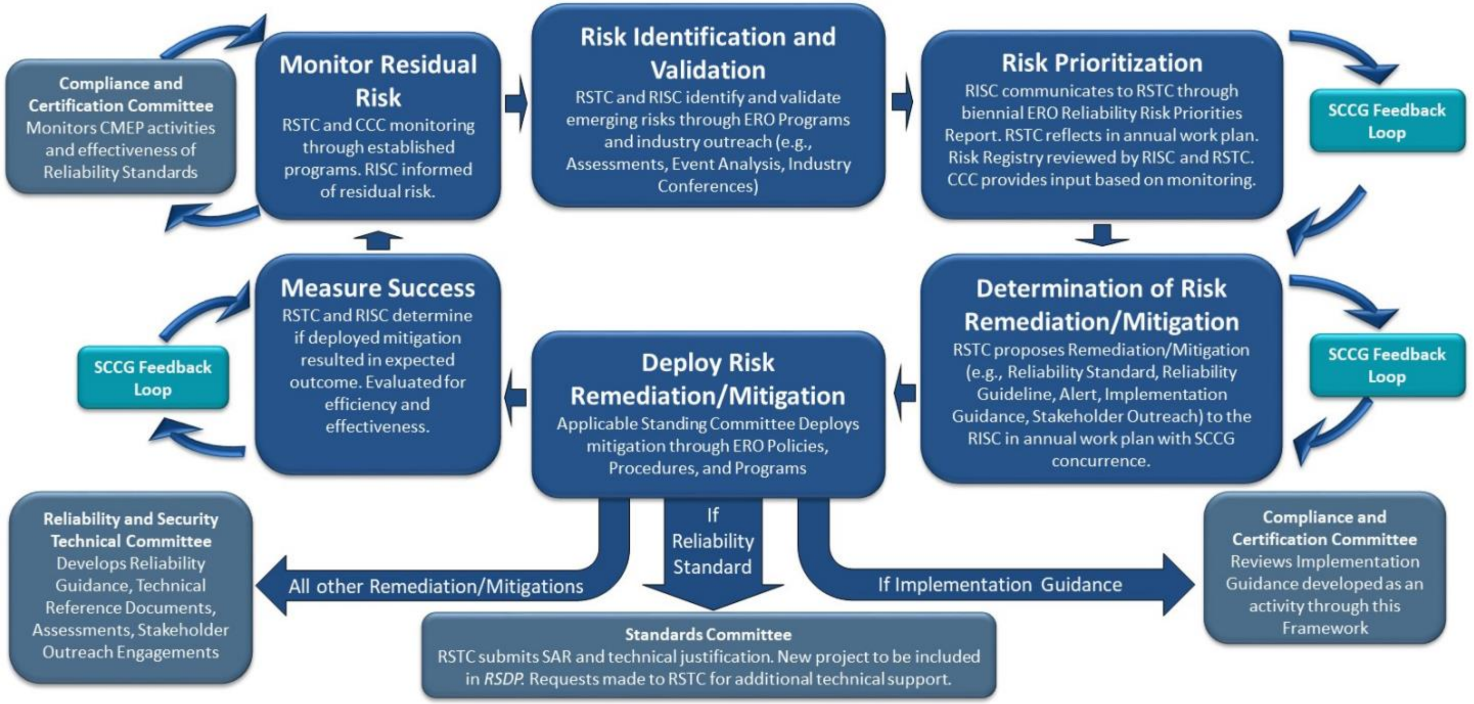

About NERC



- Not-for-profit international regulatory authority
- Mission to assure the effective and efficient reduction of risks to reliability and security of the grid.
  - Develops and enforces Reliability Standards
  - Annually assesses seasonal and long-term reliability
  - Monitors the bulk power system through system awareness
  - Educates, trains, and certifies industry personnel
- Designated Electric Reliability Organization (ERO) for North America, subject to oversight by the Federal Energy Regulatory Commission (FERC) and governmental authorities in Canada.
- Jurisdiction includes users, owners, and operators of the bulk power system, which serves nearly 400 million people.

ERO Work Priorities

ERO Risk Management Framework



2021 ERO Reliability Risk Priorities Report

Risk Mitigation Toolbox:

- ERO Reports and Assessments
- Standard Authorization Requests
- Reliability and Security Guidelines
- Compliance Implementation Guidance
- Technical Reference Documents
- Technical Reports
- White Papers
- Lessons Learned
- Alerts
- Industry Outreach and Engagement
- Etc.

NERC IBR Strategy

Risk Analysis	Interconnection Process Improvements	Best Practices and Education	Regulatory Enhancements
Event Analysis	Improvements to GIAs and GIP	Reliability Guidelines	NERC Standards Projects
Disturbance Reports	Enhanced Interconnection Requirements	Webinars and Workshops	BES Definition Review
Alerts	Modeling and Study Improvements	Outreach and Engagement	Inverter-Specific Requirements and Standards
Lessons Learned	IEEE 2800-2022	Emerging Reliability Risk Issues	Risk-Based Compliance

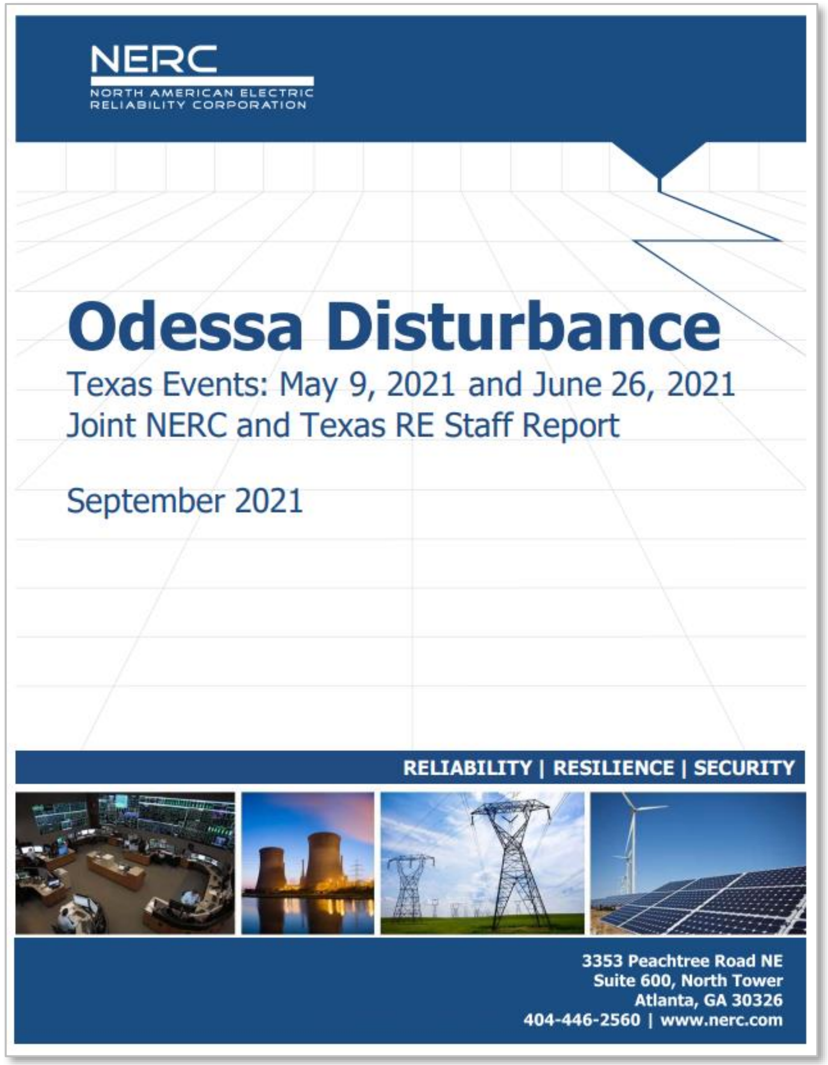
NERC IBR Strategy

NERC Disturbance Reports

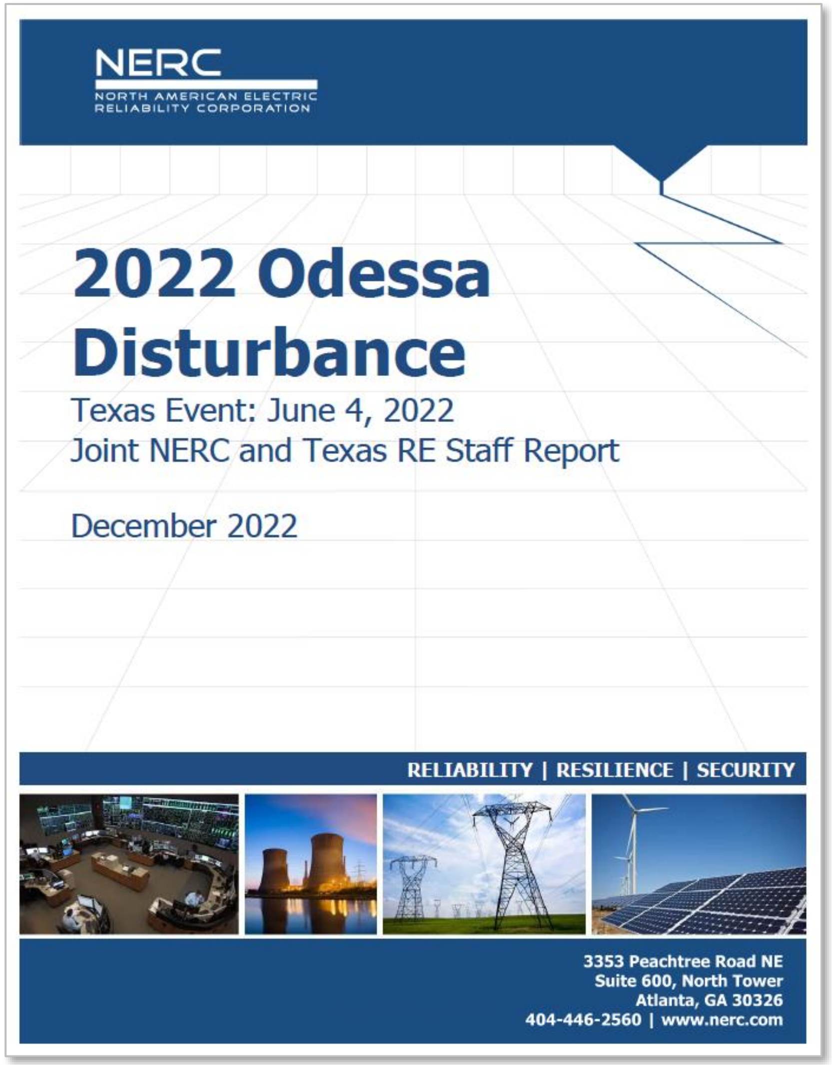
Planned Upcoming Reports:
- BESS-Related Events in California in 2022

https://www.nerc.com/pa/rrm/ea/Pages/Major-Event-Reports.aspx

Odessa Disturbance Reports

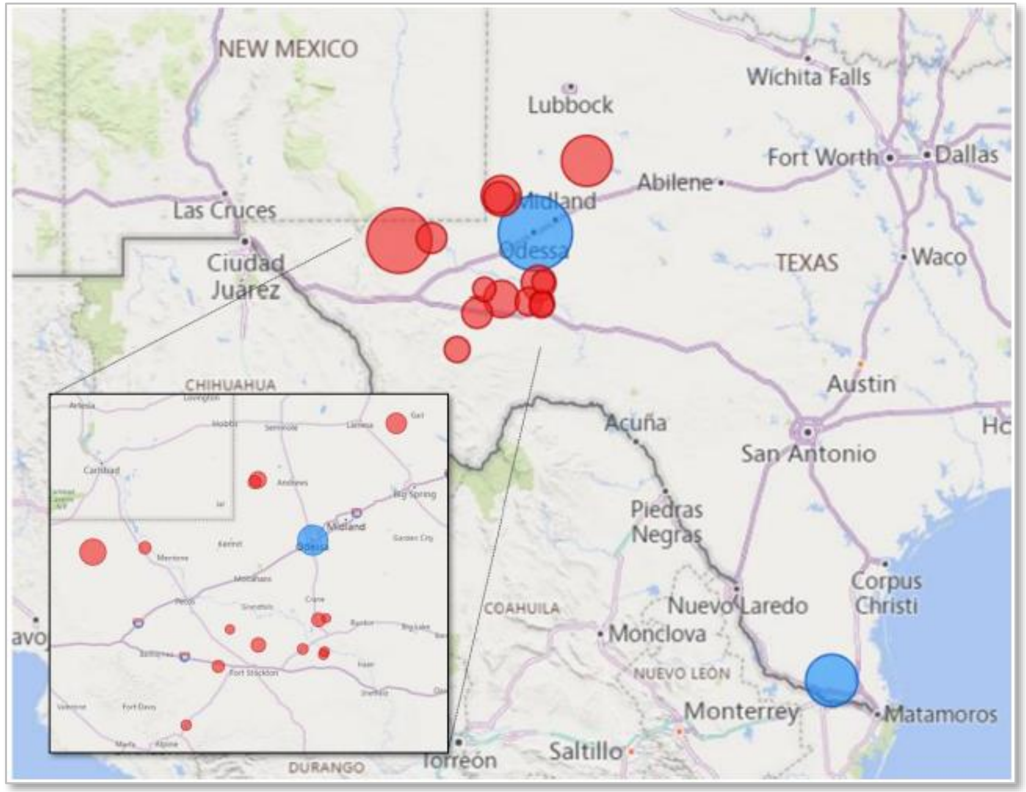


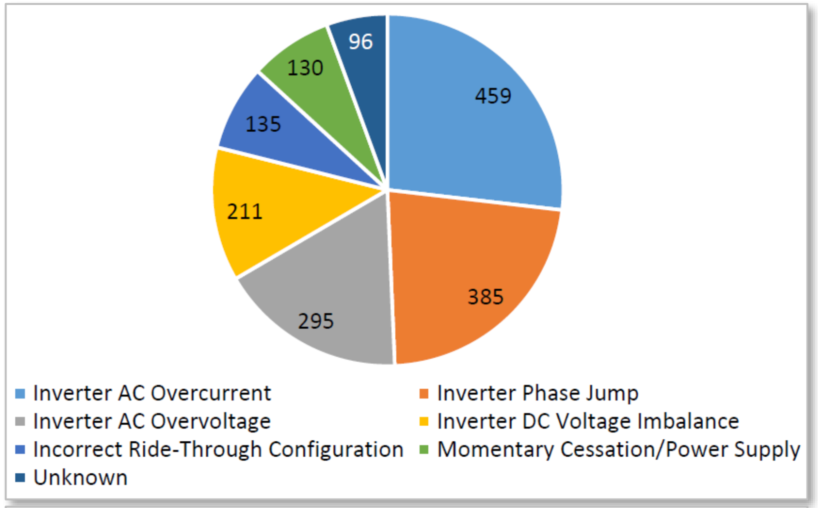
https://www.nerc.com/pa/rrm/ea/Documents/Odessa_Disturbance_Report.pdf

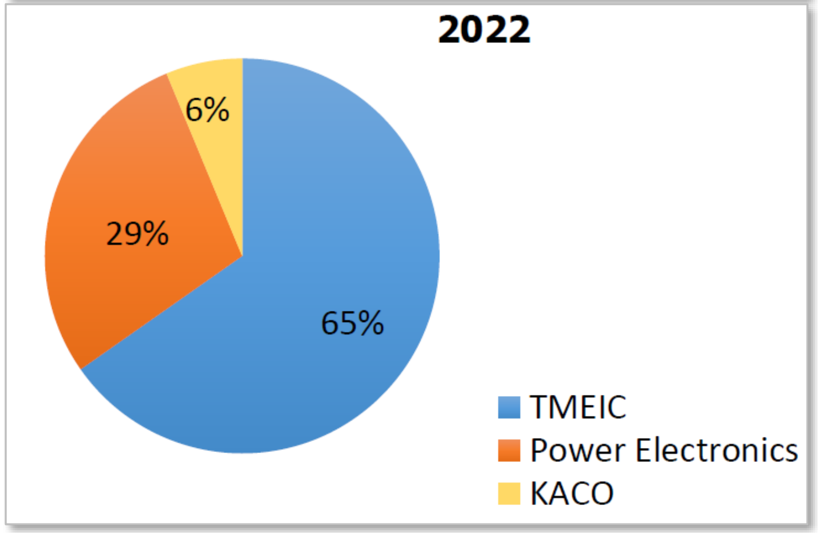


https://www.nerc.com/comm/RSTC_Reliability_Guidelines/NERC_2022_Odessa_Disturbance_Report%20(1).pdf

2022 Odessa Disturbance Details







Cause of Solar PV Reduction

Table 1.1: Causes of Solar PV Active Power Reductions

Cause of Reduction	Odessa 2021 Reduction [MW]	Odessa 2022 Reduction [MW]
Inverter Instantaneous AC Overcurrent	–	459
Passive Anti-Islanding (Phase Jump)	–	385
Inverter Instantaneous AC Overvoltage	269	295
Inverter DC Bus Voltage Unbalance	–	211
Feeder Underfrequency	21	148*
Unknown/Misc.	51	96
Incorrect Ride-Through Configuration	–	135
Plant Controller Interactions	–	146
Momentary Cessation	153	130**
Inverter Overfrequency	–	–
PLL Loss of Synchronism	389	–
Feeder AC Overvoltage	147	–
Inverter Underfrequency	48	–
Not Analyzed	34	–

* In addition to inverter-level tripping (not included in total tripping calculation.)
** Power supply failure

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Review of Affected Solar Plants

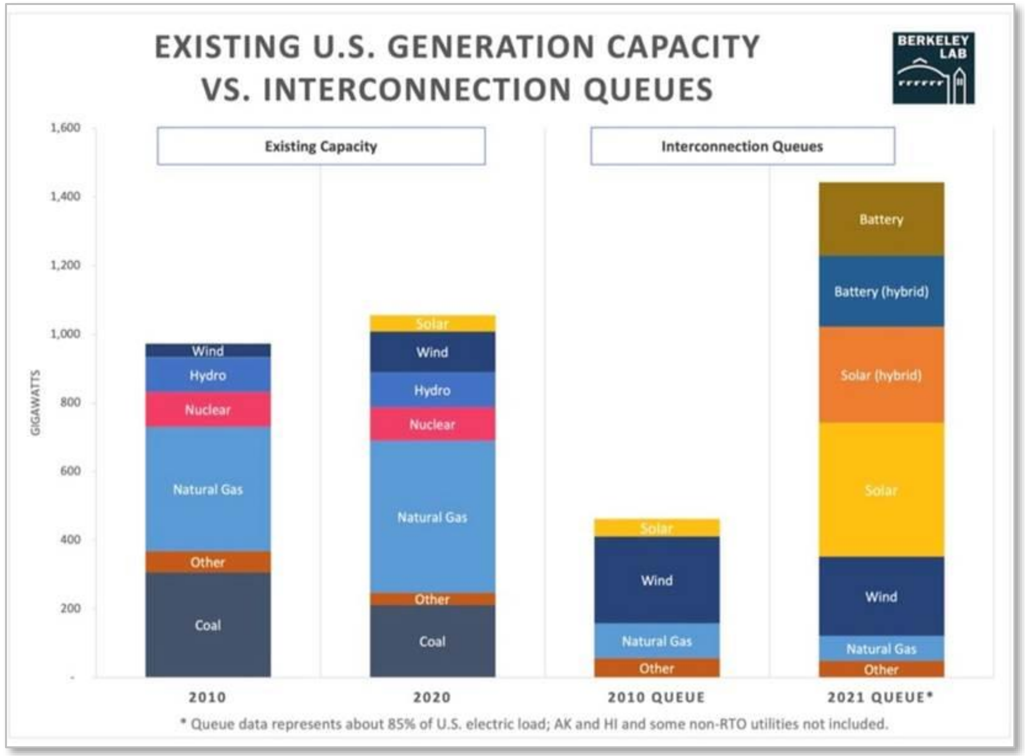
Table A.1: Review of Solar PV Facilities

Facility ID	Capacity [MW]	Reduction [MW]	POI Voltage [kV]	In-Service Date	Cause of Reduction
Plant B	152	133	138	June 2020	Inverter phase jump (passive anti-islanding) tripping.
Plant C	126	56	345	November 2020	Inverter phase jump (passive anti-islanding) tripping.
Plant E	162	159	138	May 2021	Inverter ac overvoltage tripping.
Plant U	143.5	136	138	August 2021	Inverter ac overvoltage tripping; feeder underfrequency tripping.
Plant F	50	46	69	September 2017	Unknown.
Plants I & J	304	196	345	June 2020	Inverter phase jump (passive anti-islanding) tripping.
Plant V	253	106	345	July 2021	Inverter dc voltage imbalance tripping.
Plants K & L	157.5	130	138	September 2016	Momentary cessation/inverter power supply failure.
Plant M	155	146	138	March 2018	Inverter dc voltage imbalance tripping; incorrect inverter ride through configuration.
Plant N	110	35	138	March 2017	Unknown.
Plant O	50	15	138	November 2016	Unknown.
Plant P	157.5	10	138	August 2017	Inverter ac overcurrent tripping.
Plant Q	255	12	138	December 2020	Inverter ac overcurrent tripping.
Plant R	268	261	138	June 2021	Inverter ac overcurrent tripping.
Plant S	100	94	138	December 2019	Inverter dc voltage imbalance tripping.
Plant T	187	176	138	September 2021	Inverter ac overcurrent tripping; feeder underfrequency tripping.
TOTAL		1,711			

* Naming convention of facilities is a continuation of the 2021 Odessa Disturbance; therefore, plant numbering is not necessarily alphanumeric but does match the labeling used in the 2021 Odessa Disturbance.

* Denotes plants that went into commercial operation in late 2020 onward

Rapidly Growing Solar PV Portfolio



Source: LBNL

ERCOT Interconnection Queue for ~~2021~~ 2022 Odessa Events:

- **Time of Event:** ~~7,200~~ 8,660 MW solar PV resources in ERCOT
  - Additional ~~790~~ 3,010 MW in commissioning process
- **Near Future:** ~~25,000~~ 28,850 MW solar PV resources with signed interconnection agreements in ERCOT generation interconnection queue between now and 2023

NERC Standards Under Development

Inverter-Based Resource Performance Enhancements:

- Project 2021-04 Modifications to PRC-002-2
- Project 2020-02 Modifications to PRC-024 (Generator Ride-Through)
- Project 2020-06 Verification of Models and Data for Generators
- Project 2021-01 Modifications to MOD-025 and PRC-019
- Project 2022-04 EMT Modeling
- Project 2021-02 Modification to VAR-002
- (Upcoming Project) Updates to EOP-004
- (Upcoming Project) IBR Performance Issues
- (FERC NOPR) Future IBR Projects…

Recommended Practices and Industry Guidance

IBR Risk Issues

- Poor IBR modeling during interconnection process
- Lack of adequate studies during interconnection process
- Poor and disparate interconnection requirements
- Lack of industry-wide performance standards
- Poor IBR commissioning practices
- IBR ride-through performance failures
- Pace of interconnection with insufficient reliability studies
- Complacency regarding need for emerging technologies
- Energy sufficiency and energy security risks
- Lack of industry resourcing, expertise, and knowledge

DO NOT DISCREDIT THE CRITICALITY OF EACH AND EVERY ONE OF THESE BULLETS

Market Operations Perspective

Market Operations

Guillermo Alderete Bautista

Director, Market Analysis & Forecasting
California ISO (CAISO)

Inverter-Based Resources
Market Operations Perspective

Guillermo Bautista Alderete, Ph.D.
Director, Market Analysis and Forecasting
California ISO Corporation

February 2023

California ISO

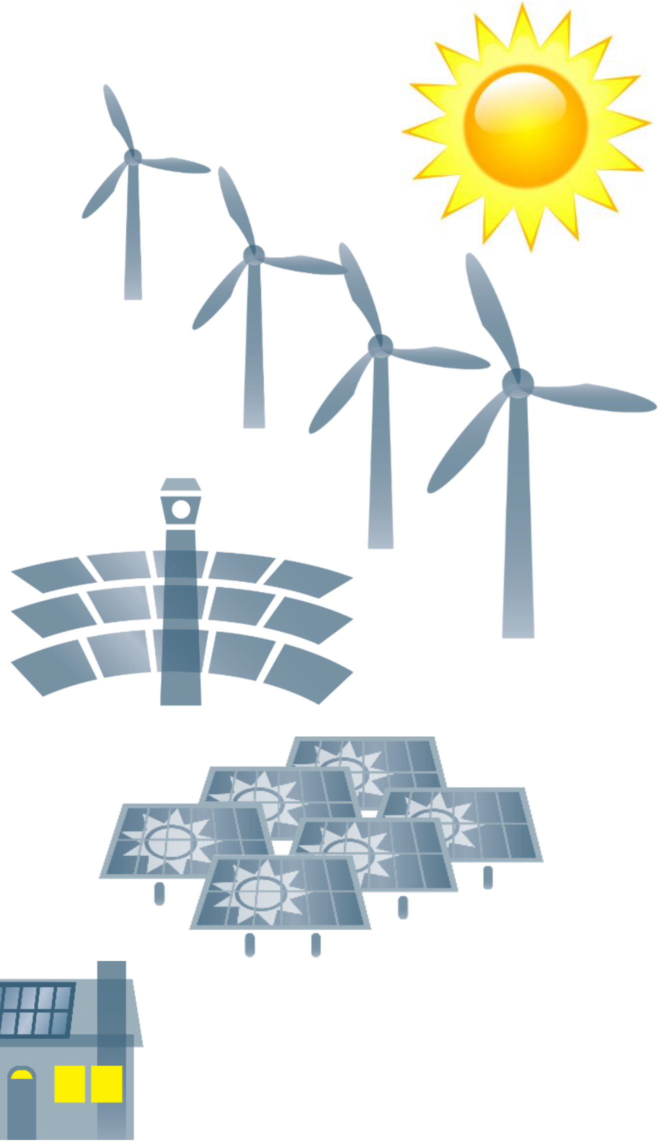
- **Nonprofit** public benefit corporation
- Part of Western Electricity Coordinating Council
- Uses advanced technology to balance supply and demand every 4 seconds
- Operate markets for wholesale electricity and reserves
- Manage new power plant interconnections and grid expansions
- Energy Imbalance Market covers 10 Western States and British Columbia with $3.4 Billion of economic benefit so far

Renewable goals are setting the pace in multiple markets. CAISO case:

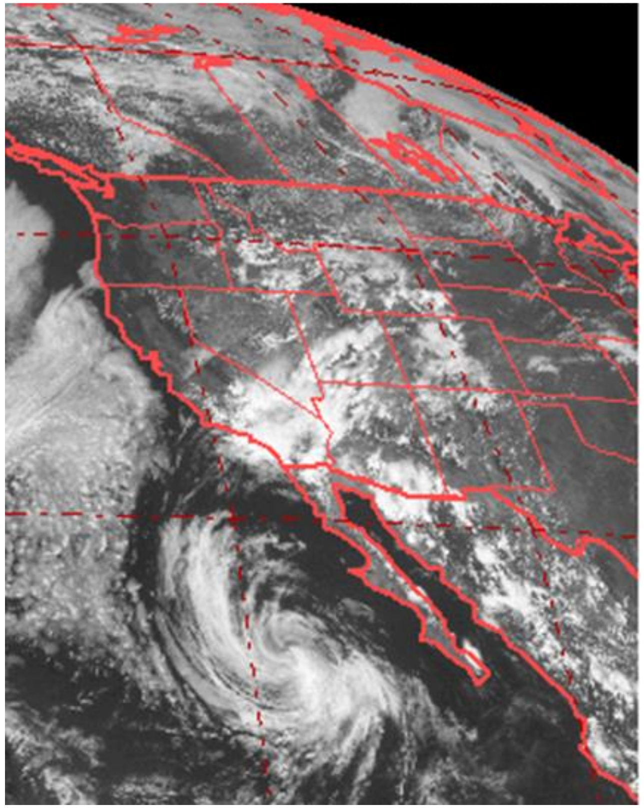
- Currently Installed:
  - 15,000 MW of utility-scale solar
  - 7,000 MW of wind
  - 11,000 MW of consumer rooftop solar

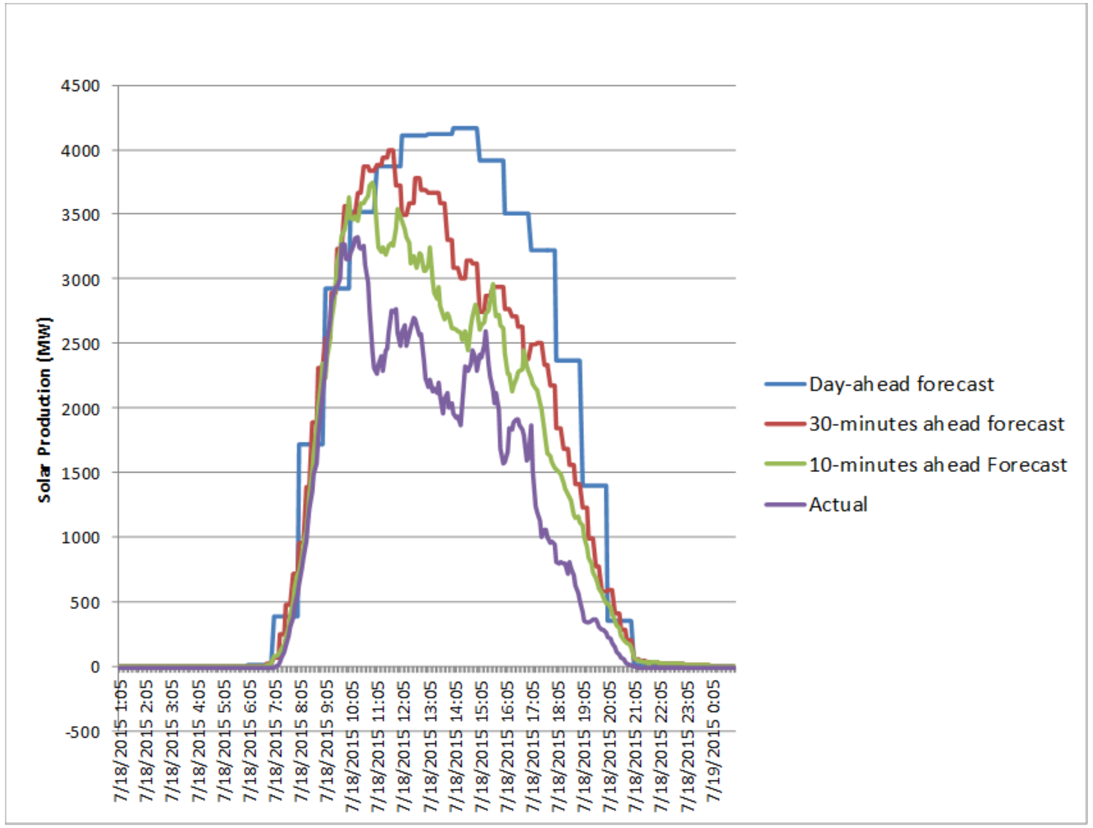
- Additional renewables:
  - 4,000+ MW additional utility-scale renewables by 2026
  - ~16,750 MW of consumer rooftop solar by 2026

- Projected 5000+ MW of storage and hybrid resources

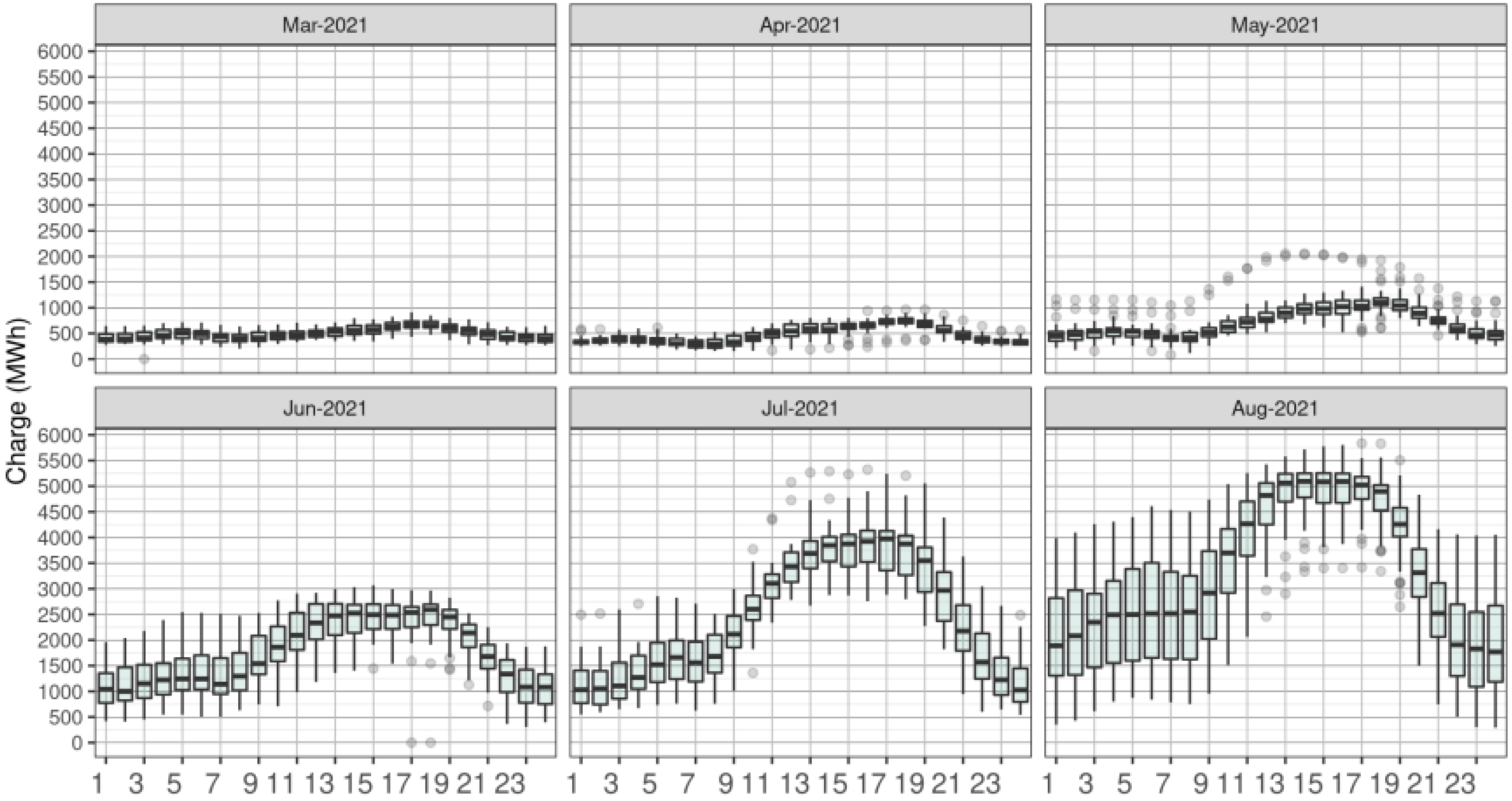


Variability poses a great forecasting challenge which results in uncertainty in market and systems operations





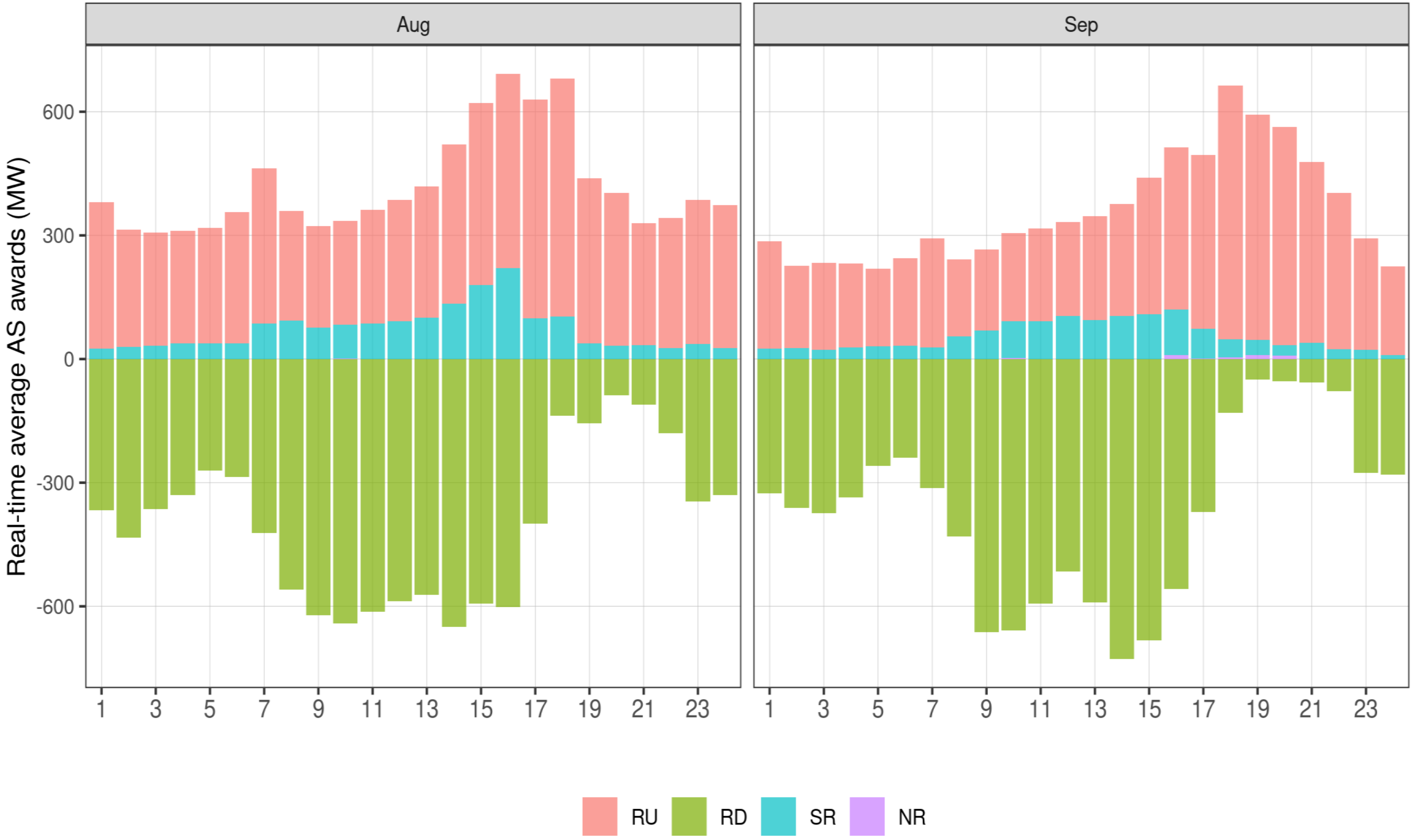
The advancement of new technology is changing the markets landscape. The case of explosive growth of storage resource:



A suite of solutions are necessary

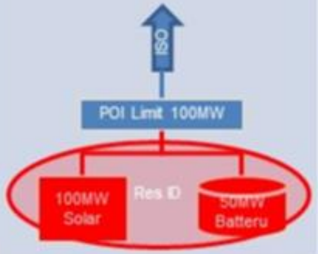
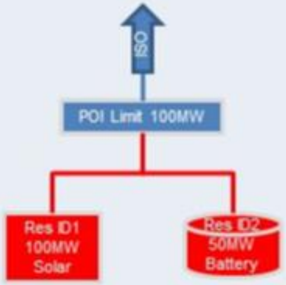
Storage – increase the effective participation by energy storage resources.	**Western EIM expansion** – expand the western Energy Imbalance Market.
Demand response – enable adjustments in consumer demand, both up and down, when warranted by grid conditions.	**Regional coordination** – offers more diversified set of clean energy resources through a cost effective and reliable regional market.
Time-of-use rates – implement time-of-use rates that match consumption with efficient use of clean energy supplies.	**Electric vehicles** – incorporate electric vehicle charging systems that are responsive to changing grid conditions.
Renewable portfolio diversity – explore procurement strategies to achieve a more diverse renewable portfolio.	**Flexible resources** – invest in fast-responding resources that can follow sudden increases and decreases in demand.

Integration of storage resources has changed the dynamic of the regulation market



Rapid growth in storage technologies require enhanced market design to support market participation

- Expected to have 5,000 MW of renewable + storage by 2024
- Use-limited batteries required complex models
- Advanced forecasting techniques needed to consider the type of configuration

Hybrid vs. Co-located	Definition	Forecasting / Dispatch
Hybrid 	A Generating Unit, with a unique Resource ID at a single Point of Interconnection, with components that use different fuel sources or technologies.	• No aggregate forecast for hybrid • Hybrid expected to follow dispatch
Co-located 	A Generating Unit with a unique Resource ID that is part of a Generating Facility with other Generating	• VER component will be forecast • VER dispatched rules • Battery will dispatched and state of charge managed

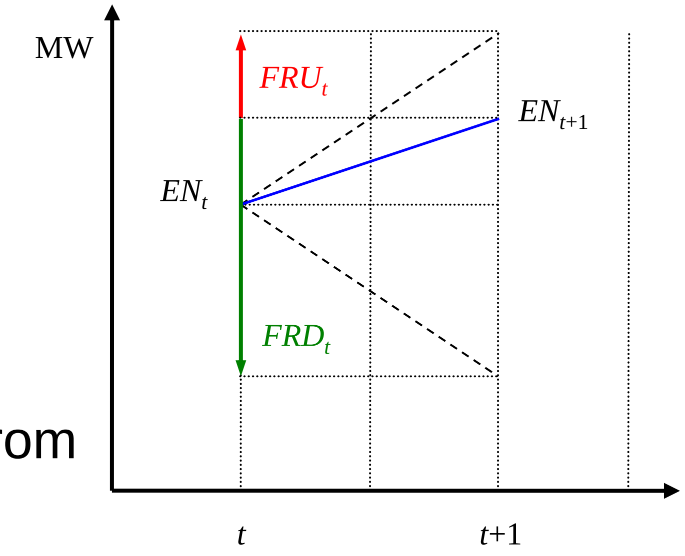
Markets Operations need to internalize the complexities of inverter-based resources

- Renewable forecasts are generated and consumed every 5 minutes
- Renewable resources can economically bid
- Renewable resources are optimally dispatched in the market like any other type of generation resource
- Renewable resources receive and must follow operating instructions
- Storage resources can mitigate for oversupply conditions and minimize energy curtailments
- New flexible ramping product to handle uncertainty of renewable resources

Advancements to handle uncertainty in CAISO's market and system

New market products to handle uncertainty explicitly

- Secures ramping capability in the fifteen-minute market and real-time dispatch
- Accounts for upward and downward ramping needs
- Compensates resources who provide ramping and charges those that consume ramping capability
- Aligns cost allocation with those who benefit from additional ramping capability to meet net load uncertainty
- CAISO is working on implementing an imbalance reserve product for the day-ahead market



Renewable Dispatch Perspective

Renewable Dispatch

Mahesh Morjaria

EVP, Plant Operational Technology

Terabase Energy

terabase

Lessons Learned on IBR Dispatch

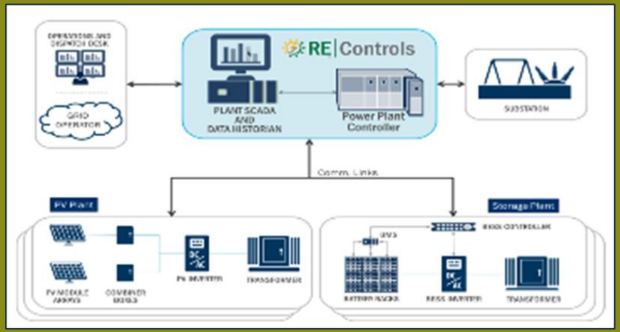
February 24, 2023

Mahesh Morjaria, Ph.D.
EVP, Plant Operational Technology
MMorjaria@Terabase.Energy

Lessons Learned on IBR Dispatch

Utility-scale PV Solar provides Clean Energy, **Essential Reliability Services & Flexibility**

Solar hybrid plants provide Clean & Competitive **Firm Capacity & Grid Enhancements**



Plant controls play a critical role in enabling these services

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Grid-Friendly IBR Plant

What are the key functions needed
to support grid stability and reliability?

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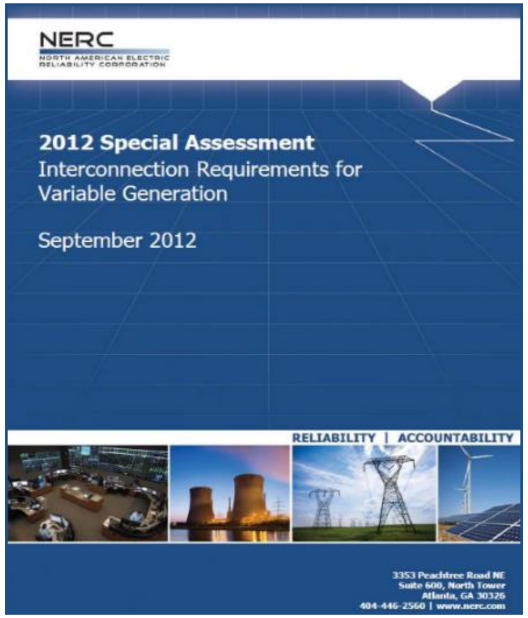
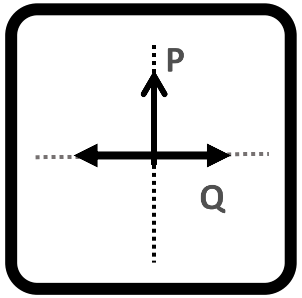
Key Capability of Grid-Friendly PV Plant



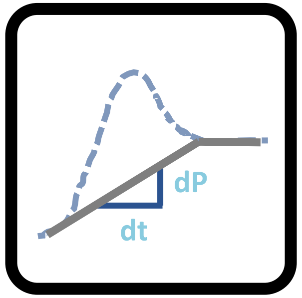
Features Required by NERC to be a Good Grid Citizen:

- Voltage regulation
- Active power control (ramping. curtailment)
- Grid disturbance ride through (voltage and frequency excursions)
- Primary frequency droop response
- Short circuit duty control

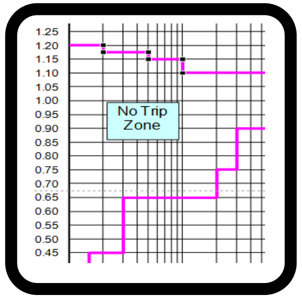
Voltage Support



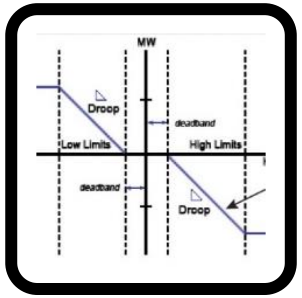
Power Control



Ride Through



Frequency Droop



Base Capability

Sources: (1) NERC: 2012 Special Assessment Interconnection Requirements for Variable Generation
(2) M. Morjaria, D. Anichkov, V. Chadliev, and S. Soni. “A Grid-Friendly Plant.” *IEEE Power and Energy Magazine* May/June (2014)

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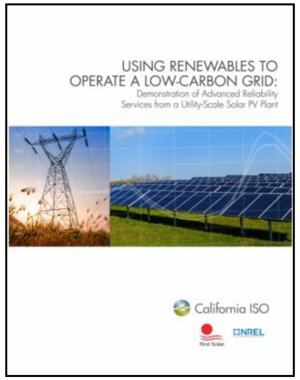
Solar Plant Provides Essential Reliability Services

NERC: Essential reliability services

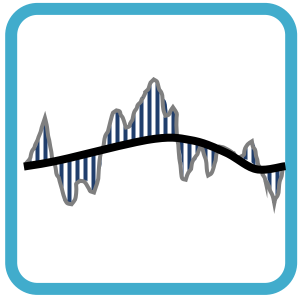
- Frequency Control
- Ramping capability or flexible capacity



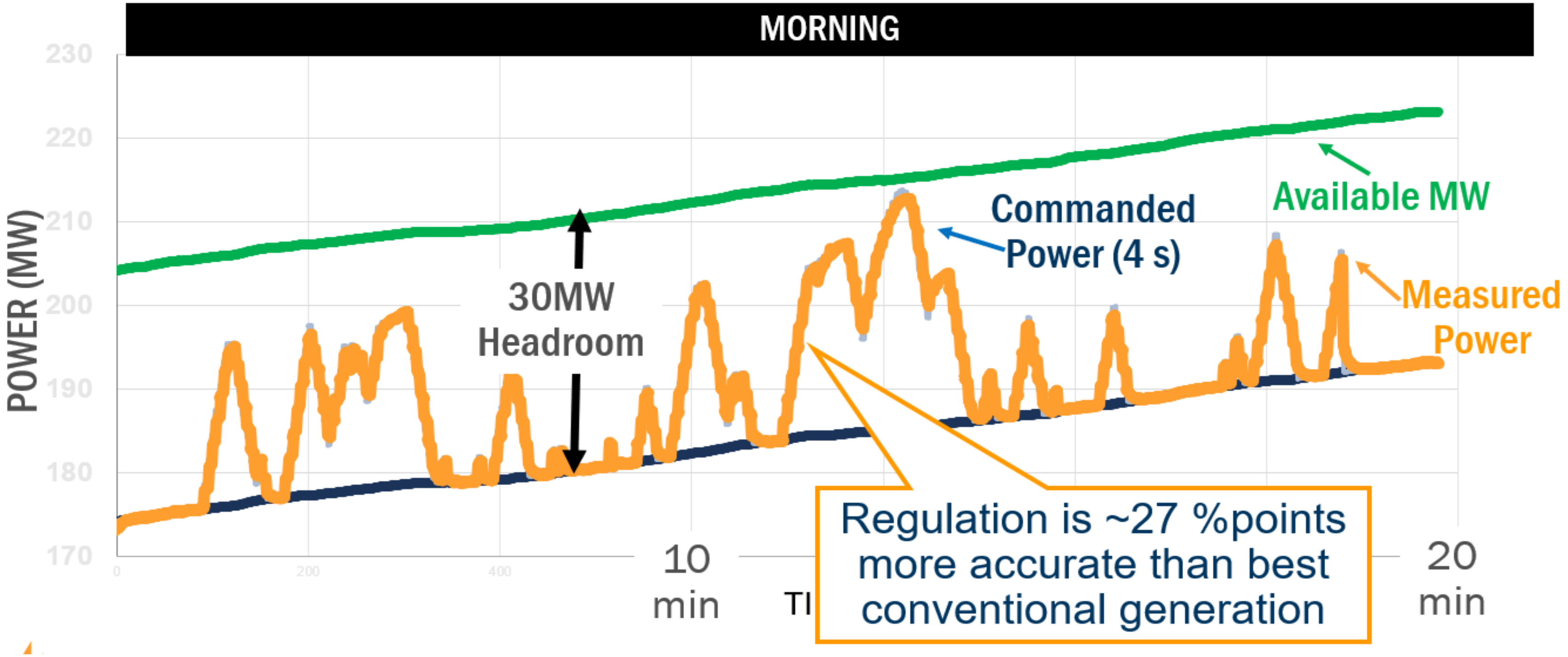
2018 Intersolar Outstanding Project Winner

2017 NARUC Award Winner

Power Regulation



- AGC
- Up-Regulation
- Down-Regulation
- Frequency Regulation
- Flexibility



Grid Reliability Services

Source: http://www.caiso.com/Documents/TestsShowRenewablePlantsCanBalanceLow-CarbonGrid.pdf.
AGC: Automated Generator Control

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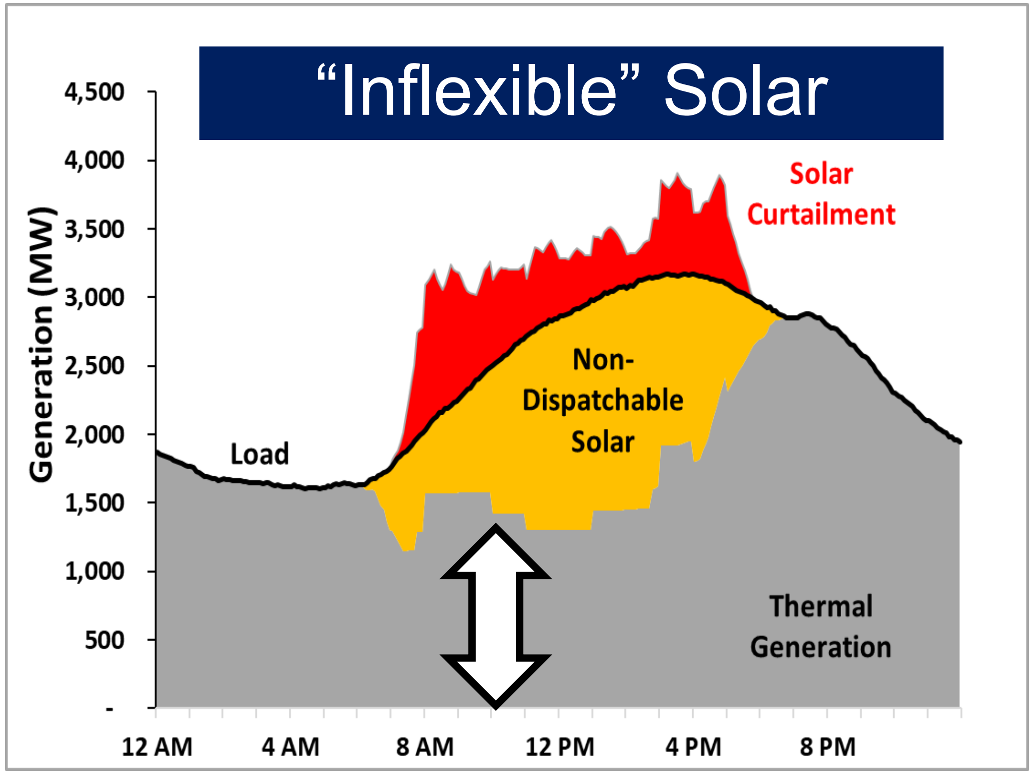
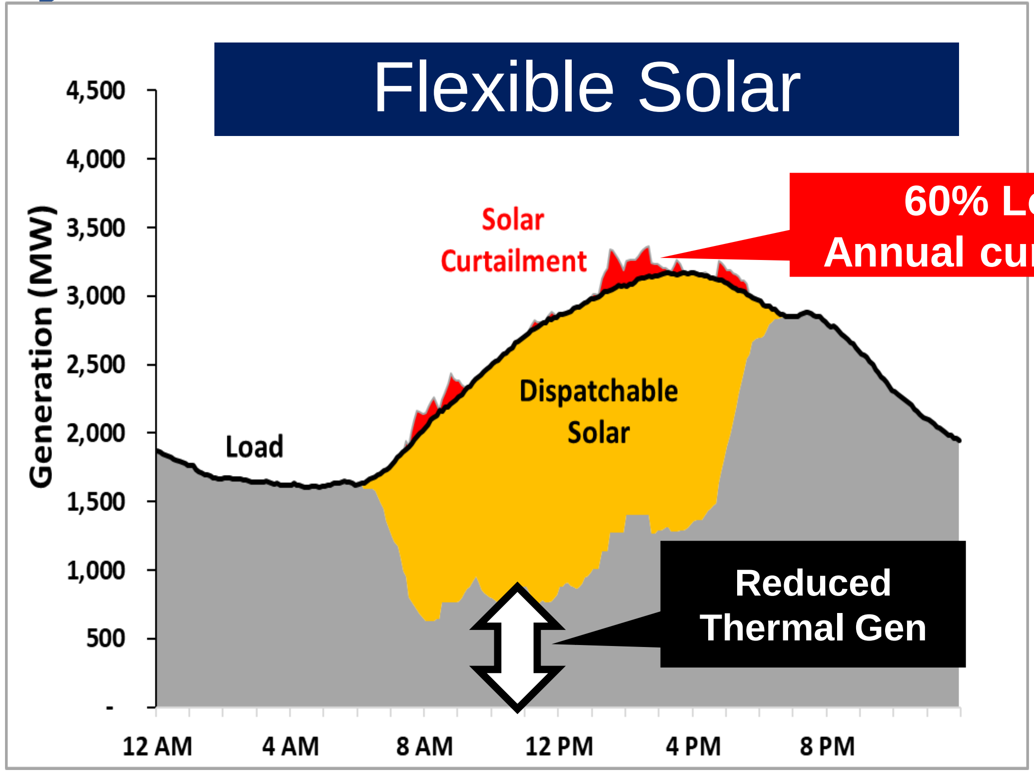
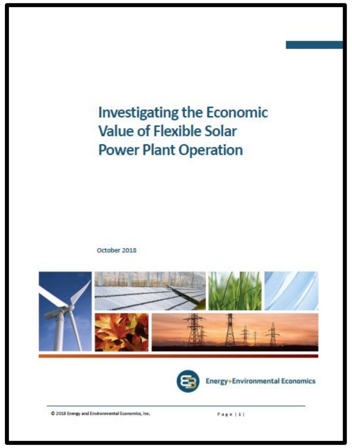
Solar Plant Provides Flexibility



Solar Provides No Regulation Reserves





Flexible Solar: Provides regulation reserves.

Source: E3,TECO, First Solar Report "Investigating the Economic Value of Flexible Solar Power Plant Operation", https://www.ethree.com/wp-content/uploads/2018/10/Investigating-the-Economic-Value-of-Flexible-Solar-Power-Plant-Operation.pdf
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TECO ENERGY AN EMERA COMPANY

Energy+Environmental Economics

First Solar.

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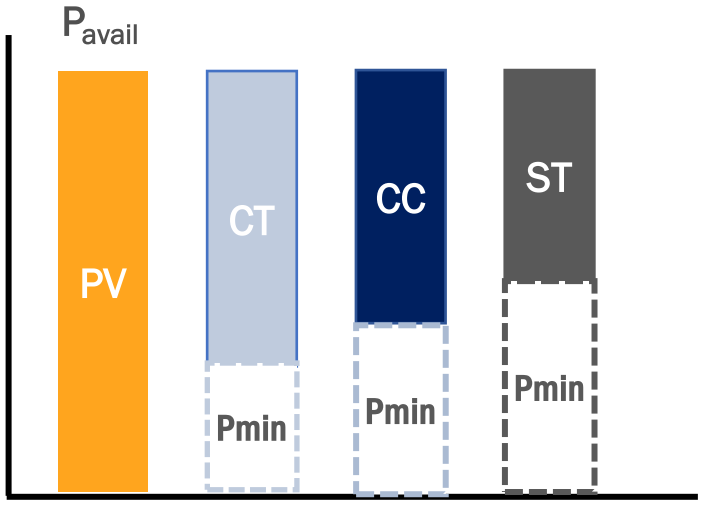
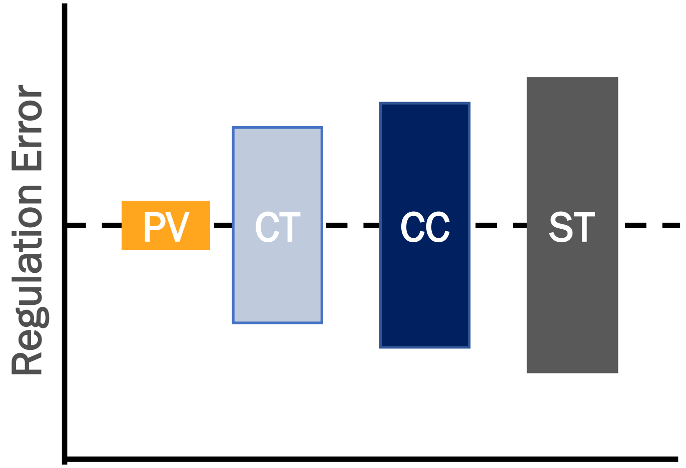
Flexibility: Key Resource Attribute of the Future Grid

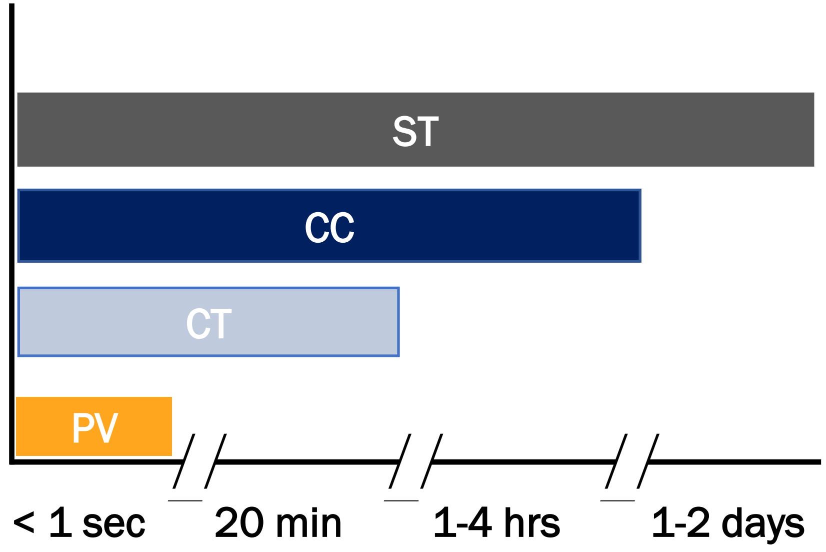
PV can operate flexibly from 0 to available power (P_{avail})



PV follows AGC (4-sec) signal with high accuracy



PV can start up in seconds (when solar resource is available)



CT Combustion Turbine

CC Combined Cycle

ST Steam Turbine

Utility-scale IBR Plant is more flexible and responsive than today's fossil fleet:

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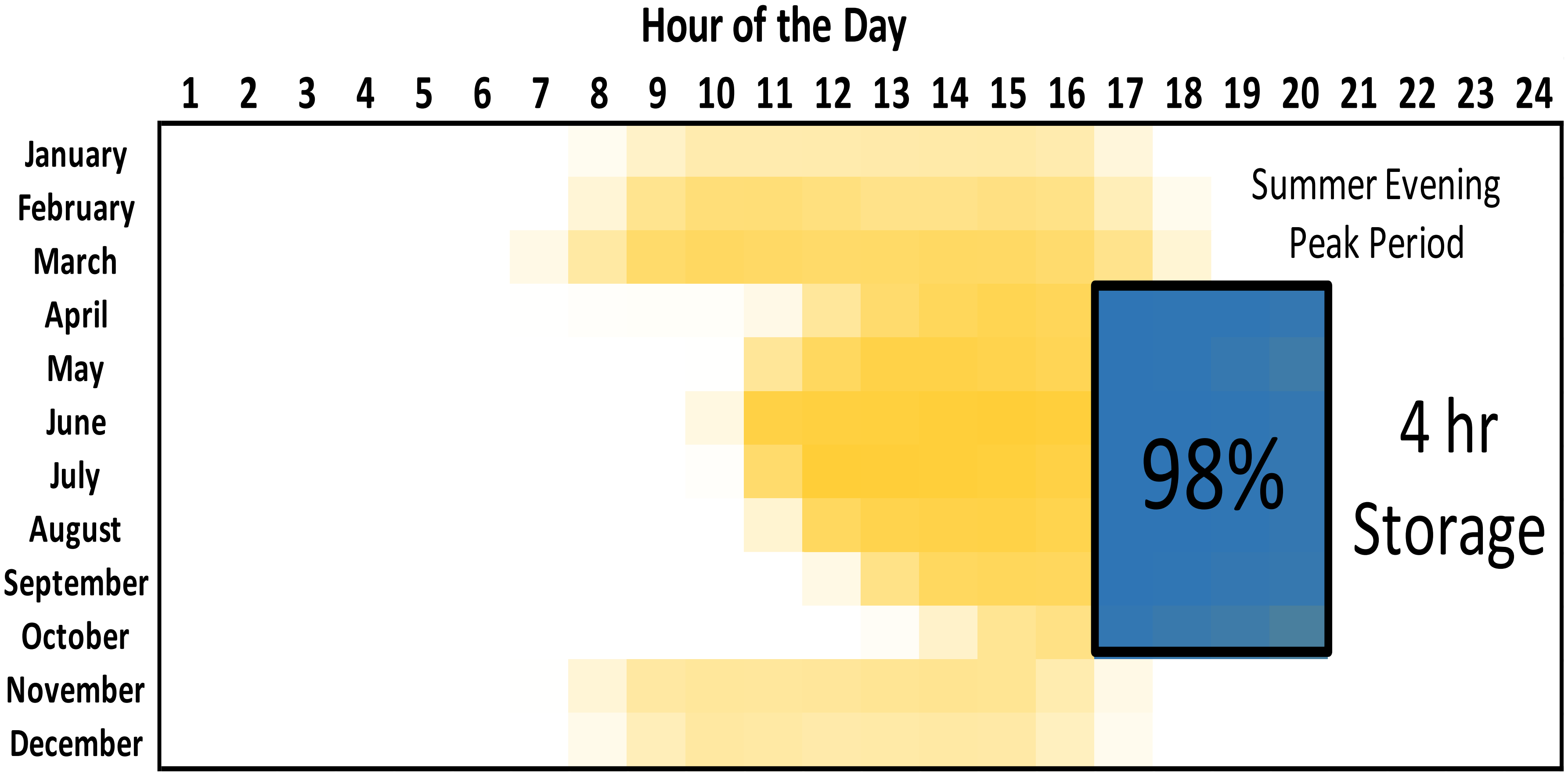
Solar and Storage Provide Firm Capacity

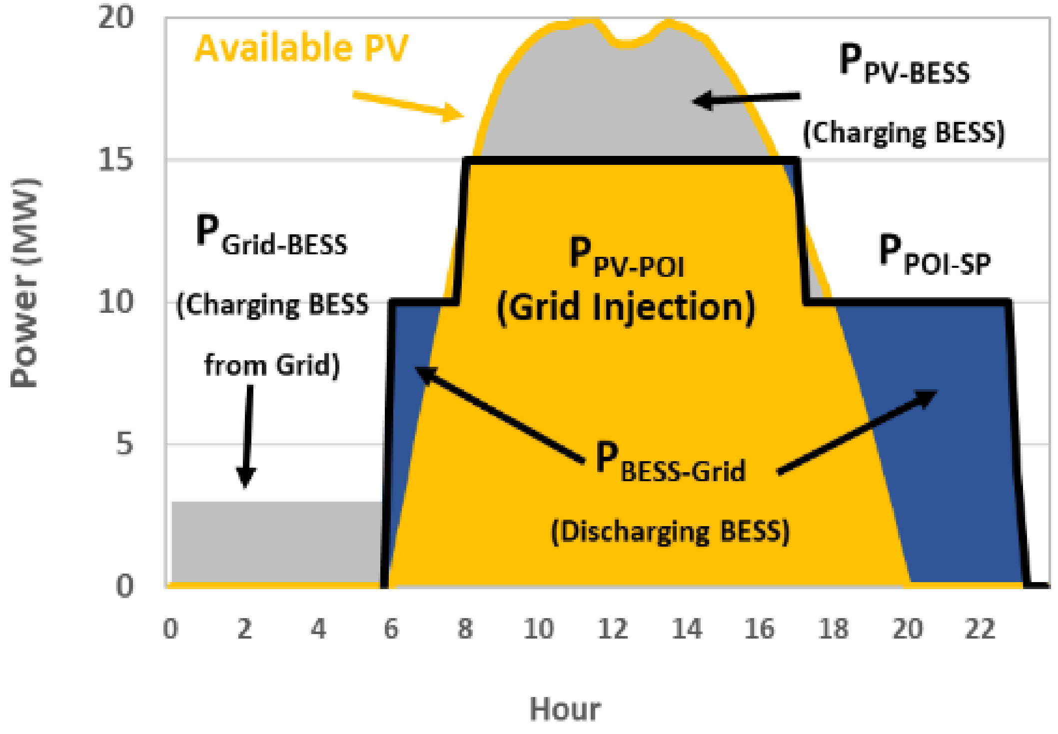
+



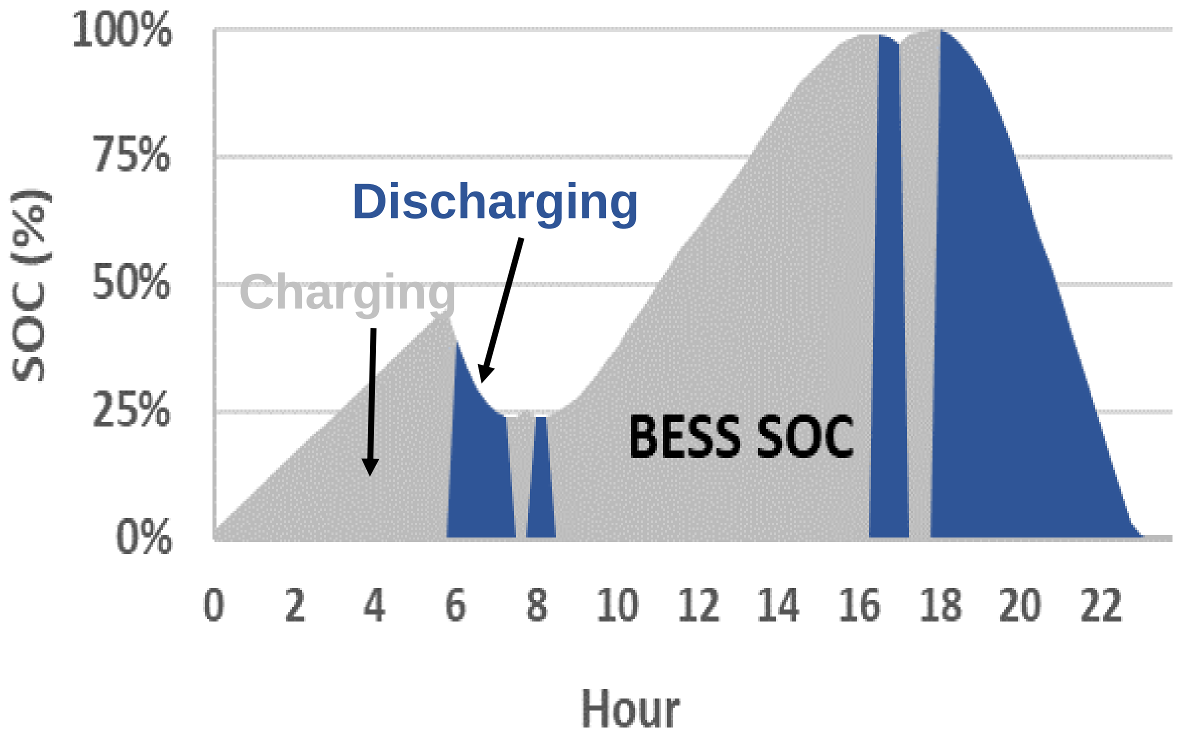
Game Changer: Clean Energy Plant
More Cost-effective Than Conventional Generation

Schedule Driven Dispatch of PV and Storage (PVS)

PVS Output Profile



PVS Charging and Discharging



Plant Controls Manages Operator-entered Schedule at POI by Charging and Discharging Storage as Required

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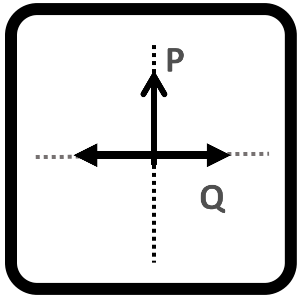
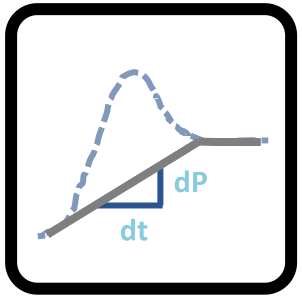
Storage Enhances Grid Capability of PV Plant

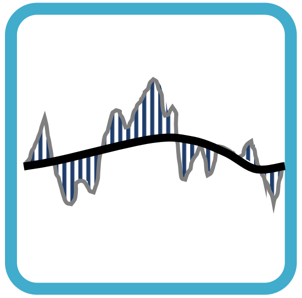
Voltage Support



Ramp Control



Power Regulation



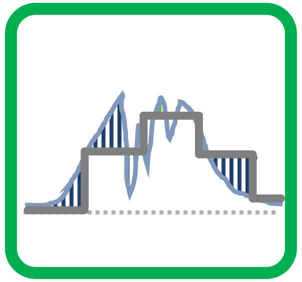
- AGC
- Up-Regulation
- Down-Regulation
- Frequency Regulation

Base Capability

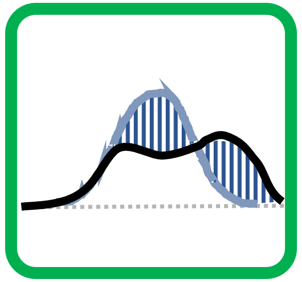
Grid Reliability Services

+

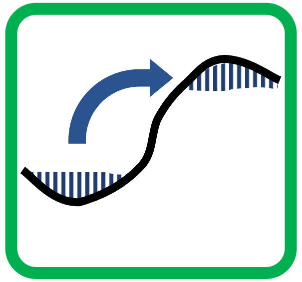
Capacity Firming



Energy Shifting



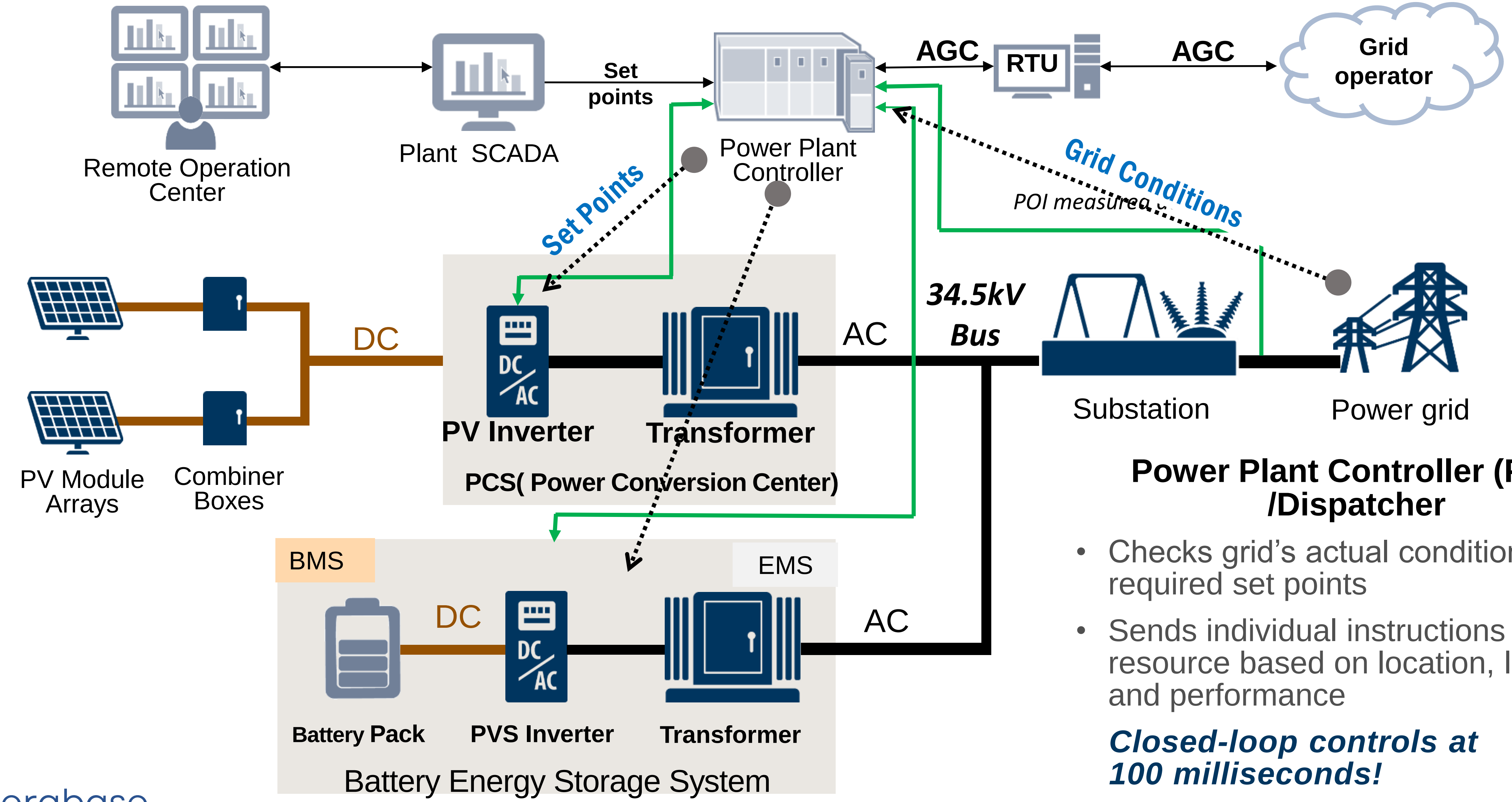
Flexibility



Grid Capabilities Enhanced with Storage

How is the grid friendly plant dispatched?

Plant Controls & SCADA System



Power Plant Controller (PPC) /Dispatcher

- Checks grid's actual conditions and required set points
- Sends individual instructions to each resource based on location, losses, and performance

Closed-loop controls at 100 milliseconds!

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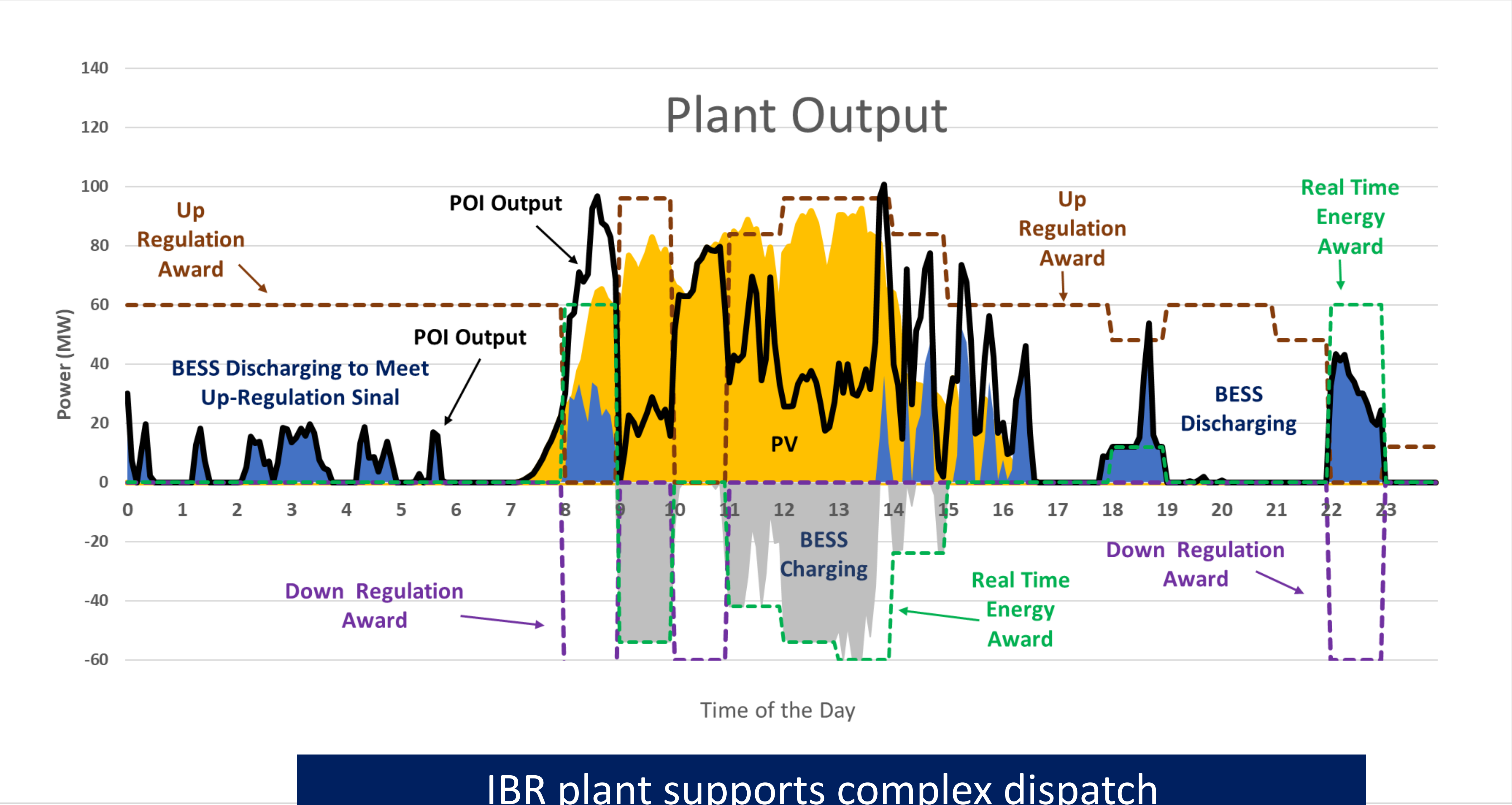
Typical Plant Operation Over a Day



IBR plant supports complex dispatch

Thank You

Mahesh Morjaria, Ph.D. - mmorjaria@terabase.energy

Utility Perspective

Utility Perspective

Keith Parks

Senior Data Scientist
Xcel Energy

Xcel Energy – Colorado System

- Xcel Energy – Colorado
  - 4000+ MW of Wind – 90% AGC capable
  - 800+ MW Utility-Scale Solar – 95% AGC capable
  - 300MW pump load frequency responsive load shed capable
  - Moved black start from pumped storage facility to thermal resources
  - Invested heavily in Renewable Energy (RE) forecasting technology
  - Implemented 30min flexibility reserve to compensate for wind down ramps
  - 250MWs of lithium-ion batteries arriving Spring 2023
  - Building Power Pathways, a major transmission project to interconnect remote wind and solar resources
    - And still, we have major challenges integrating zero-emission resources

Changing Attitudes: Resource Adequacy Year-Round

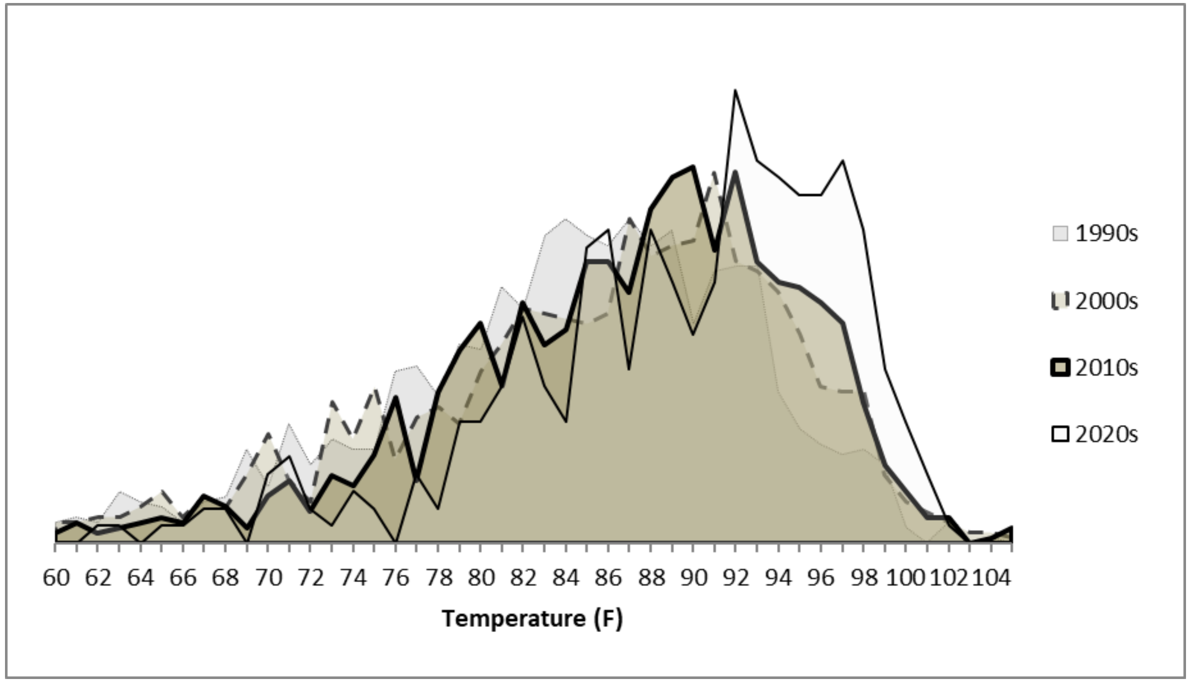
Changing Climate: Summer (Jun-Sep) Peak Temperatures

Summer in Colorado is longer.

In particular, very hot days occur early in June and now extend deep into September.

For traditional summer months (July/August) there is an increase in quite hot days though without necessarily seeing our peak temperature increase…

So, *not hotter, but lots more hot days*. And those days start sooner and last deeper into the year.



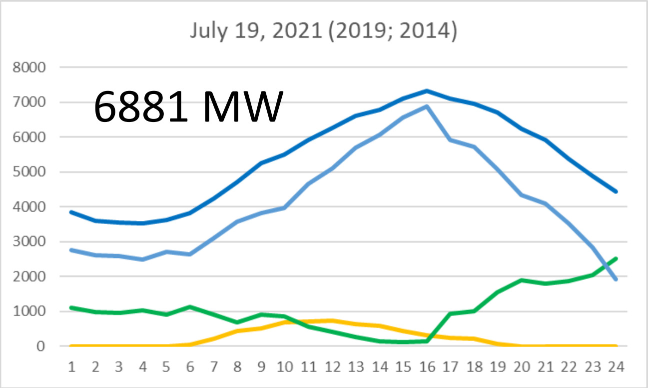
Denver - Max Summer Temperatures

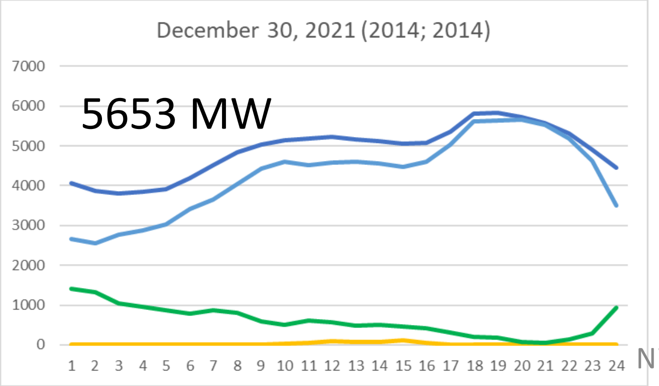
Winter Reliability

Using recent renewable energy and load years, we synthesized many 2021 and 2030 possible years. The Peak **Net Load** shifts reliability risk away from summer toward winter.

2021 Peak Net Load

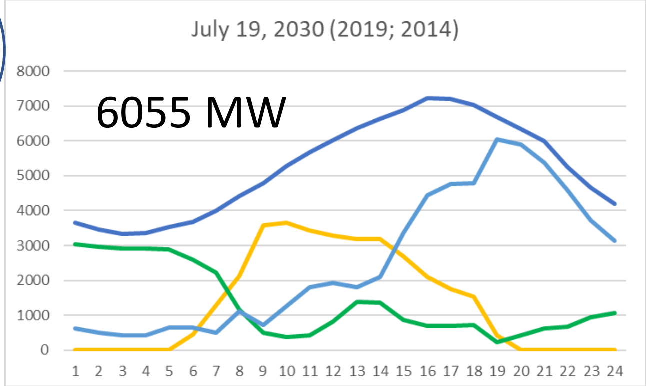
Jan	0
Feb	0
Mar	0
Apr	0
May	0
Jun	3
Jul	26
Aug	7
Sep	0
Oct	0
Nov	0
Dec	0

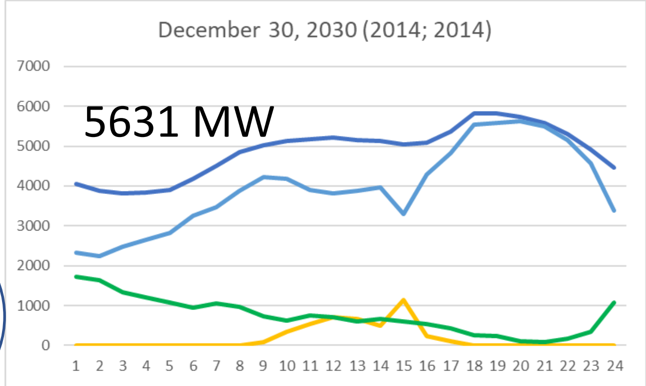




2030 Peak Net Load

Jan	5
Feb	1
Mar	0
Apr	0
May	0
Jun	4
Jul	13
Aug	7
Sep	0
Oct	0
Nov	1
Dec	5





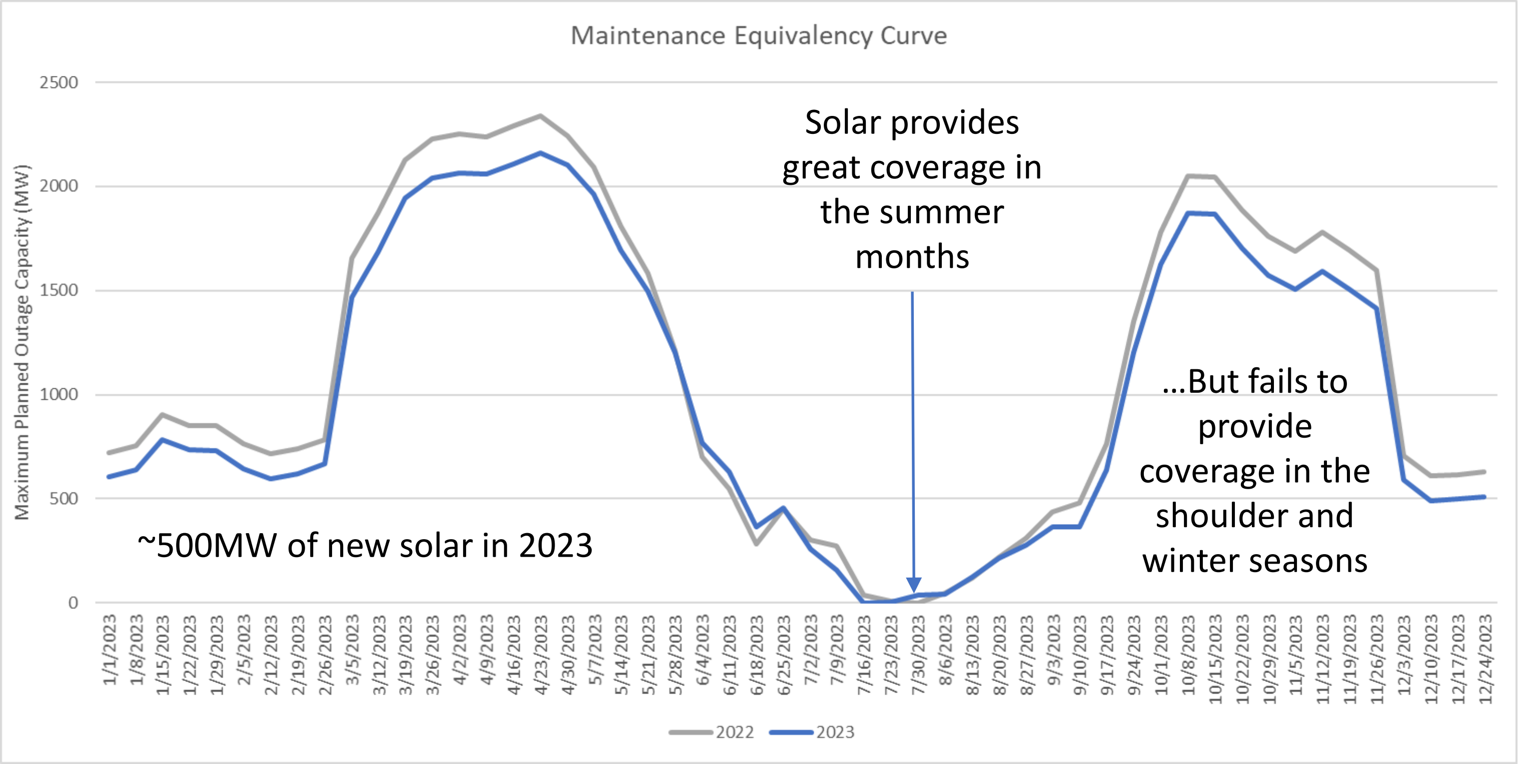
Nick Miller

Shrinking Maintenance Window

The Colorado maintenance season is divided into Spring and Fall.

The graph shows the amount of planned outage, by week of the year, that would create a design day situation.

The maintenance window shrinks with additional solar



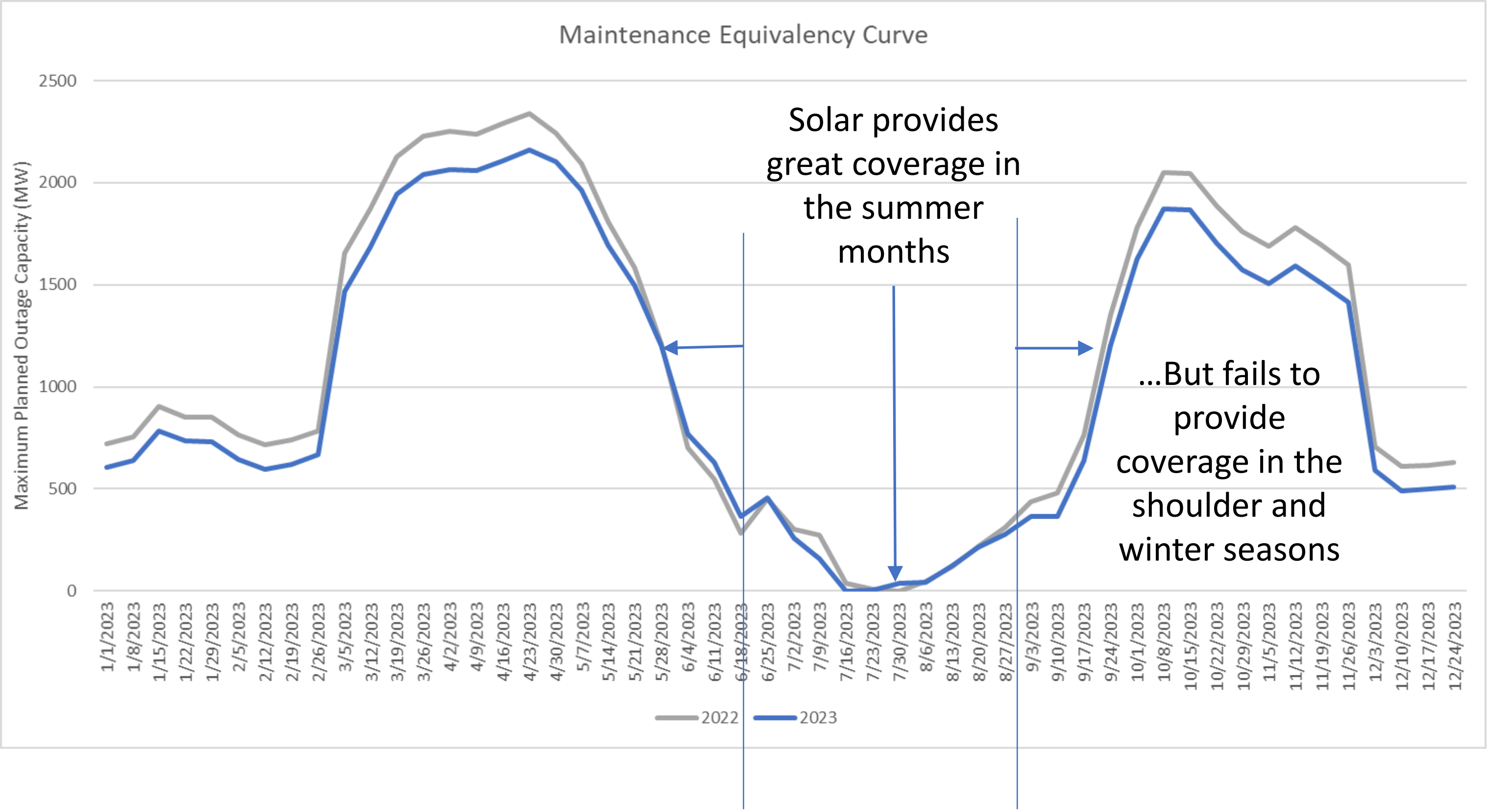
Shrinking Maintenance Window

The Colorado maintenance season is divided into Spring and Fall.

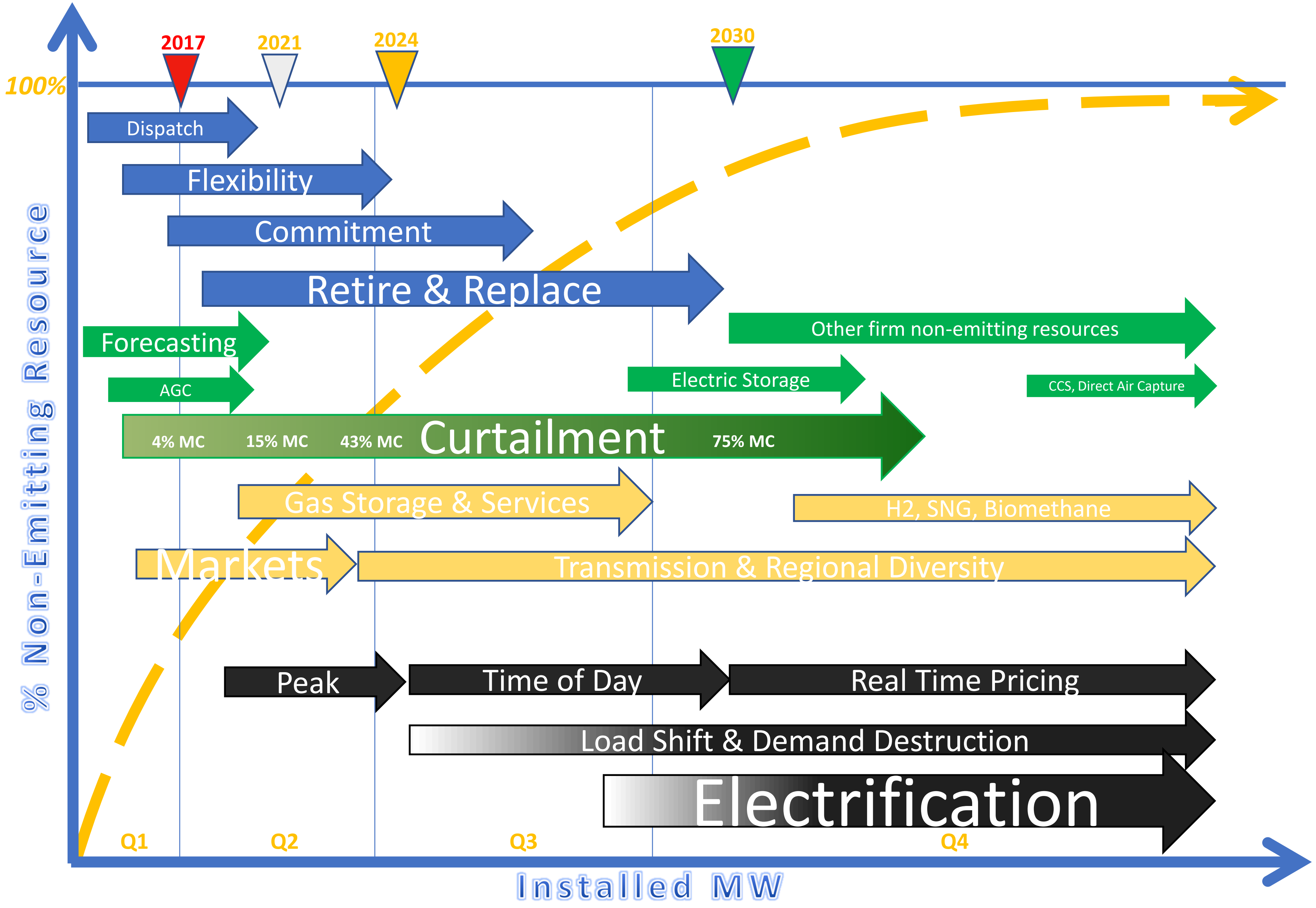
The graph shows the amount of planned outage, by week of the year, that would create a design day situation.

The maintenance window shrinks with additional solar

And the longer summer shortens the maintenance window.



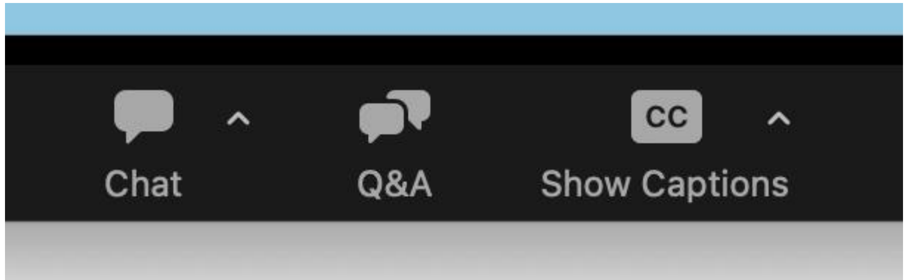
Meanwhile, the longer summer means the Fall outage season is shrinking


2017
2021
2024
2030
100%
Dispatch
Flexibility
Commitment
Retire & Replace
Other firm non-emitting resources
Forecasting
Electric Storage
AGC
CCS, Direct Air Capture
4% MC
15% MC
43% MC
Curtailment
75% MC
Gas Storage & Services
H2, SNG, Biomethane
Markets
Transmission & Regional Diversity
Peak
Time of Day
Real Time Pricing
Load Shift & Demand Destruction
Electrification
Q1
Q2
Q3
Q4
% Non-Emitting Resource
Installed MW

Coffee Break

How to Ask a Question in the Webinar

Please submit questions for the panelists using the Q&A box.



thank you!

Acronyms

AC-Alternating current

AGC -Automatic Generation Control

BESS- Battery energy storage system

BTM -Behind the meter

BMS- Battery management system

CAES- Compressed air energy storage

CCS - Carbon Capture & Sequestration

DC-Direct current

EMS- Energy management system

GFM- Grid-Forming

HVDC- High-voltage direct current

IEEE -Institute of Electrical and Electronics Engineers

kV-Kilovolt

MW- Megawatt

POI- Point of interconnection

PV- Solar photovoltaics

PVS- Solar (PV) and storage

RE- Renewable Energy

RTU- Remote terminal units

SCADA- Supervisory Control And Data Acquisition

SNG- Synthetic Natural Gas

STATCOM – Static Synchronous Compensator

SVC – Static Var Compensator

VER- Variable Energy Resources

VRE- Variable Renewable Energy