Review of Grid Reliability Services from Variable Energy Resources (VERs) and Inverter Based Resources (IBRs)

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3002029347

April 2024

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Acknowledgments

EPRI prepared this report.

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This report describes research sponsored by Electricity Transition Hub, an independent program of the Canadian Renewable Energy Association (CanREA).

This publication is a corporate document that should be cited in the literature in the following manner:
Review of Grid Reliability Services from Variable Energy Resources (VERs) and Inverter Based Resources (IBRs). EPRI, Palo Alto, CA: 2024. 3002029347.

Abstract

As rising numbers of inverter-based resources (IBRs), largely from wind, solar, and battery energy storage systems are deployed in power systems around the world, their contribution to the grid and the demand for services from them are undergoing transformation. To maintain grid stability and reliability, the participation of IBRs in some of the services will be critical. IBRs have the capability to provide some of these grid services such as operating reserves, planning reserves, and voltage support. The procurement and deployment of the services can be implemented either as mandatory interconnection requirements or as market products.

This report provides a comprehensive overview of both current and emerging opportunities for IBRs within bulk power systems and electricity markets. It concentrates on the reliability services (ancillary services) of the bulk power system, with a special emphasis on the ability of variable energy resources, like wind and solar, to deliver these services. It presents a thorough examination of both traditional and emerging ancillary services within the bulk power system, discussing the potential roles for IBRs. This includes technical definitions and characteristics, contemporary performance criteria, and compensation mechanisms for each of the identified services.

Variable resources such as wind and solar have the technical and control capability to provide most grid services; however, they rarely do in practice due to eligibility rules, grid operator confidence and forecast uncertainty, and for economic reasons. Further actions may be necessary to investigate these barriers further and explore the potential benefits of more robust participation from these resources across the globe.

Keywords

Ancillary services
Inverter based resources (IBRs)
Reliability services
Variable energy resources (VERs)
Wholesale electricity markets

Executive Summary

Deliverable Number: 3002029347
Product Type: Technical Report
Product Title: Review of Grid Reliability Services from Variable Energy Resources (VERs) and Inverter Based Resources (IBRs)

Primary Audience: This report is intended for general audiences interested in grid reliability services from variable energy resources and inverter-based resources, such as developers and operators of these resources

Secondary Audience: Secondary users include system and market operators and entities that procure grid services

KEY RESEARCH QUESTION

As rising numbers of inverter-based resources (IBRs), largely from wind, solar, and battery energy storage systems are deployed in power systems around the world, their role on the grid is changing and the services needed from them have evolved. This study explored the technical capability for these resources to provide grid services, such as such as operating reserves, planning reserves, and voltage support, and methods to procure and deploy IBRs for these services.

RESEARCH OVERVIEW

This study presents a review grid services and deployment methods in markets across North America, developed through a desktop review of public materials and a consolidation of previous research conducted by EPRI on this topic.

Executive Summary

KEY FINDINGS

- Maintaining future grid stability and reliability hinges on IBRs providing some of the services currently (or formerly) provided by synchronous generators
- The procurement and deployment of grid services can be implemented either as mandatory interconnection requirements or as market products.
- Procurement and compensation mechanisms can consider the costs of provision
- At the same time, future energy markets are likely to change. Procurement methods may need to adapt to new conditions and price signals

WHY THIS MATTERS

Research Value: This report provides a foundational understanding of how IBRs and VERs can contribute to the spectrum of grid reliability services today and into the future.

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PROGRAMS: Electricity Market Design and Operation, P246; Transmission Operations, P39; Transmission Planning, P40; Bulk System Integration of Renewables and Distributed Energy Resources, P173

Outline

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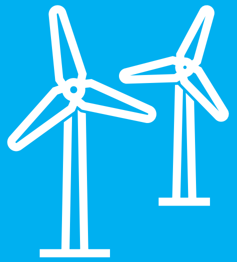
- Introduction
- Grid Services Overview
- Ancillary Service Definitions and Characteristics
- Grid Services Markets and Revenues
- Conclusions
- References

Introduction

Variable Energy Resources

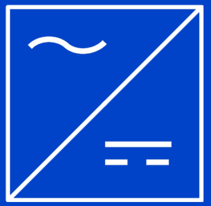


- Also called intermittent resources
- Primarily wind and solar generation
- Output fluctuates and cannot be predicted with perfect accuracy

Increases in production variability and forecast uncertainty may increase the need for several grid services

Inverter technology can benefit system reliability, reduce operating costs and provide an additional revenue opportunity

- Inverter: a power electronic device that converts direct current (dc) electricity to alternating current (ac) electricity
- Primarily wind, solar, and storage resources
- Inverter can generally respond faster than mechanical systems
- Do not provide inherent synchronous inertia or system strength



Inverter Based Resources

Types of IBRs

NERC [1]: defines IBRs as resources that include

- Type 3 and Type 4 wind turbines
- Solar PV
- Batter Energy Storage Resources
- HVDC circuits
- Flexible AC transmission system devices (e.g. synchronous compensators, static volt-ampere reactive compensators)

Differences between IBRs and Synchronous Generation

Inverter Based Resources

- Driven by power electronics and software
- No natural inertial energy
- Very low fault current
- Very fast and flexible ramping
- Very fast power control
- Capable of providing grid reliability services
- Dispatchable based on available Power/energy
- Sensitive power electronics switches

Synchronous Generation

- Driven by physical machine properties
- Large rotating natural inertial energy
- High fault current
- Provide ramp capability at varying levels
- Inherent inertial energy injection
- Generally provide essential grid reliability services in practice
- Dispatchable between minimum and maximum limits
- Rugged equipment tolerant to extremes

Grid following (GFL) vs Grid forming (GFM) control

Time scale	Grid Following (GFL)	Grid Forming (GFM)
Sub-transient	Constant output current for P/Q control	Constant output voltage for V/f control
Transient	Active and reactive power control	Voltage and frequency control
Steady – state	May follow the same droop characteristics	

Grid Following (GFL)

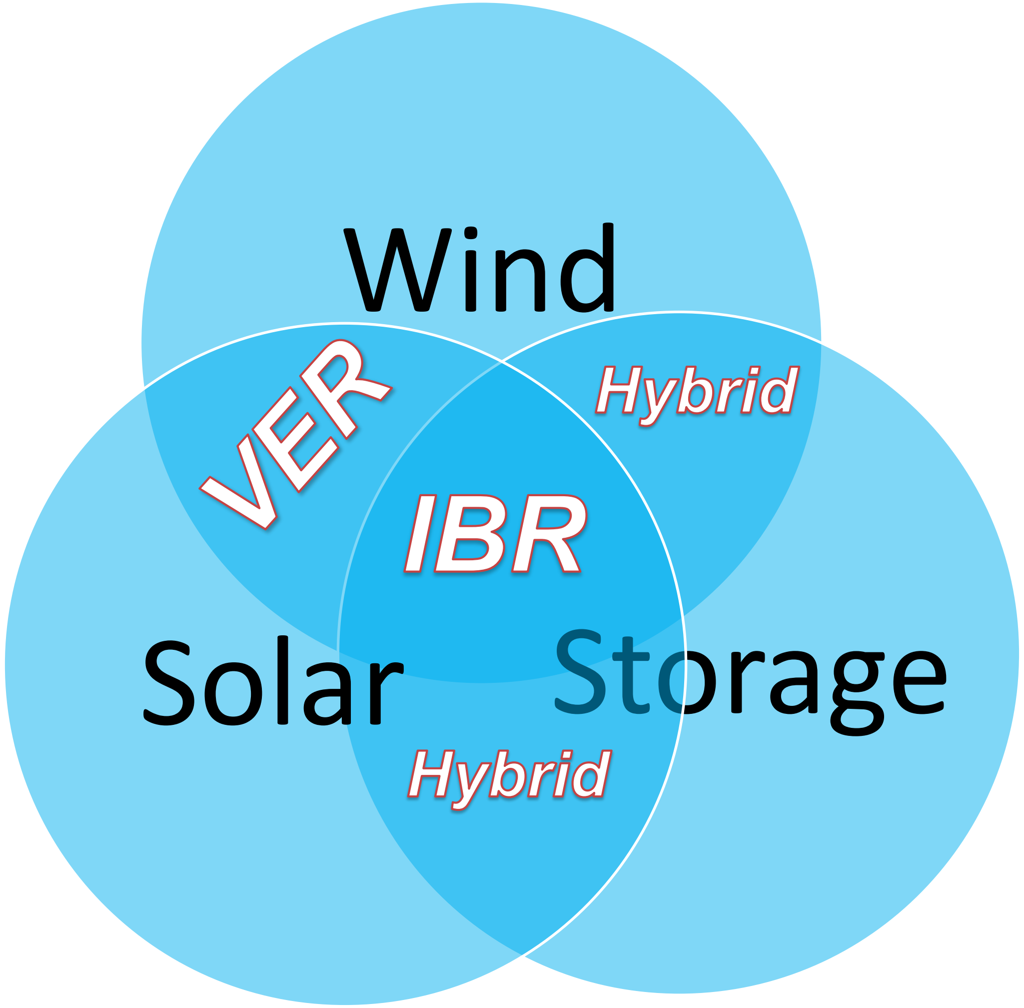
- Maintain a constant output current phasor to control the active and reactive power injected by the IBR into the network in the sub-transient to transient timeframe.
- They are inherently dependent on grid strength and cannot operate in islanded mode or provide black-start capabilities

Grid Forming (GFM)

- Maintain a constant internal voltage phasor and frequency, which is controlled to maintain synchronism with other devices and to regulate IBR active and reactive power in the sub-transient to transient timeframe.
- Can provide black start and continue operation even in thein the absence of synchronous generators.

[2] Grid Forming Inverters EPRI Tutorial (2023). EPRI, Palo Alto, CA: 2023. 3002028090. For more, see: https://sites.google.com/view/unifi-consortium/publications

What's in a name?



Generally, Grid Services = Ancillary Services = Essential Reliability Services

- Other Terms:
  - **VRE**: Variable Renewable Energy
  - **IPR**: Intermittent Power Resource
  - **DIR** and **DVER**: Dispatchable Intermittent Resource and Dispatchable Variable Energy Resource
  - **ZFCR**: Zero Fuel Cost Resource
  - **GFM** and **GFL**: Grid forming inverters and grid following inverters

Grid Services and IBRs: Is it an odd couple?

Power System Transformation

Grid **needs** are evolving

Technologies that **contribute** to grid needs are evolving

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Some **grid codes** require IBR/VER contribution

Markets for service provision can provide additional **revenue**

Key Remaining Challenges

Lack of confidence from system operators

- Can operators trust in VERs/IBRs in performing services?

Lack of (or understanding of) economic value

- Can VER/IBR reduce costs and earn profit from grid services?

Technical control capabilities are not a barrier!

Grid Services Overview

Ancillary Services

Ancillary services are services used in electric power systems to ensure the operational reliability of the bulk power system

Defined in FERC Order 888 (1996)

Those services that are necessary to support the transmission of capacity and energy from resources to loads while maintaining reliable operation of the Transmission Service Provider's transmission system in accordance with good utility practice

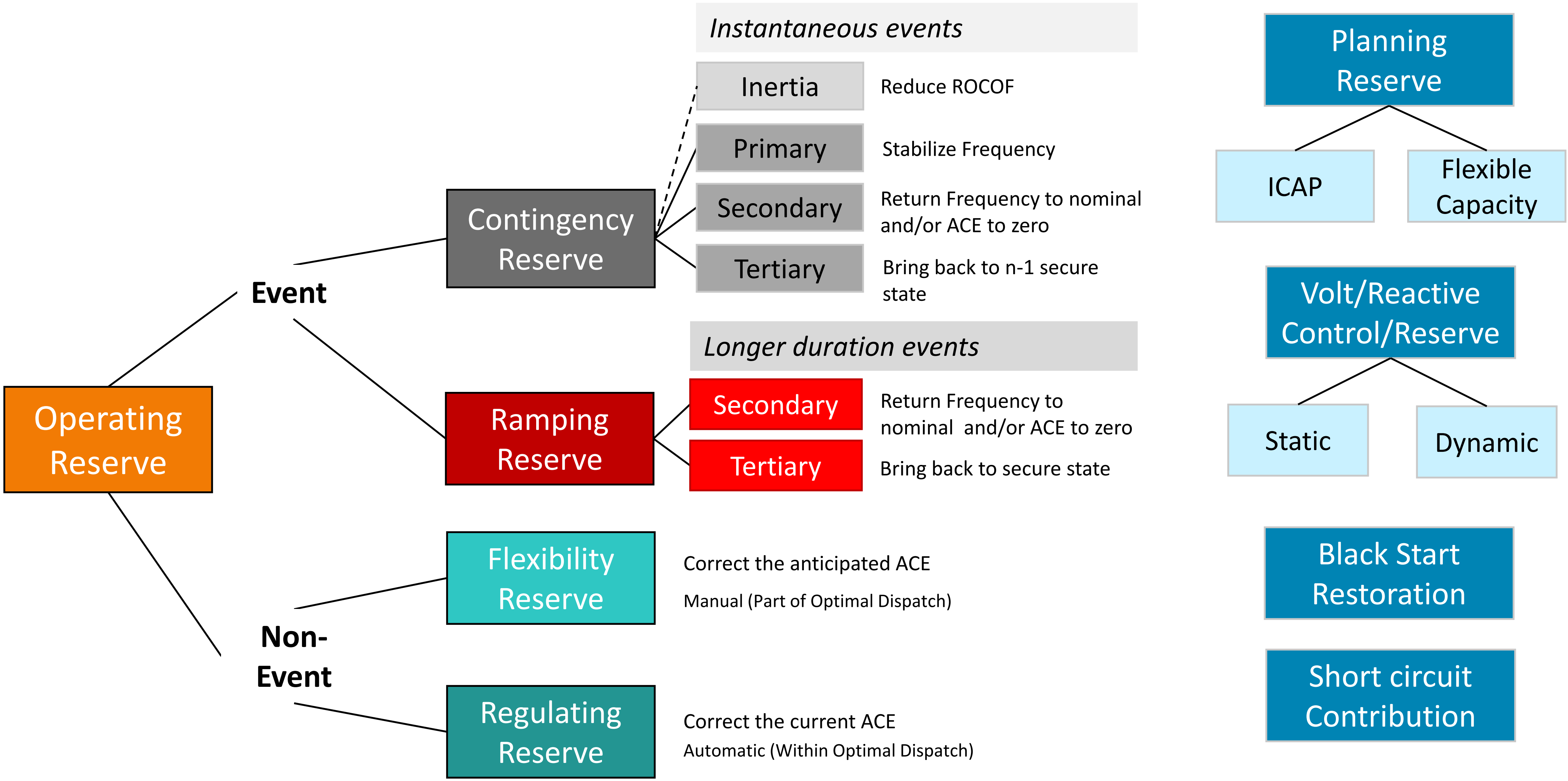
Typically focused on transmission system

Additional services may support distribution system reliability but are not the focus of this report.

Subset of services have revenue sources

Some services have competitive auctions where suppliers are paid a competitive price for providing the service.

Ancillary Services



[3] *Ancillary Services in the United States: Technical Requirements, Market Designs and Price Trends*. EPRI, Palo Alto, CA: 2019. 3002015670.

Operating Reserves [2]

- Resources with different technical characteristics are deployed based on their response times, usually arranged from the quickest to the slowest.
- Contingency Reserves
  - Spinning Reserves
  - Non-Spinning Reserves/Supplemental Reserves
- Regulating Reserves
  - During normal operations, reserves are requires to meetrandom variations in net load and to minimize the Balancing Area Control error (ACE).

Operating Reserves (continued)

- Frequency Responsive Reserves
  - Inertial Response
  - Primary Frequency Response (PFR)
  - Fast Frequency Response (FFR)
- Ramping Reserves and Flexibility Reserves
  - Least well defined of the reserve products
  - Explicitly included in some regions as a product; other times may be embedded in other products
  - Time horizon and objective of product varies

FERC has sought to revise ancillary service requirements

FERC Orders impact the development of NERC Standards, which are applicable in Canada, and influence the development of industry practices across North America

2011 — Order 755

Requires wholesale power markets to ensure proper compensation of performance-based frequency regulation which included that lost opportunity costs

2012 — Order 764

Includes requirements for intra-hour scheduling, acknowledging that hourly scheduling might result in greater imbalance charges to VERs

2016 — Order 827

Requires all newly interconnecting technologies include the capability to provide reactive power and voltage support.

2018 — Order 841

Requires ISOs to adjust market participation rules to allow for energy storage resources to be able to participate in ancillary services that they are capable of providing

2018 — Order 842

Requires all newly interconnecting resources to have frequency response capabilities

2022 — Order 2222

Requires ISOs to enable participation of distributed energy resource aggregations to participate in energy, ancillary services and capacity markets

Relevant NERC Standards

- **BAL-001-2**: Control Performance Standard 1 (CPS1) and the Balancing Authority ACE Limit (BAAL) [4]. **Impact: Regulating Reserve**
- **BAL-002-3**: The Disturbance Control Standard (DCS) includes minimum holding requirement, recovery times, and restoration times. **Impact: Contingency (Secondary and Tertiary, spinning and nonspinning) Reserve**
- **BAL-003-2**: Frequency Response Obligation (FRO) requires minimum frequency response from BAAs. **Impact: Contingency (Primary) Reserve**
- **VAR-001-5**: Voltage levels are maintained within acceptable limits. **Impact: Voltage control**
- **EOP-005-3**: requires plans for restoration based on a balancing area's black start resources. **Impact: Black start service**

- **FERC Order 901: New or modified reliability standards [5]. Addresses: reliability gaps related to IBRs: data sharing; model validation; planning and operational studies; and performance requirements.**

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FERC Order 901 Summary

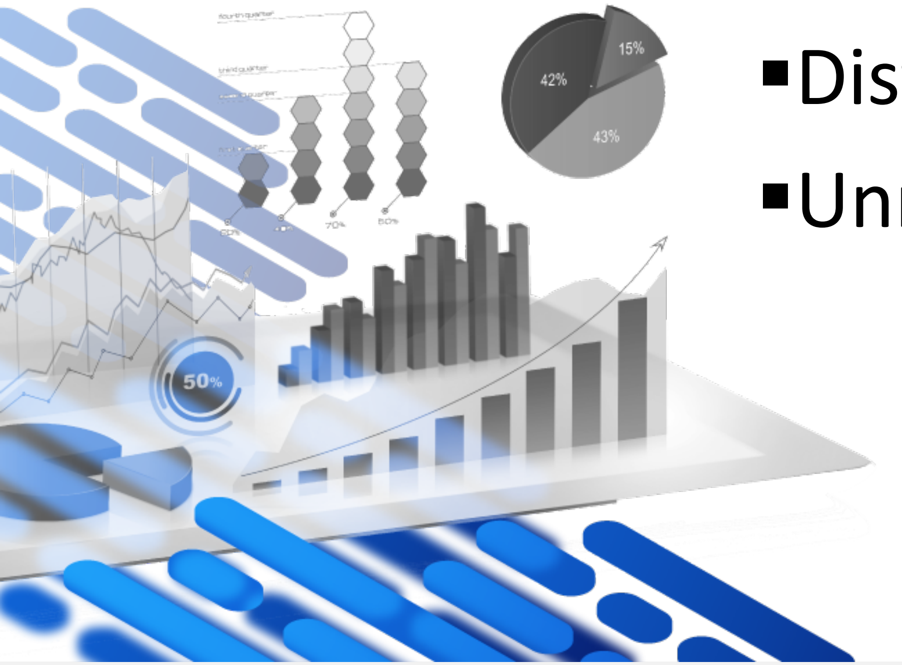
- Issued October 19, 2023
- Directs NERC to submit a detailed standards development plan to address inverter-based resource reliability gaps in four areas [3]
  - Data sharing
  - Model validation
  - Planning and operational studies
  - Performance requirements
- Informational filing with comprehensive work plan submitted on January 17, 2024
- New or modified standards to be submitted by November 2026

FERC Order 901: Need

- Several incidents have highlighted shortcomings in the Reliability Standards pertaining to IBRs.
- The measures currently being taken are inadequate for mitigating the reliability risks associated with IBRs.
- The present Reliability Standards fail to sufficiently cover the reliability risks related to IBRs.

IBR Reliability Gaps – Data Sharing

- The Reliability Standards must require that generator, transmission, and distribution providers to share data with planners, coordinators, operators, and authorities to predict IBRs' impact on bulk power system.
  - Registered IBRs data sharing
  - Disturbance monitoring data
  - Unregistered IBR and IBR-DER data sharing



IBR Reliability Gaps – Model Validation

- The Reliability Standards must require that comprehensive, validated, timely IBR models for planners, coordinators, operators, and authorities to predict IBRs' (registered and unregistered IBRs individually and in the aggregate, as well as IBR-DERs in the aggregate) impact on bulk power system.
  - Industry-approved generic component models
  - Verification of IBR plant dynamic model performance
  - Validating and updating system models
  - Coordination to create and update planning, operational, and interconnection-wide data and models

IBR Reliability Gaps – Planning and Operational Studies

- The Reliability Standards must require that validated IBR models for studies to assess impacts of registered and unregistered IBRs, individually and collectively, including IBR-DERs, on bulk power system.
- It is necessary to mandate that planning and operational studies evaluate the effects of all IBRs, both within and across planning and operational boundaries, under standard operating circumstances as well as during contingency events.

IBR Reliability Gaps – Performance Requirements

The Reliability Standards must ensure that registered IBRs

- Offer frequency and voltage assistance during deviations to aid in meeting the system's requirements for vital reliability services.
- Set definite and trustworthy technical boundaries and capabilities for registered Inverter-Based Resources to guarantee consistent and dependable operation under both standard conditions and during contingency events.
- Require that the operational aspects of registered IBRs contribute towards meeting the overall system needs for essential reliability services.
  - Registered IBR frequency and voltage ride-through requirements
  - Bulk power system planner and operator voltage ride-through mitigation activities
  - Post-disturbance IBR ramp rate interactions and phase-lock-loop synchronization

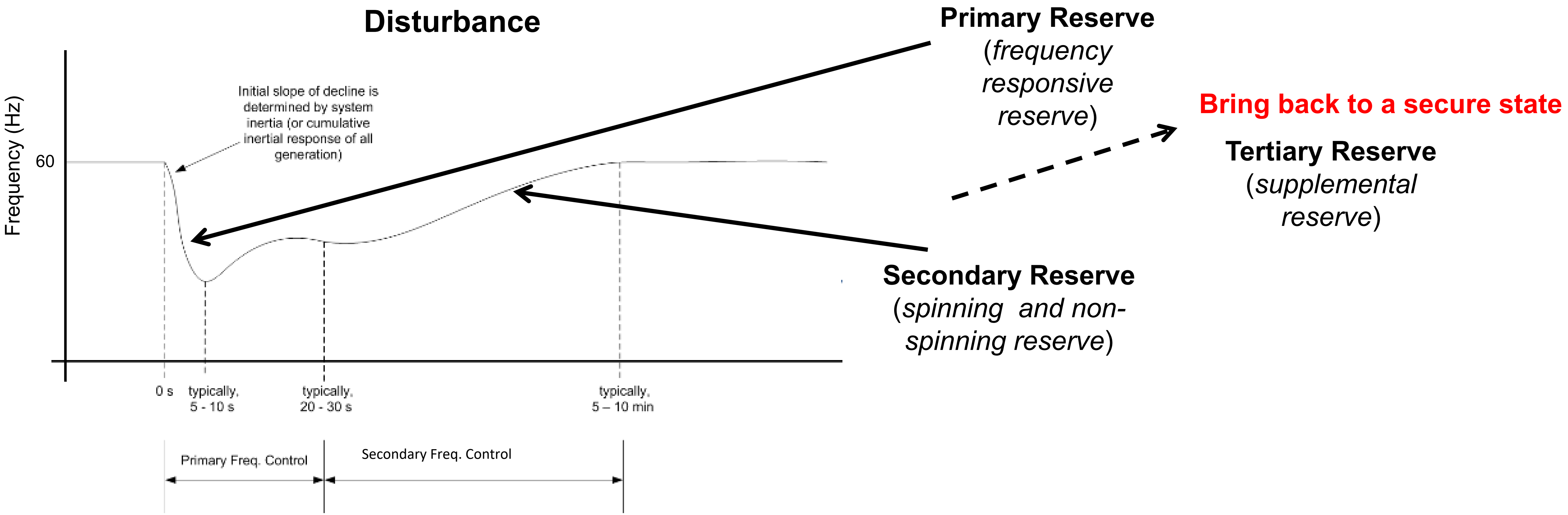
Ancillary Service definitions and characteristics

Ancillary Service Technical Definitions, Characteristics

Objective	Quantity of Need	Speed of Response
Duration of Response	Frequency of Deployment	Deployment Mechanism
Eligible Providers	Direction of Service	Compensation Mechanism

Contingency Reserve
(Secondary and Tertiary/ Spinning and Non-Spinning Reserves)

Contingency Reserve



Contingency Reserve

Other Common names: spinning/non-spinning reserves, synchronized/non-synchronized reserves, 10-minute spinning/non-spinning reserves, supplemental reserves

- **Definition**: Generation capacity reserved to address unplanned outages
- **Purpose**: Used following a contingency to correct the frequency and/or ACE
- **Performance requirements**:
  - Speed: 10 minutes (BAL-002)
  - Duration: 30 – 60 minutes
  - Deployment process: Event-Based
  - Resource participation: Both online and offline
  - Direction: Upward
  - Market process: Day-Ahead and Real-Time markets
  - Frequency to be called: Event-based (generator contingency)
- Required tests and certifications

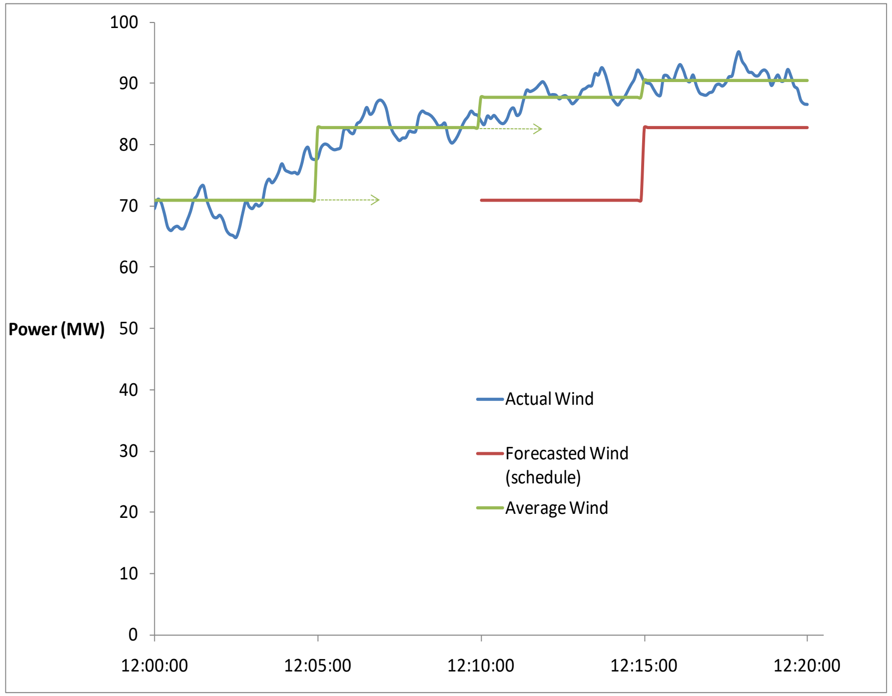
- The performance requirements in some ISOs/RTOs effectively preclude wind and solar from providing these reserves.
- Standalone VER has been integrated into system dispatch in all ISO/RTO markets in North America but, to our knowledge, is not yet meaningfully providing contingency reserves in any of them.
- CAISO certified its first solar facility to provide spinning reserve in June 2019, but the amount of reserves solar has provided has been extremely small. CAISO is also developing participation models that would allow standalone VER to participate more fully in AS markets. SPP appears to allow VER to provide downward regulation reserves, though it is not clear how frequently it is doing so. ERCOT is currently the only area in the US that formally allows wind and solar to provide contingency reserve services.
- However, storage (batteries) are eligible to provide contingency reserves in all ISOs.

Contingency Reserve: Practical Characteristics

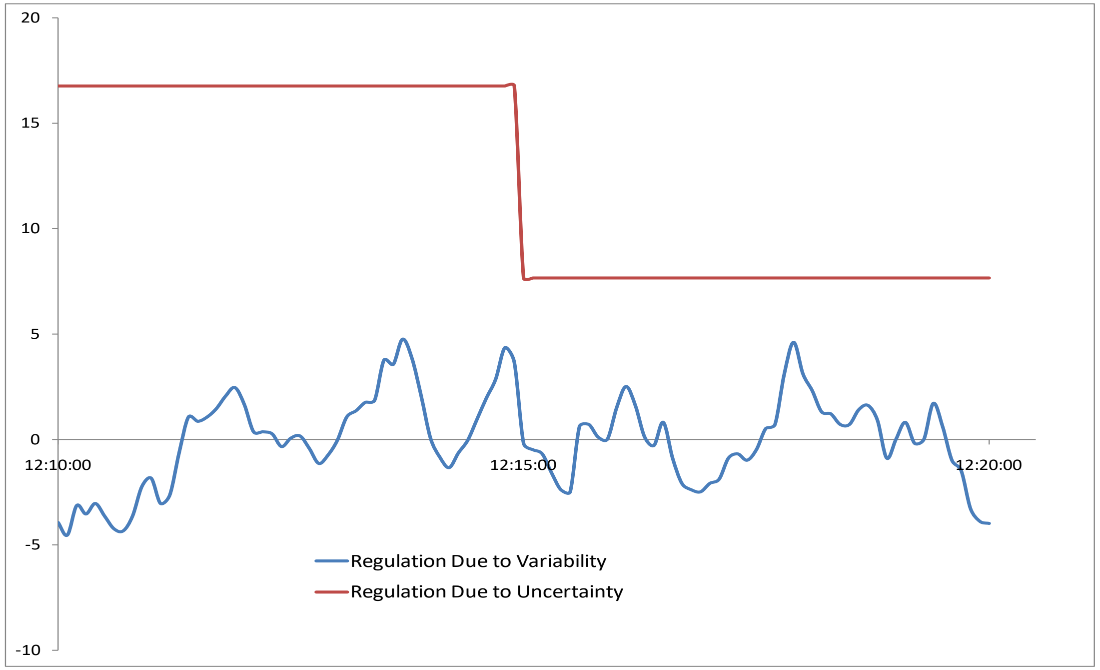
	ISO-NE	NYISO	PJM	MISO	SPP	ERCOT	CAISO	IESO	AESO
Product name – Spinning reserve	Ten-Minute Spinning Reserve (TMSR)	Spinning Reserve	Synchronized Reserve (SR)	Spinning Reserve	Spinning Reserve	Responsive Reserve ERCOT Contingency Reserve Service (ECRS)	Spinning Reserve	10 min operating reserve sync (10S)	Spinning Reserve
Product name – Non-spinning reserves and supplemental reserves	Ten-Minute Non-Spinning Reserve (TMNSR)	Non-spinning reserve	Non-Synchronized Reserve (NSR)	Supplemental reserve	Supplemental Reserves	Non-spin reserve	Non-spinning Reserve	10 min operating reserve non-sync (10N), 30 min operating reserve non-sync (30R)	Supplemental Reserves
Minimum continuous energy when dispatched	60 min	60 min	30 min	60 min	60 min	None specified ECRS -2 hours	30 min	60 min	60 min
Eligibility Requirements	Must have electronic dispatch capability. Offline resources can provide up to audited CLAIM10 for 10-min reserve.	Must offer as flexible (not fixed). If online, must not be block loaded. Special rules for demand side AS and BTM resources.	Nuclear, wind, solar, storage resources, and hydro have default values of Tier 1 Synchronized Reserve set to 0, unless request extension.	All regulation qualified resources except energy storage is eligible. Dispatchable intermittent resources are not eligible.	Resources can self-certify, may require deployment test.	Governors must be in service. Requires testing over 8-h period where ERCOT may ask it to provide service at any time.	Must be able to respond to 5-min dispatch. Includes certification and testing to qualify	Equal to the largest first contingency loss on the system. Typically, ~900 MW.	greater of (1) the single largest contingency and (2) the sum of 3% of AESO hourly integrated load plus 3% of AESO hourly integrated generation.

Regulation Reserve

Regulating Reserve



- Corrects for variability and uncertainty
- Automatic Generation Control (AGC)
- Area Control Error (ACE)
- Selected based on lease cost (opportunity and wear-and-tear)



- 2-6 second cycle through AGC
- Correct the current imbalance
  - Between economic scheduling intervals

Regulation Reserve

Other Common names: Regulation, AGC reserve, load frequency control, regulating up and regulating down

- **Definition**: Continuous control of resources' regulating range through AGC signals every few seconds
- **Purpose:** Minimize the BAA's ACE (manage actual variability; both over- and under-generation conditions)
- **Performance requirements**:
  - Speed: 2-6 second signal, response may be slower
  - Duration: 15-60 minutes
  - Deployment process: Non-event (continuous)
  - Resource participation: online, require AGC communication and control
  - Direction: bidirectional
  - Market process: DA/RT
  - Frequency to be called: AGC every 2-6 seconds
  - Required tests and certifications

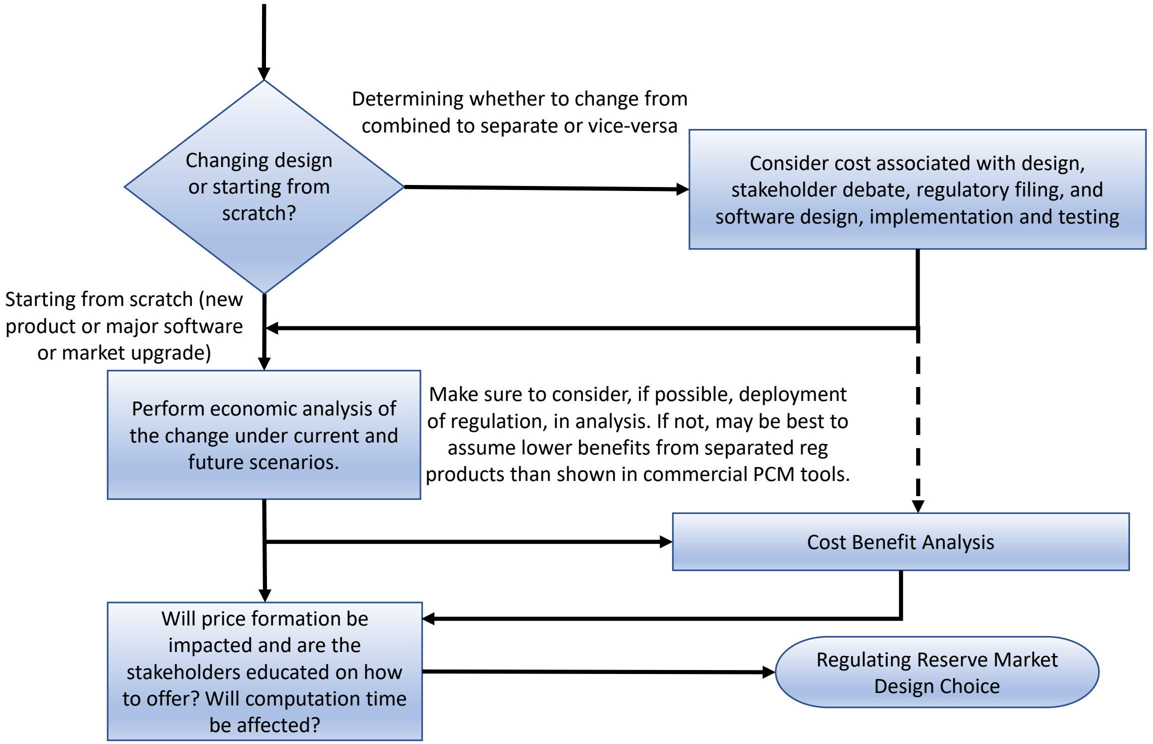
- The ability to provide regulation service can vary by operators' duration requirements
- Some ISOs, including ERCOT, PJM, and SPP, allow VERs to participate in frequency regulation markets.
- In ERCOT and PJM, batteries are currently providing over 60% and 30%, respectively, of the total regulation capacity (and other ISOs have growing participation by these resources).
- IBRs respond faster and more efficiently to regulation signals than do traditional resources.
- Studies have shown VERs to be technically capable of providing regulation, but there is loss of energy market revenue for them to do so.

Regulation Reserve: Practical Characteristics

	ISO-NE	NYISO	PJM	MISO	SPP	ERCOT	CAISO	IESO	AESO
Product name	Regulation	Regulation	Regulation	Regulation	Regulation Up, Regulation Down	Regulation Service	Regulation Up, Regulation Down	Regulation	Regulation
Regulation up / Regulation down product	combined	combined	combined	combined	separate	separate	separate	combined	combined
Frequency of signal (sec.)	4 sec.	6 sec.	2 sec.	4 sec.	4 sec.	4 sec.	4 sec.	4 sec.	4 sec.
Duration requirement (min)	15	15	15	15	60	8	15	15	15
Frequency Response and/or Control Signals	AGC set points at 4 sec intervals	6 sec. automatic control signal (telemetered every 6 sec.)	AGC signal	Automatic control signal every 4 sec. (telemetered every 2 sec.)	Follow a dispatch signal (test includes max Regulation Ramp Rate)	Automatic control signals (additional qualifications for Fast Responding Regulation Service)	Control full range without manual intervention and sustain its ramp rate	AGC signal	AGC signal
Minimum Response	1 MW/min; Gen: Min (5 MW, or 2*[AGC SetPoint Deadband + 1]; Others: 1 MW	During testing Min (Regulation Capacity response rate * 5 minutes, or max capacity)	0.1 MW	-	-	-	0.5 MW	-	-
Instructions or rules for intermittent resources	-	-	-	DIRs are not eligible for DA or RT operating reserve	Setpoint instructions if cleared for regulation down	Post 2010 resources must provide primary frequency response	-	-	-
Terminology for Renewables	Renewable Technology Resource	Intermittent Power Resources	-	Dispatchable Intermittent Resource (DIR)	Dispatchable Variable Energy Resource (DVER)	Intermittent Renewable Resource (IRR)	Eligible Intermittent Resource (EIR)	-	-

Regulation: Separate the Service or Keep it the Same?

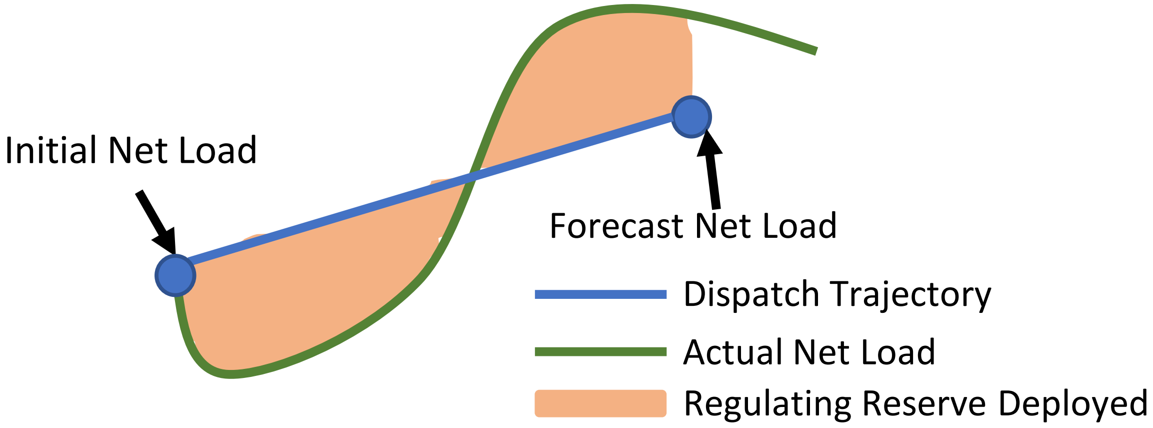
- Key Question: *What are the advantages and disadvantages of bifurcating the regulating reserve product into two directional products?*
- Key Points:
  - Regulation is a key service that is **procured through ancillary service markets** in U.S. ISO/RTO markets
  - About **half** U.S. market operators have a **single** regulating reserve product and **half** have **two directional** products
  - Regions with a combined product are considering a **move to separate products**
  - **Economic efficiency benefits** are the key stated reason why the move to two products
  - Separate products also allow for **different directional requirements** when probability and magnitude of upward/downward changes differ
  - In this analysis, we found clear economic efficiency benefits to separating out the products, but they **may be overstated without considering deployment of regulation**
  - **Price formation** can be **complicated** with separate products
  - The impact on market clearing **computational efficiency** is **unclear**
  - There are **significant costs** associated with the **assessment** and **stakeholder processes** that may **outweigh benefits**

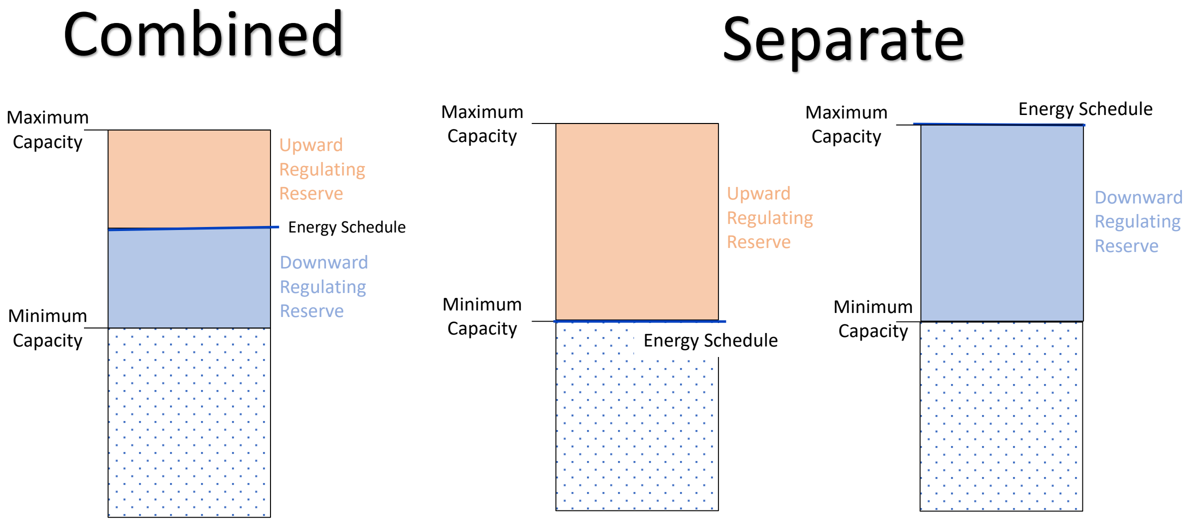


Separating may be better, but enough to justify a change?

Regulating Reserve Service and Ancillary Service Market: One Combined Products or Two Separate Bifurcated Directional Products?. EPRI, Palo Alto, CA: 2023. 3002025037.

Regulation: Combined and Separate





Combined: A resource must have ample "head room" **AND equal** amount of ample "leg room" to provide regulation based on its minimum and maximum capacity

Separate: A resource need **only** ample head room **OR** ample foot room to provide either regulating up **OR** regulating down, respectively. Renewables often have ample foot room since they have a minimum capacity equal to 0, but do not have head room unless they have been curtailed below the available energy level.

	ISO-NE	NYISO	PJM	MISO	SPP	ERCOT	CAISO	AESO	IESO
Product name	Regulation	Regulation	Regulation	Regulation	Regulation Up, Regulation Down	Regulation Service	Regulation Up, Regulation Down	Regulation	Regulation
Regulation up / Regulation down product	Combined	Combined	Combined	Combined	Separate	Separate	Separate	Combined	combined

Primary Frequency Response

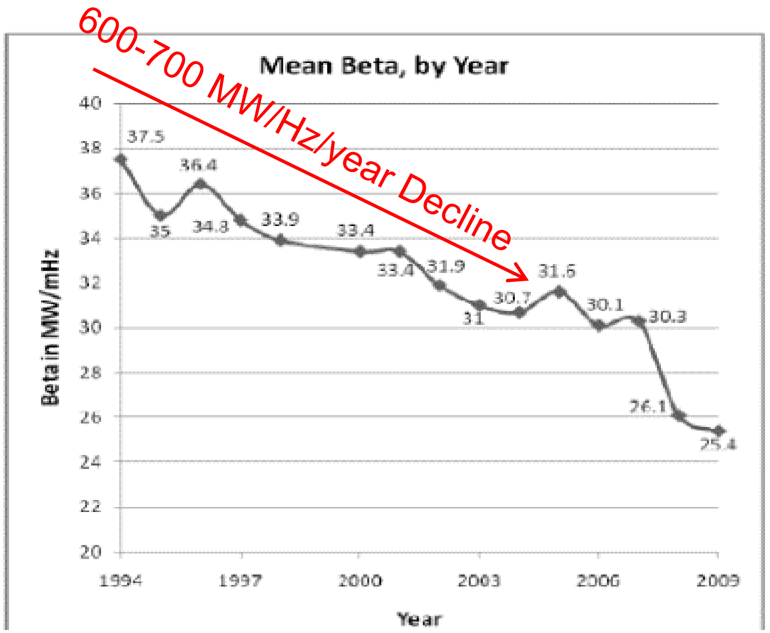
Frequency Control

Other Common names: primary contingency reserve, frequency responsive reserve, governor response, primary control reserve, or frequency governor response.

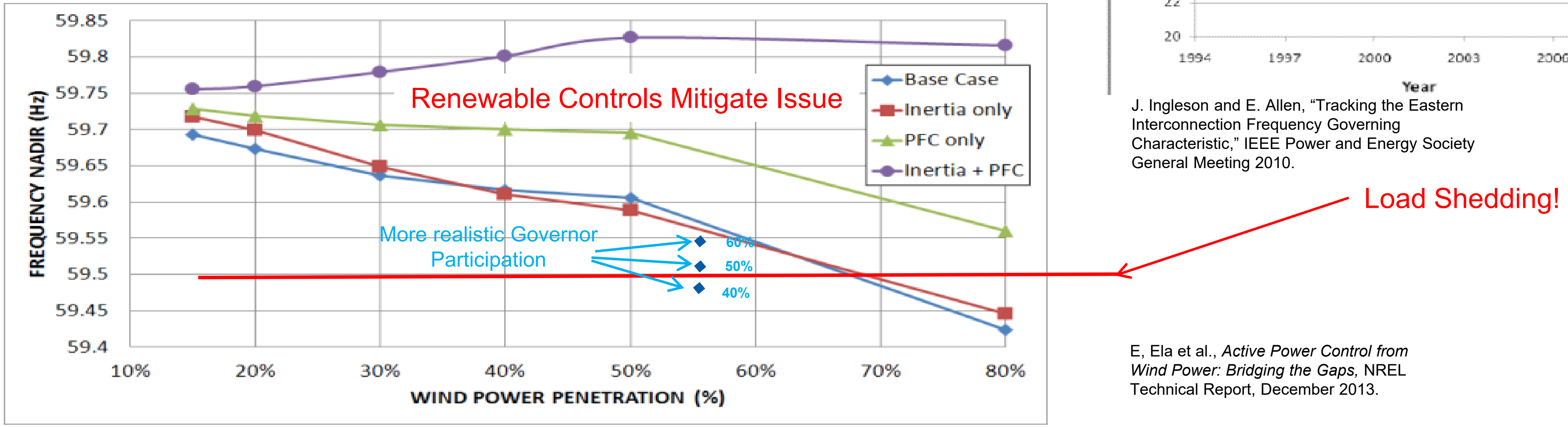
Objectives

- Avoid Under frequency load shedding
- Share responsibility across an interconnection
- Stable frequency

- Current issues exist
  - Governor dead bands, blocked governors, sliding pressure



J. Ingleson and E. Allen, “Tracking the Eastern Interconnection Frequency Governing Characteristic,” IEEE Power and Energy Society General Meeting 2010.



E, Ela et al., *Active Power Control from Wind Power: Bridging the Gaps*, NREL Technical Report, December 2013.

VERs with control supports interconnection frequency response

Regulation vs. Primary Frequency Response (PFR)

- Regulation brings ACE to zero, PFR is proportional to frequency deviation and stabilizes frequency
  - PFR does not correct frequency deviation (to zero), but arrests it from further decline
  - Regulation corrects frequency deviation by correcting ACE
- Regulation (theoretically) only corrects for imbalances within area, primary frequency response corrects imbalances across interconnection
- Primary frequency response is autonomous local control, regulation is through AGC, as directed by system operator
- Primary frequency response typically for large contingency events (> 36 mHz), regulation used all the time
- Regulation ensures that it does not counter what the area should be providing through PFR through frequency bias
- Regulation performance through Control Performance Standards (CPS1); PFR through frequency response obligation (FRO)
  - The Balancing Area ACE Limit requirement has overlap across the two
- Markets exist explicitly for regulation; implicit or do not exist for PFR

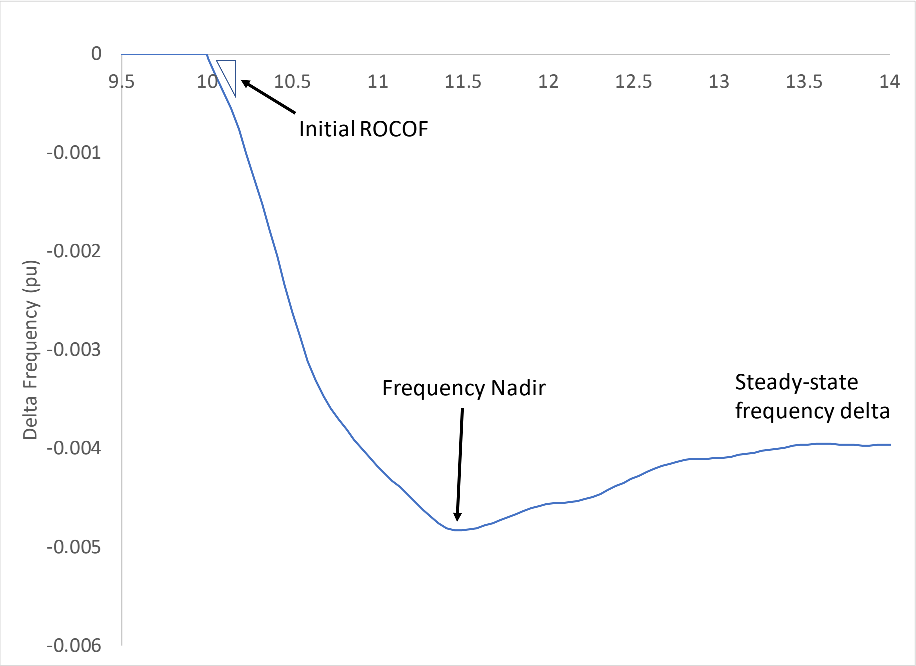
FERC Order 842

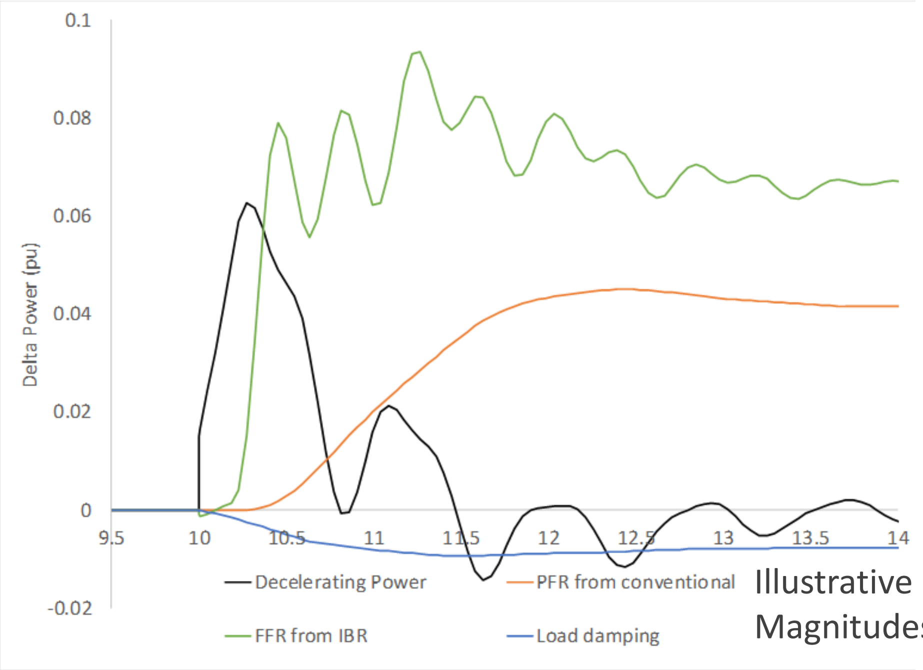
- Requires all newly interconnecting facilities, synchronous and non-synchronous (IBRs) to install, maintain, and operate equipment capable of providing primary frequency response as a condition of interconnection
- Requires a 5% droop and 36 mHz dead band or less
- Sustainable response (no withdrawal)
- Storage to provide response but exempt from sustainable response if state-of-charge is limited
- Did not include head room requirements or compensation requirements

Fast Frequency Response

How does it differ?

- Thermal and hydraulic time constants exist for **PFR** from thermal and hydro generation
- **Synchronous inertia** – immediate response to event, slows down rate of change of frequency, but does not balance mechanical supply to load
- Fast Frequency Response
  - PFR, that needs control signal to trigger but power electronics lack substantial time delays
  - Can support raising frequency nadir and frequency response
  - Not the same as synchronous inertia
  - Generally, requires operation below maximum availability for IBRs
  - Research looking at operating power systems without any inertia and "grid forming inverters"





Illustrative only
Magnitudes not relevant

Synchronous Inertia

- Slows the rate of frequency decline
- Maintain synchronism
- Less inertia could require more or faster primary frequency response to avoid UFLS
- IBRs do not provide synchronous inertia
- Methods for extracting inertia of rotating wind turbines to the grid lead to a "pay back" in energy to prevent stalling
- No inertia requirement in U.S.
  - ERCOT has a minimum inertia monitor of 100 GVA*s [7]
  - Hydro Quebec requires synthetic inertia response from IBRs

Hydro Quebec's – Synthetic Inertia Requirements

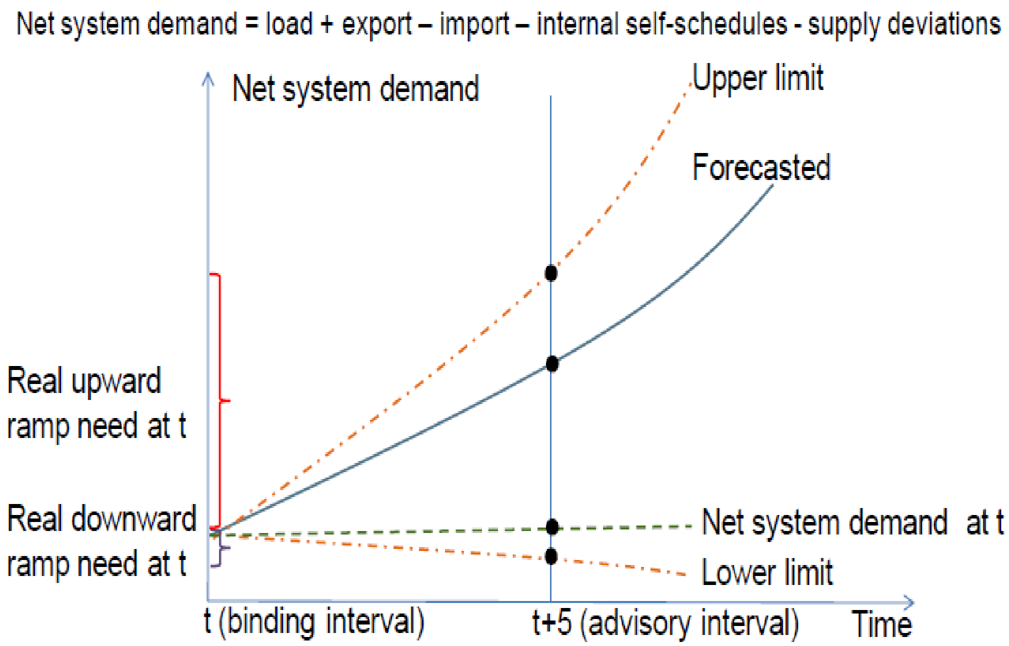
- Hydro Quebec requires its generation resources to provide inertia or inertia emulation. [8]
- Hydro Quebec has included a new term to describe IBRs, "SERMO", which is defined as an energy source (such as wind energy, solar irradiation or energy stored in a battery) connected through inverters.
- The generating stations using SERMOs with installed capacity greater than 10 MW must be designed with the following frequency control functions:
  - Primary frequency control for all SERMO technologies
  - Inertial response (synthetic inertia) for wind generating stations only
- This mandated requirement by Hydro Quebec - for an asynchronous resource to provide a service provided by synchronous resources - is unique across the worldwide electricity industry.

Flexibility/Ramping Reserves

Flexible ramping reserves

Other Common names: ramp capability, load following, flexible ramp, following reserve

- Requirements based on short-term variability and uncertainty
  - 5-10 minute variability
  - Avoid ramp infeasibilities that lead to price spikes
  - Low-priced demand curves
- **MISO**: Since May 2016
- **CAISO**: Since November 2016
- **SPP**: 2021
- **Longer-term products in development**



Real ramping need:
Potential net demand change from interval t to interval t+5
(net system demand t+5 – net system demand t)

Short-Term Ramping Reserves: Practical Characteristics

	MISO	CAISO	SPP
Product name	Up and down Ramp Capability	Flexible Ramping Product–upward and downward reserves	Ramp Capability Product
Time Requirement	10 mins	5 mins	10 mins
Quantity Requirement Method	Expected variability + unexpected uncertainty (e.g.1075 MW since 9/2021)	Expected variability + 95th percentile of uncertainty 2023 added a regression model that utilizes the “prevailing load/wind/solar forecasts” to accompany the historical histogram	Net load changes plus 95th percentile of uncertainty
Quantity Requirement	Large range depending on time of day. Approximately 2,000 MW for upward ramp capability on average.	Also varies significantly. Up to about 350 MW for upward ramp capability.	Varies significantly depending on hour of day (e.g. > 1400 MW during morning ramp and at the minimum of 200 MW when variability/uncertainty is low such as in the late evening). Average ~500.
Included market or process	Day-Ahead Market, real-time look ahead commitment, and real-time market	Both Fifteen Minute Market and real-time (5-minute) economic dispatch	Day-ahead, RUC, and real-time

Long-Term Ramping Reserves: Practical Characteristics

	MISO	CAISO (proposed)	SPP
Product name	Short-Term Reserve	Imbalance Reserve	Uncertainty Product
Time Requirement	30 mins	15-min, but focused on day-ahead	One Hour
Quantity Requirement	Dynamically determined offline through loss of generation and flow constraints Requirements exist for “local, sub-regional, and market-wide needs”	Based on forecast differences between day-ahead and fifteen-minute market	Forecasted net obligation change and net obligation forecast error
Online & Offline Participation	Yes	Yes	Yes
Offer or Lost Opportunity Based	Online resources at lost opportunity, while offline resources provide an offer		Online resources at lost opportunity, while offline resources provide an offer
Approx. Requirement Range			0 – 2000 MW. Varies hour to hour and by day.

Reactive power supply/ Voltage control service

Reactive power supply/ Voltage control service

- **Definition**: generation service for producing or absorbing of reactive power to maintain transmission voltages on transmission facilities within acceptable limits.
- **Purpose**: to control voltage variations and to increase the power transfer capability of the system.
- **Performance requirements**:
  - Power Factor Range: within the power factor range of 0.95 leading to 0.95 lagging
  - Point of Measurement: Reactive power requirement is measured at the high side of the generator substation.
  - Control option: Static (from slower resources), dynamic (faster resources)
  - Real Power Output Level: Generating Facility is required to meet the reactive power requirements at all levels of real power output

- Per the FERC Order 827, issued in 2016, all newly interconnecting technologies must have the capability to provide reactive power and voltage support.
- This includes non-synchronous technologies such as wind power (type 3 and 4) and modern solar generators.
- Voltage control service does not have competitive auction-based markets in any of the North American ISOs.
- It is generally paid as a cost-based service, where ISOs compensate resources for the costs that are incurred when providing the service, including the lost opportunity costs.

FERC Order 827

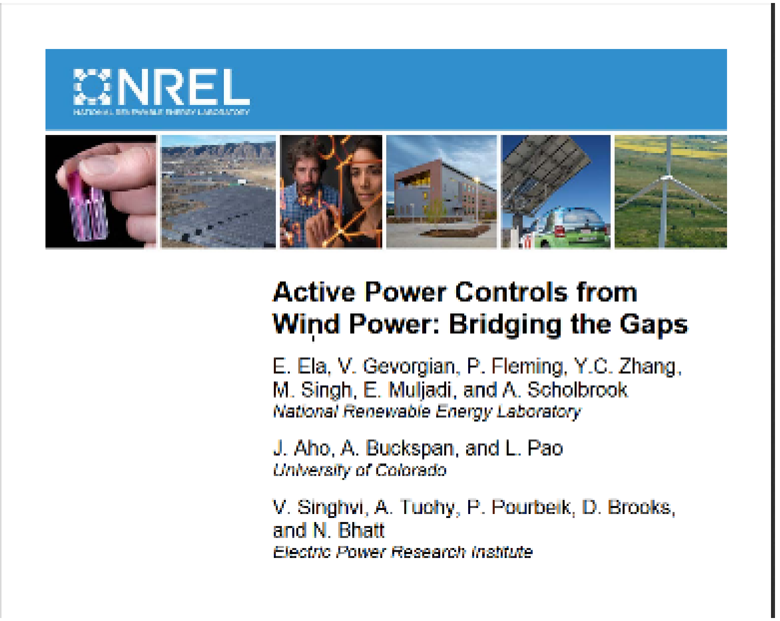
- Eliminate exemption for new wind generation (and other non-synchronous generation) to provide reactive power support
- Applies only to new generation and not existing
  - Would apply to existing plants making upgrades with new interconnection requests
- Dynamic reactive power at high-side of generator substation and not point of interconnection
  - Due to commenter's suggestions of higher costs at point of interconnection
  - Rather than combination of static support at point of interconnection
- Requirement is for all active power output
  - Current PJM requirement exempts wind generation when below 25% of max capacity
- No changes to compensation procedures
  - Existing methodologies for synchronous generators may not apply to nonsynchronous generators – need to propose a method for calculating compensation

Services by VERs/IBRs

Can wind (and solar) provide Ancillary Services?

And are they?

- Technical capability to provide most services demonstrated and proved [9], [10]
- FERC Order 827, 842 requires capability

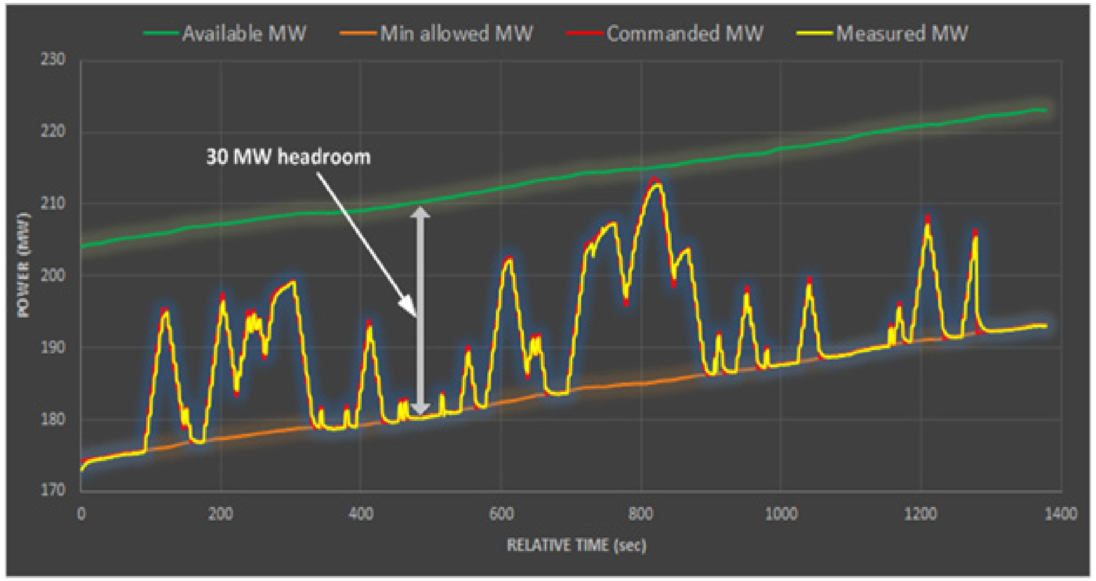

NREL

Active Power Controls from Wind Power: Bridging the Gaps

E. Ela, V. Gevorgian, P. Fleming, Y.C. Zhang, M. Singh, E. Muljadi, and A. Scholbrook
National Renewable Energy Laboratory

J. Aho, A. Buckspan, and L. Pao
University of Colorado

V. Singhvi, A. Tuohy, P. Pourbeik, D. Brooks, and N. Bhatt
Electric Power Research Institute

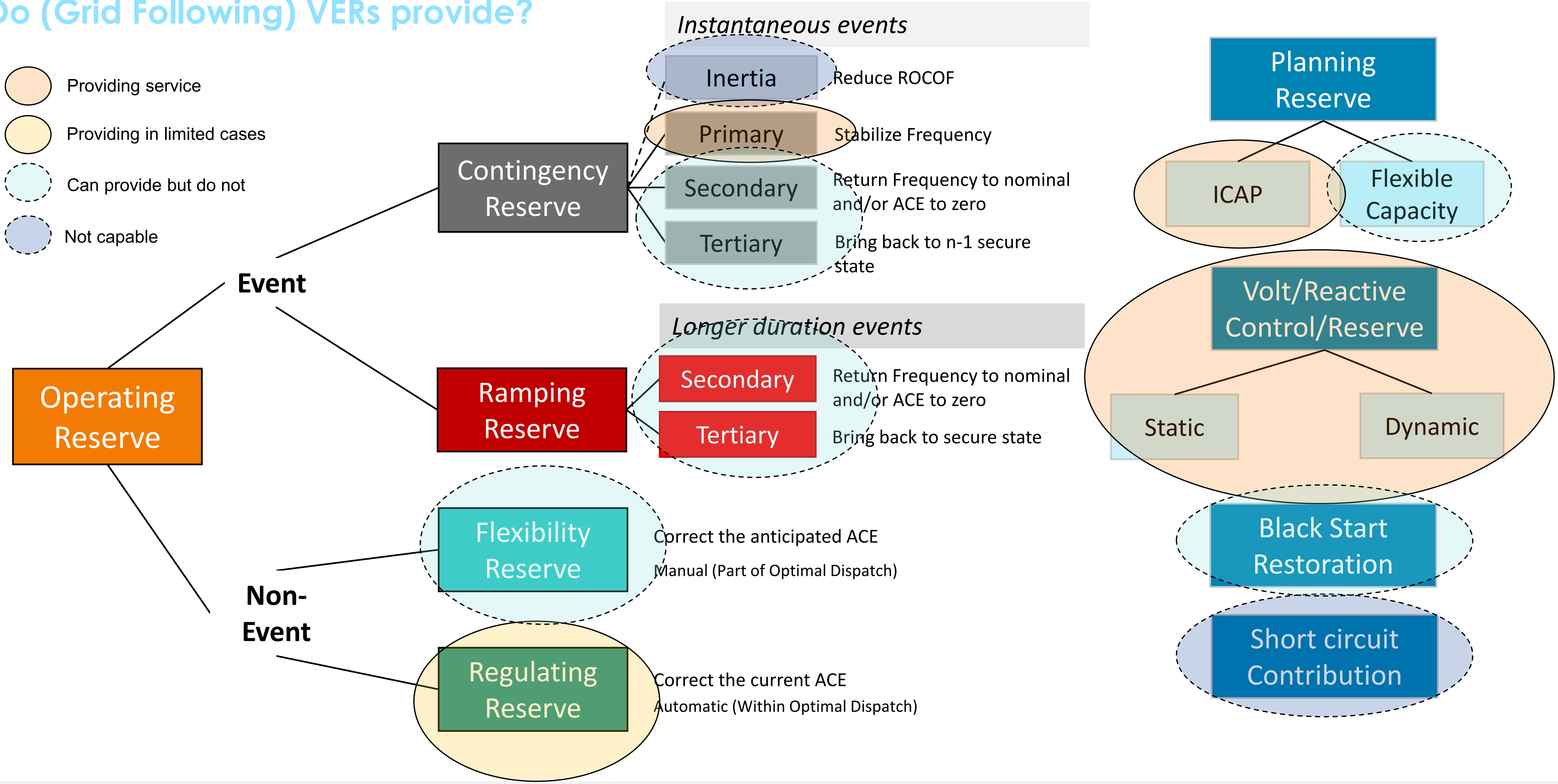


CAISO, First Solar, NREL, "Demonstration of Essential Reliability Services by a 300-MW Solar Photovoltaic Plant," NREL/TP-5D00-6799, March 2017.

- Challenges still exist
  - Regulatory
  - Economic
  - Forecast uncertainty (Operator confidence)

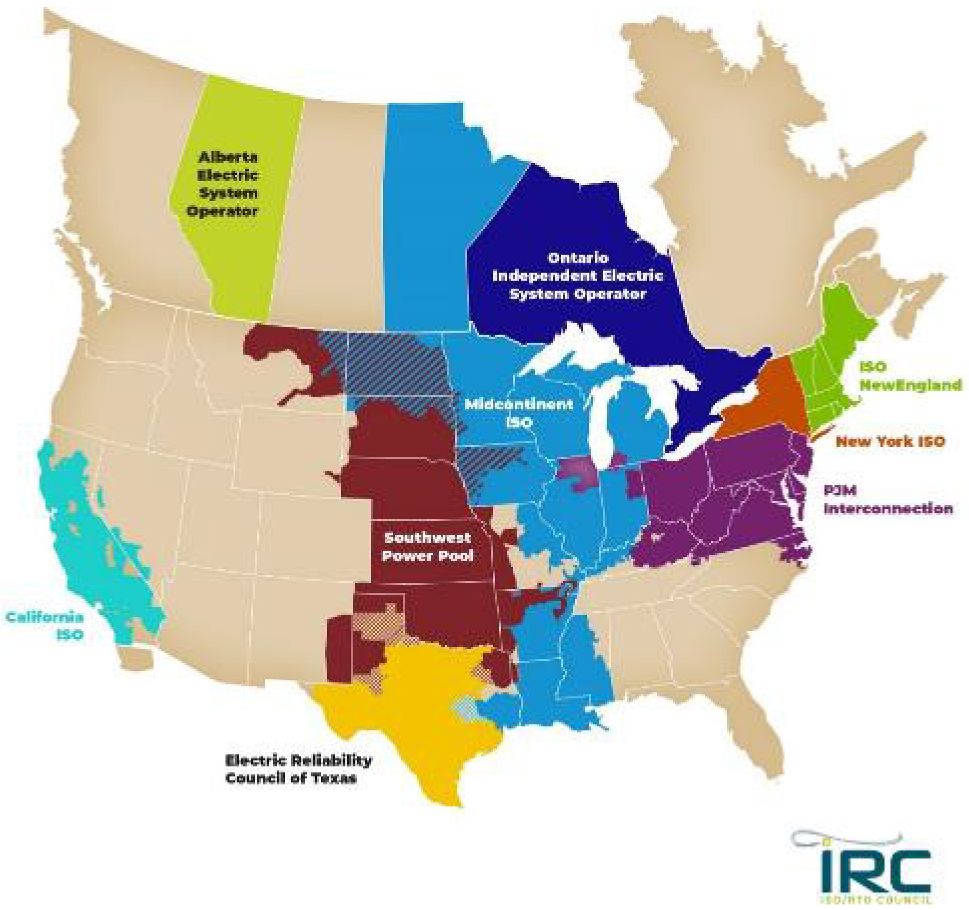
Ancillary Services

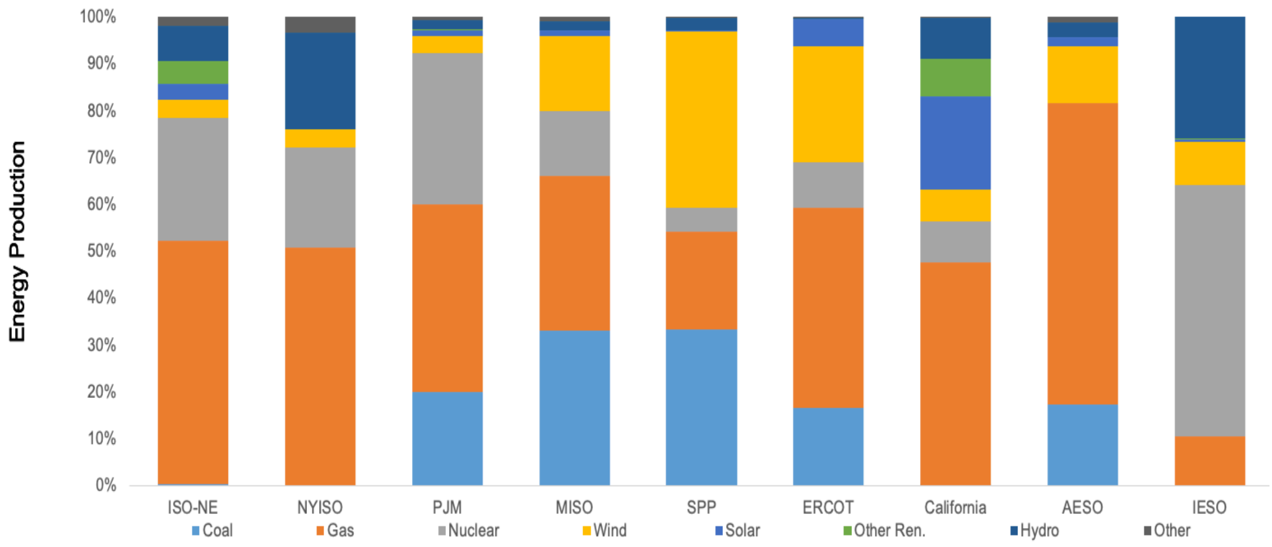
Do (Grid Following) VERs provide?



Grid Services Markets and Revenues

Electricity Market Comparisons

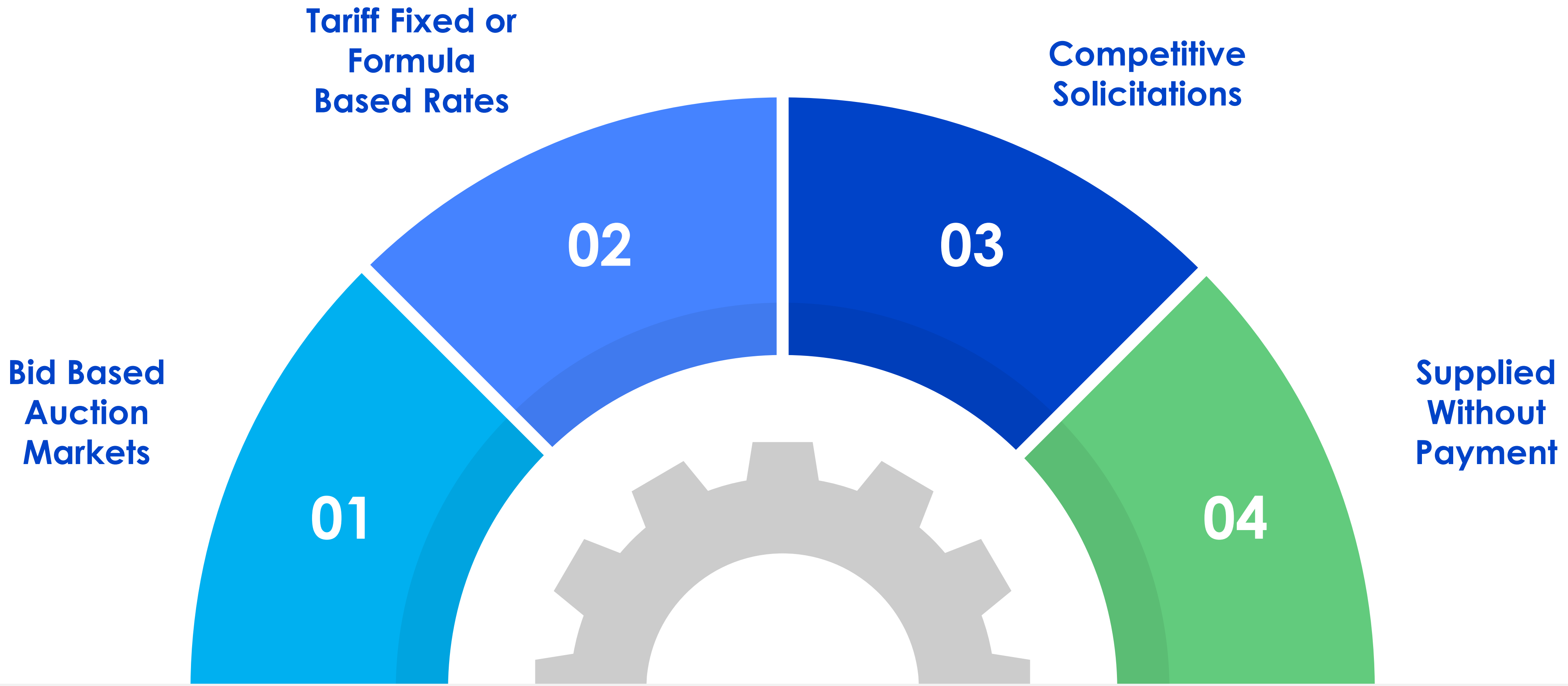




	Total Market Volume ($B)	All-in-Price ($/MWh)	Energy ($B)	Ancillary Services Markets ($M)	Uplift ($M)	Financial Transmission Rights ($M)	Capacity Market ($M)
AESO (CAD$)	20.4	162.46	19.9	501	4.57	N/A	N/A
CAISO	21.6	95	21.1	237	700	265	N/A
ERCOT	32.2	74.92	29.3	1,572	368	1,098	N/A
IESO (CAD$)	23	47.8	6.6	59	260.93	60.1	68.48
ISO-NE	16.7	140	11.7	100	50	0.6	2,000
MISO	48.5	73	43	106	140	385	5,979
NYISO	13.6	90.18	11.9	181	94	144	2,247
PJM	86.22	105.34	62.4	844	290	1,647	6,252
SPP	54	50.83	48.6	584	173	2655	N/A

[11] *Wholesale Electricity Market Design in North America: Reference Guide: 2022 Review*. EPRI, Palo Alto, CA: 2022. 3002024553.

Mechanisms to Procure Ancillary Services



From an IBR’s perspective…

The decision about whether to provide ancillary services must balance potential revenues with the cost of providing the service

Market Revenues

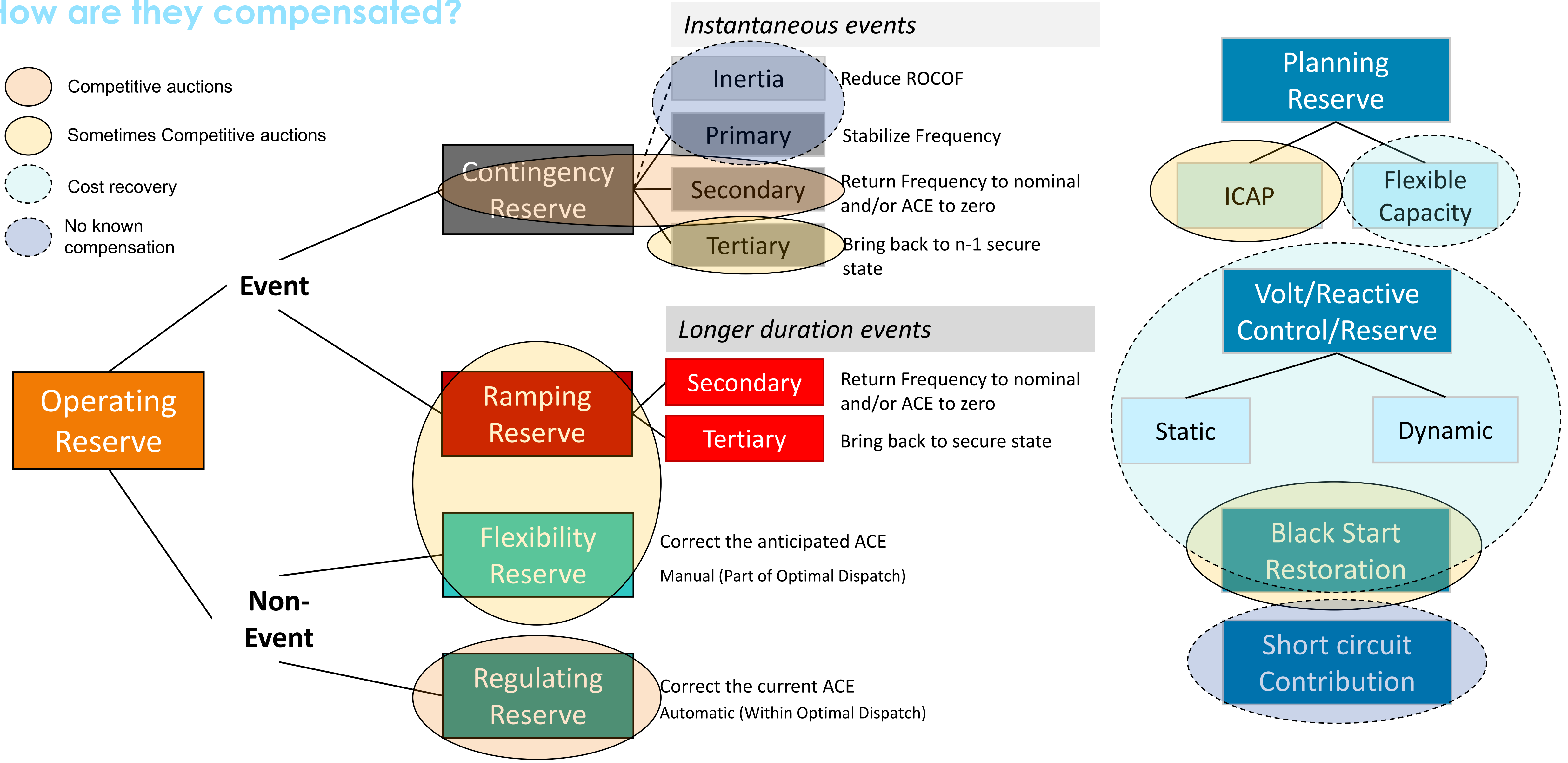
- Ancillary Service Markets are small and thin
- Potential revenues could grow over time

Cost of Provision

- Foregone energy revenues
- Renewable energy or emission credits
- Financial incentives based on energy production
- Equipment or administrative costs

Ancillary Services

How are they compensated?



Why do not all services have competitive markets?

- Some reliability attributes are not currently incentivized
- Sometimes auctions and market-based pricing for certain services may be impractical

Reasons why a market product may not be implemented	Example
Too complex to design (e.g., software complexity)	Volt/VAR support
Too specific to certain local areas (little to no competition)	Volt/VAR support
System inherently has more than sufficient amounts of the service	Synchronous Inertia
Costs for the service may be small, so cost of administrating market product may outweigh benefits	Black start (restoration) service
A specific resource requirement rather than a system-wide need	Low Voltage Ride Through

The examples are used for illustrative purposes only and the reason may not be necessarily true for each example in each region.

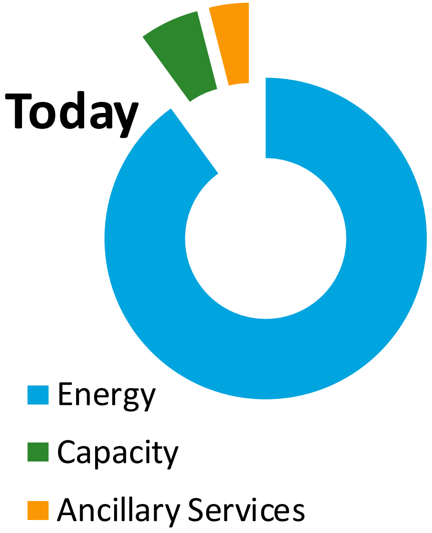
Markets are not necessarily needed for every grid service!

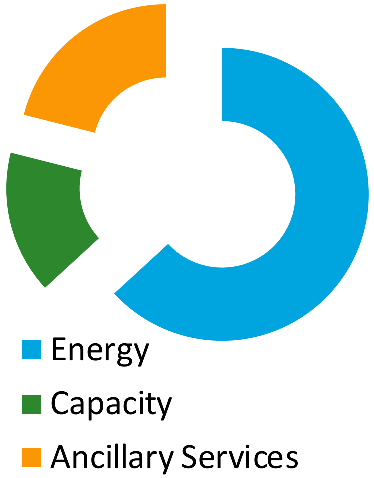
Ancillary Service Market Design

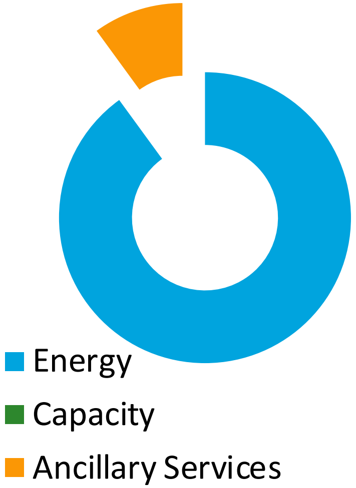
- Two-Settlement
- Payments for capacity reserved not deployed reserve
- Co-optimization with energy and lost opportunity cost
- Pricing Hierarchy and Cascading
- Administrative Shortage Pricing
- Market Power mitigation
- Regulation pay for performance

Future Market Outcomes

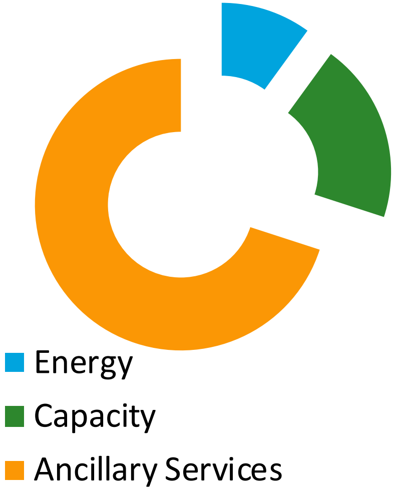
Today

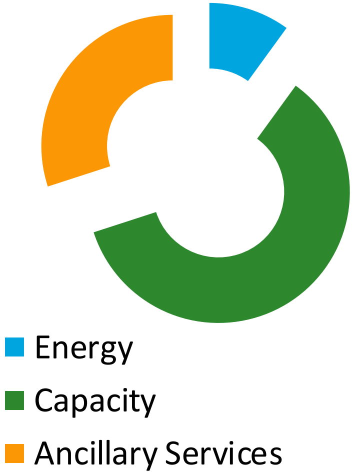






Which Future?





Fully Decarbonized Markets: Recent Industry Research & Price Formation Fundamentals. EPRI, Palo Alto, CA: 2023. 3002028684.

Ancillary Service Considerations for Future System Scenarios

Does this product (e.g., "x-minute reserve") still make sense and provide value on this future resource mix and scenario?

Will ancillary services be a substantial revenue source on future systems?

Will pricing be on opportunity costs or will we need greater incentives?

How does this emerging technology provide this flexibility service differently than existing technologies?

Are we setting the requirements for this product based on what they are actually used for?

Are there new grid services in the future that we don't know about? Will they need to be incentivized?

EPRI

Overcoming Barriers

Technology Barrier

- **Challenge**: Limitations in technology (resource or grid operator) to provide and deliver the grid service.
- **Action**: Develop and demonstrate the control strategy. Show that it works and service can be provided.

Reliability Barrier

- **Challenge (performance)**: Grid Operators are not certain whether these technologies will perform adequately or if it will negatively impact the system.
- **Action**: Run power system simulations to demonstrate reliability benefits.

Economic Barrier

- **Challenge**: Technology to provide a specific service may be too expensive, or cost to hold back energy to provide grid services may not be justifiable.
- **Action**: Run techno-economic simulations (e.g., production cost simulation) to demonstrate whether true and under what circumstances.

Barrier Unresolved

Informing stakeholders is key to addressing all barriers

Conclusions and Next Steps

Takeaways

- Penetrations of IBRs are growing
- Maintaining future grid stability and reliability hinges on IBRs providing some of the services currently (or formerly) provided by synchronous generators
- The procurement and deployment of the services can be implemented either as mandatory interconnection requirements or as market products.
- Procurement and compensation mechanisms can consider the costs of provision
- At the same time, future energy markets are likely to change. Procurement methods may need to adapt to new conditions and price signals

Next Steps on a Pathway toward VER/IBR Providing Grid Services

- Education and collaboration
- Demonstrations and pilots of large facilities
- Evaluating tariff for eligibility criteria that is technology neutral
- Studies into potential efficiency and revenue opportunities
- Operational strategies (probabilistic information and exceedance forecasts)
- New technology concepts (Grid-forming inverters)

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