Frequency Response Phase 2 Working Group Meeting

February 9, 2017

Cathleen Colbert
Market and Infrastructure Policy
## February 9 working group agenda

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<tr>
<th>Time</th>
<th>Topic</th>
<th>Presenter</th>
</tr>
</thead>
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<tr>
<td>10:00 – 10:05</td>
<td>Introduction</td>
<td>Kim Perez</td>
</tr>
<tr>
<td>10:05 – 10:15</td>
<td>NERC &amp; FERC guidance on frequency response</td>
<td>Cathleen Colbert</td>
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<tr>
<td>10:15 – 10:25</td>
<td>Comparing frequency control and operating reserve markets</td>
<td>Cathleen Colbert</td>
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<td>10:25 – 10:35</td>
<td>California Energy Storage Association Presentation</td>
<td>Alex Morris</td>
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<td>10:35 – 12:00</td>
<td>Brainstorm Session</td>
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<tr>
<td>12:00 – 1:00</td>
<td>Lunch</td>
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<td>1:00 – 1:45</td>
<td>Frequency responsive controls</td>
<td>Sebastian Campos</td>
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<tr>
<td>1:45 – 2:30</td>
<td>Primary frequency response design options</td>
<td>Sebastian Campos</td>
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<td>2:30 – 3:50</td>
<td>Discussion</td>
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<tr>
<td>3:50</td>
<td>Next Steps</td>
<td>Kim Perez</td>
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ISO policy initiative stakeholder process

POLICY AND PLAN DEVELOPMENT

Issue Paper → Straw Proposal → Draft Final Proposal → Board

Stakeholder Input

We are here
Objectives
Frequency Response Phase 2

• ISO expects frequency response will continue to worsen as non-conventional technologies increase

• Without explicit procurement of primary frequency response:
  – ISO cannot ensure it will position the fleet to provide sufficient frequency response
  – ISO needs to mitigate risk of non-compliance by procuring transferred frequency response

• ISO is concerned with relying on procuring compliance instrument to meet reliability requirement in the long term and believes it has received guidance to pursue other approaches
NERC & FERC GUIDANCE ON FREQUENCY RESPONSE
NERC’s Essential Reliability Services

Essential Reliability Services (ERS) are the reliability building blocks necessary to maintaining reliability.

<table>
<thead>
<tr>
<th>ERSs in Functional Terms</th>
<th>Effects of Lack of ERS Availability</th>
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<tbody>
<tr>
<td>- The primary objective of Voltage Support is to maintain the voltages in the transmission system within a secure, stable range.</td>
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<td>- Voltage Support is location-specific and requires reactive power control from reactive resources distributed throughout the power system.</td>
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<tr>
<td>- Frequency Support ensures the frequency of the BPS can be synchronized and stabilized for both normal and contingency conditions.</td>
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<tr>
<td>- Daily operation of the BPS requires a continuous balance of load and resources (generation and demand-side resources).</td>
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<tr>
<td>- Operational flexibility is needed to manage real-time changes in load and generation.</td>
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<tr>
<td>- Localized voltage issues can spread to a wider area, causing loss of load.</td>
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<tr>
<td>- Exceeding design voltage parameters can destroy equipment by breaking down insulation.</td>
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<tr>
<td>- Undervoltage conditions can lead to motor stalls and equipment overheat.</td>
<td></td>
</tr>
<tr>
<td>- Voltage collapse can lead to cascading drop in voltage and cause undesirable events.</td>
<td></td>
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<tr>
<td>- Large frequency deviations can result in equipment damage and power system collapse.</td>
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<tr>
<td>- Interconnection frequency deviation can result in: 1. Loss of generation 2. Load shedding 3. Interconnection islanding</td>
<td></td>
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<tr>
<td>- Puts BPS stability and the reliability area at risk.</td>
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<tr>
<td>- Imbalance in generation and load can overload transmission facilities.</td>
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<tr>
<td>- Protection equipment can malfunction or be damaged.</td>
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<tr>
<td>- Prolonged imbalance can result in violation of NERC Reliability Standard (BAL-001-1).</td>
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</table>
Frequency support from frequency control is a fundamentally different service than voltage support.

**Frequency control services:**
- Active/real power output
- Requires maintaining reserves
- Grid service
- Fungible service between resources
- Overlaps with energy capacity

**Voltage support services:**
- Reactive power output
- Does not require maintaining reserves
- Location specific service (necessary for generator to deliver energy)
- Not fungible service between resources
- Doesn’t overlap with energy capacity
Frequency control stages compared to products – potential and existing

- Inertial Response
- Primary Frequency Response
- Secondary Frequency Response
- Tertiary Frequency Response

Market Products

- Synthetic Inertia/Fast Frequency Response
- Primary Response
- Secondary Response
  - Regulation Up/Down
  - Spinning Reserves
  - Non-spinning Reserves
Frequency support services compared to products – potential and existing

- **Inertia**
  - Inherent
  - Synthetic

- **Frequency Disturbance Performance**
  - Frequency Control
    - Primary
    - Secondary

- **Active Power Control (APC)**
  - Ramping

- **Operating Reserves**
  - Regulation
  - Load Following
  - Spinning
  - Non-spinning
  - Supplemental

**Market Products**
- Synthetic Inertia/Fast Frequency Response
- Primary Response
- Secondary Response
- Flexible Ramping
- Regulation Up/Down
- Spinning Reserves
- Non-spinning Reserves
FERC proposed rules on primary response

FERC proposes to require all resources submitting a new interconnection request that results in filed executed/unexecuted interconnection agreement to:

- Install frequency response capability

\textbf{Policy Change}

- Set governor or equivalent controls to be operated, \textit{at a minimum}, with maximum 5 percent droop and \(\pm 0.036\) Hz deadband settings

\textbf{Existing Policy}

- Provide sustained response until frequency returns to a stable value within the governor’s deadband setting

\textbf{Policy Change}

- Not inhibit provision of primary frequency response, with certain exceptions

\textbf{Existing Policy}

- Base droop settings on nameplate capability with a linear range of 59-61 Hz
COMPARING FREQUENCY CONTROL AND OTHER MARKETS
Frequency control services are fundamentally different services than operating reserves

<table>
<thead>
<tr>
<th>Frequency control services:</th>
<th>Operating reserve services:</th>
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</thead>
<tbody>
<tr>
<td>– Automatic active/real power output to stabilize frequency</td>
<td>– Operator controlled active/real power output</td>
</tr>
<tr>
<td>– Requires maintaining reserves</td>
<td>– Requires maintaining reserves</td>
</tr>
<tr>
<td>– Grid service providing Interconnection security</td>
<td>– Generation &amp; demand balancing service</td>
</tr>
<tr>
<td>– Energy will not be delivered as byproduct of response</td>
<td>– Energy may be delivered as byproduct of balancing function</td>
</tr>
<tr>
<td>– Fungible</td>
<td>– Largely fungible</td>
</tr>
<tr>
<td>– Does not require transfer capability</td>
<td>– Requires transfer capability to ensure feasible delivery</td>
</tr>
</tbody>
</table>
Frequency control services require reserves above operating reserves that are not procured for RA

- Frequency responsive reserves are reserves:
  - Automatically deployed to arrest & stabilize frequency
  - Not ISO dispatchable to manage gen & load balance
  - Must be maintained above firm demand and operating reserves margin

- ISO believes that resource adequacy or flexible resource adequacy capacity procured to ensure RA to ensure energy deliverability cannot be awarded frequency responsive reserves since these reserves cannot be released by ISO dispatch to ensure deliverability during peak or ramping needs
Operating reserves considerations important to evaluating frequency response product

- The manner of response from regulation as well as the potential primary response from unloaded capacity could impact the amount of frequency response needed ➔ amount of reserves needed

- For example, may need to adjust when regulation signals are sent as ISO frequently observes notable secondary response around 20 or 30 seconds following an event and if ACE is positive may send Reg Down dispatch signals while primary response is provided ➔ regulation might dampen measured response impacting amount

- For example, may need to adjust requirement based on expected frequency response performance from regulation or spin since both are expected to be frequency responsive ➔ operating reserves might result in reducing frequency response requirement
Can regulation undermine the FRM if ACE signal is moving units down when response is measured?

- ISO analyzed 36 frequency response events from Jan – Nov 2016 to see what direction Regulation signal was moving regulation units.
- 7 of the 36 events had an ACE signal on average that was positive.
- Should the ISO consider deeper analysis to determine whether it should account for an upward bias needed.
FREQUENCY RESPONSIVE CONTROLS
Overview

This section will discuss:

- Governor control functionality (theoretical and observed)
- Inverter control functionality
- Under-frequency relay device functionality
Governor controls allow conventional generators to provide frequency response

- Governor controls, i.e. speed controls, determine the speed and rate at which a conventional resource provides real power output in response to changes in system frequency to provide frequency response in MW/0.1Hz
ISO observation of actual thermal and hydro response

**Generation Outage**

**Frequency out of dead band**

**Transient Period**

**Point B**

- **Response (MW)**
  - **Hydro Response**
  - **Thermal Response**
Inverter Technology

(Images and diagrams showing solar panels, wind turbines, and power grid components. Diagrams illustrate the flow from DC/AC inverters to AC/AC inverters, leading to the grid.)
Inverter Technology

- Requires unloaded capacity or battery charge available to deploy
- Inverters typically operate as controlled current sources. This means that the high-frequency switching of the inverter is controlled so that the output current from the inverter is actively forced to follow a reference signal.
- With an optimum design the output current control can be extremely fast (<1ms response) and accurate (<1%)
PV Units test

- Droop response of PV Units can be set on Controls of the Plant

The ISO conducted test with First Solar to measure the ability of PV Units.

Source: Using Renewables to Operate a Low-Carbon Grid – California ISO
Wind Turbines Generators (WTG)

- Advanced controllers that combine torque and pitch control to implement primary control during frequency events are required.

The variable-speed WTG can provide the power boost during the frequency decline if the generator, power converter, and wind turbine structure are designed to withstand the overload necessary. (Type 3 and 4)

Source: Understanding Inertial and Frequency Response of Wind Power Plants – NREL
Inertial response of the conventional generators is dependent on their physical mass, and the physics of the synchronous machine, and cannot be changed. In the case of wind turbines, the inertial response can be tuned to improve power system performance during the initial decline of the frequency after loss of generation.

Depending on the technology of the WTG this units could provide FFR/PFR without reserving Headroom, but with high dependency of wind speed.

Source: Understanding Inertial and Frequency Response of Wind Power Plants – NREL
Batteries Energy Storage System (BESS)

- BESS have the capability to respond against frequency changes, this response can be through a droop control or through a pick up regarding its frequency settings.
- These technologies can have autonomous response, or be controlled through an ISO signal if its required.
Batteries Energy Storage System (BESS)

- FR provided in less than 500 ms
- BESS responds in over and under frequency events

Source: Model Homologation Report - BESS Power Plant Cochrane – AES Gener Chile
Pump Storage Hydro

- Pump storage hydro can provide PFR in different ways, depending on the operation mode.
- If the unit is generating, can provide PFR through its governor control.
- If the unit is pumping, could provide PFR by losing its pumping load with under-frequency relays.

Can it provide PFR through modulated load shedding response that could be similar to a droop response?

Source: The Silver Creek Pumped Storage Project
Demand Response

• Load usually provides frequency response based on under-frequency relay technologies. This could impact its proportional response to frequencies greater than their pick up.
  – Could load perform on a proportional response? What types of devices should be implemented?

• Load characterization allows industries to detect non-critical process that can be stopped for short periods, and allows them to provide PFR.
  – Has the industry developed this type of study?
Take Aways

• ISO continues to believe there is no ground for excluding any technology types from any future frequency response product

• ISO believes that governor and inverter frequency control devices can be programmed to provide proportional response and proportional decline of response as frequency stabilizes

• ISO will consider input on its questions as to whether pumped storage and demand response controls would provide proportional response
PRIMARY FREQUENCY RESPONSE DESIGN OPTIONS
### ERCOT

#### Primary Frequency Response
- Instantaneous proportional increase or decrease in real power output
- 12 to 14 sec to fully deployed
- Attained to GOV response
- Arrest the Frequency Decay and re-set frequency closer to 60 Hz.
- Resources providing PFR must be able to respond proportionally to frequency deviation
- Droop setting not to exceed 5% - Governor DB <= +/- 0.036 Hz
- Generators without PFR responsibility may have bigger DB

#### Fast Frequency Response
- Fully deployed within 30 cycles (0.5 seconds)
- Increase the time to reach the frequency nadir and mitigate the RoCoF in the same period.
- Sustained for at least 10 minutes
- Needed in periods with low inertia.
- Requires PMU measurement.
- Mainly provided by demand resources
- 2 trip setpoints: 59.8 & 59.7

#### Fast Responding Regulation
- Fully deployed within 60 cycles (1 second)
- Must be able to be deployed up to 8 minutes
- Fast Resources e.g. Batteries
- Requires high speed data recorder for verification.
- Two modes of providing regulation service:
  - Self deploy in response to locally sensed frequency deviation (over a prescribed dead-band)
  - Response to special signal from ISO AGC
- Load can participate with percentages of responsibility according with frequency bands.
## National Grid

<table>
<thead>
<tr>
<th><strong>Mandatory frequency response</strong></th>
<th>Capability for all large resources (&gt;100MW [&gt;30MW in Scotland]) connected to the grid</th>
</tr>
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<tbody>
<tr>
<td>Report monthly basis costs and capability associated with providing the frequency response</td>
<td>Generators instructed to provide the service must De-Load its energy provision to a level that at least can provide the amount of primary response required</td>
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<tr>
<td></td>
<td>Holding payment and energy payment</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Firm frequency response</strong></th>
<th>Availability fee: a per-hour fee for the hours a generator will provide services.</th>
</tr>
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<tbody>
<tr>
<td>Market available to every market participant</td>
<td>Window initiation fee: a fee awarded each time the generator provides firm frequency response.</td>
</tr>
<tr>
<td>Can be bid from one to 23 months</td>
<td>Nomination fee: a per-hour fee for each hour the units provides frequency response.</td>
</tr>
<tr>
<td></td>
<td>Response energy fee: a per-MW fee for the frequency response actually provided.</td>
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</tbody>
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<table>
<thead>
<tr>
<th><strong>Frequency response by demand management</strong></th>
<th>Demand resources can apply each year to become frequency responders.</th>
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<tbody>
<tr>
<td></td>
<td>Bilateral contracts with the NG to interrupt their supply should the system frequency fall below 49.7 Hz</td>
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<tr>
<td></td>
<td>Load must be shed within 2 seconds and remain offline for up to 30 minutes</td>
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<td></td>
<td>Minimum response of 3 MW</td>
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<thead>
<tr>
<th><strong>Enhanced frequency response</strong></th>
<th>Respond in under 1 second and provide response for up to 15 minutes.</th>
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<tbody>
<tr>
<td>Contracted on no more than 48 months, through a competitive tender process.</td>
<td>Resources will be compensated on a per-MW basis, scaled by an availability factor determined by how accurately the unit followed the supplied response curve.</td>
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</table>
AEMO (Australia)

- The AEMO performs this procurement in real time only, FCAS are not procured in the day-ahead market.
- The registered resources will submit simultaneous bids for energy, regulation, and contingency reserves. AEMO co-optimizes these bids to create six different clearing prices for contingency market.
- The MW amount that a unit can provide as frequency response is limited by the MW amount of energy the unit is generating at as well as its droop’s technical parameters.
- All units are paid at the marginal bid.

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<tr>
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<th>Raise</th>
<th>Lower</th>
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<tr>
<td>Fast contingency FCAS</td>
<td>6 second response to a major drop in frequency sustained for 60 seconds</td>
<td>6 second response to a major rise in frequency sustained for 60 seconds</td>
</tr>
<tr>
<td>Slow contingency FCAS</td>
<td>60 second response to a major drop in frequency sustained for 5 minutes</td>
<td>60 second response to a major rise in frequency sustained for 5 minutes</td>
</tr>
<tr>
<td>Delayed contingency FCAS</td>
<td>5 minute response to a major drop in frequency sustained indefinitely</td>
<td>5 minute response to a major rise in frequency sustained indefinitely</td>
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</table>
50 Hz (Germany)

- Deployment of activated primary control reserve (PCR) has to be realized within 30 seconds
- PCR is procured in weekly tenders that means that successful offers of PCR have to be able to guarantee a provision over a weekly period.
- Outcomes will reflect capacity price merit-order
- The minimum bid amount is 1 MW
- PCR will be paid as bid, considering only provision, the energy is not getting payed separately
- PCR is considered a symmetric product
- Technical pre-qualification is required with physical evidence.
NEXT STEPS
Next Steps

Stakeholders are asked to submit written comments by **February 23, 2017** to InitiativeComments@caiso.com.

ISO will host another working group meeting to present an initial straw proposal with options as result of this working group meetings discussion and follow-up comments prior to releasing the straw proposal.

ISO will notice the next working group meeting and does not have a firm date at this time.
APPENDICES
Frequency Control Stages
NERC defines 4 frequency control stages:

- **Inertia** - Ability of a machine with rotating mass inertia to arrest frequency decline and stabilize the system

- **Primary** – automatic & autonomous deployment at unit
  - Fast primary – automatic & autonomous deployment at unit within matter of cycles after event

- **Secondary** – manual or automated dispatch from signal
  - Fast Secondary – dispatch from signal tuned to faster deployment than conventional secondary signals

- **Tertiary** – reconfigure reserves and dispatch generation
NERC frequency control stages

Frequency Response Types

- Pre-event (Value A)
- Transient and Post-event (Value B)
- Primary Control
- Tertiary Control
- Secondary Control

Frequency (Hz)

Minutes Relative to Frequency Event (T+/-)
Categories of Operating Reserves and Frequency Control
## Frequency Control Categories

<table>
<thead>
<tr>
<th>ERS Element</th>
<th>Definition</th>
<th>Type of Service</th>
<th>Response Time</th>
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</thead>
</table>
| Primary FC  | Automatic and autonomous response to frequency variations through a generator’s droop parameter and governor response. | • Local frequency sensing  
• Provided through generator governor control  
• Can be provided through deliberate control of electronically coupled wind, solar, storage, and DR resources.  
• Less communication infrastructure  
• May include automatic load shedding. | t ~ seconds |
| Secondary FC| This is a service that returns frequency to nominal value and minimizes unscheduled transient power flows due to power imbalance between neighboring control areas. | • Centralized within control centers through AGC  
• Significant communication infrastructure  
• Typically provided by generation but some DR can provide this service. | Slower than Primary  
Primary < t > 15 minutes |
## Operating Reserves Categories

<table>
<thead>
<tr>
<th>Table 1: Operating Reserves Categories</th>
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<tbody>
<tr>
<td><strong>Description and Operation</strong></td>
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<tr>
<td><strong>Regulation</strong></td>
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<tr>
<td><strong>Load Following</strong></td>
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<tr>
<td><strong>Spinning Reserve</strong></td>
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<tr>
<td><strong>Non-Spinning Reserve</strong></td>
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<tr>
<td><strong>Supplemental Reserve</strong></td>
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Reliability Standards
BAL-001-2 Standard, Real Power Balancing Control Performance

- Control Interconnection frequency within defined limits
- Requires operating so that Control Performance Standard 1 (CPS1) is above defined limit in prior 12 month period
- Requires reported ACE does not exceed ACE limit for more than 30m

\[ ACE = (NI_A - NI_S) - 10\beta (F_A - F_S) \]
BAL-002-WECC-2a Standard, Contingency Reserve

- **R1** - contingency reserves requirement (BAL-002) Requires each BA to maintain a minimum ancillary service requirement that is the greater of either:
  - Loss of single most severe single contingency (G-1)
  - Sum of 3% of hourly integrated load plus 3% of hourly integrated generation
    - Amount of capacity must be deployable within 10m
- **R2** - 50% of contingency reserves requirement must come from operating reserves that are spinning and that are:
  - Immediately and automatically responsive to frequency deviations through governors or other control systems
  - Capable of fully responding within 10m
- **R3** – Any interchange transactions designated as operating reserve supplemental must be backed by addtl. Contingency reserves by sink BA
- Exception for first 60 minutes after needing to activate reserves
• New standard effective 1/1/2018

• ISO still reviewing the new standard

• Maintains policy that operating reserves should be frequency responsive
BAL-003-1 Standard, Frequency Response and Frequency Bias Setting

- R1 – achieve an annual performance measure (FRM) that is less than or equal to its frequency response obligation (FRO) to demonstrate sufficient frequency response to disturbances after an event where FRM is:
  - Change in net interchange actual between average value 20 – 52 seconds after an event and average value 16 seconds prior to the event
  - Median response across sample of events

- R2 – BA not receiving overlap regulation service using a fixed frequency bias setting consistent with NERC methodology in Area Control Error

- R3 – BA not receiving overlap regulation service using a variable frequency bias setting shall maintain setting less than zero at all times and less than or equal to BA FRO when frequency outside deadband 36 mHz

- R4 – BA performing or receiving overlap regulation service shall modify bias setting in ACE calculation to represent:
  - BA providing will report sum of bias settings for combined BAA
  - BA receiving will set setting equal to zero
BAL-003-1.1 sets performance obligation

- Primary objectives of the first requirement are:
  - Determine whether BA has sufficient frequency response for reliable operations
  - Provide feeder information needed to calculate control performance standard and frequency bias settings

- BA allocated share of interconnection obligation, which:
  - Protects against resource loss of 2 PV Units of 2,506 MW
  - Designed to limit excursion to a max drop of 0.292 Hz
  - Allocated based on share of generation and load

<table>
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<tr>
<th>California ISO’s Estimated Requirement</th>
<th>2017 FRO</th>
<th>Units</th>
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<tbody>
<tr>
<td>Western IFRO</td>
<td>858</td>
<td>MW/0.1Hz</td>
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<tr>
<td>Estimated ISO FRO (30% share)</td>
<td>258</td>
<td>MW/0.1Hz</td>
</tr>
<tr>
<td>Actual ISO FRO (22.9% share)</td>
<td>196</td>
<td>MW/0.1Hz</td>
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</table>
BAL-003-1 standard is for frequency response performance shows overlap of primary and secondary