# Essential Reliability Services from Hybrid Power Plants

Jason MacDowell
GE Energy Consulting

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**CAUTION CONCERNING FORWARD-LOOKING STATEMENTS:**

This document contains "forward-looking statements" – that is, statements related to future events that by their nature address matters that are, to different degrees, uncertain. For details on the uncertainties that may cause our actual future results to be materially different than those expressed in our forward-looking statements, see http://www.ge.com/investor-relations/disclaimer-caution-concerning-forwardlooking-statements as well as our annual reports on Form 10-K and quarterly reports on Form 10-Q. We do not undertake to update our forward-looking statements. This document also includes certain forward-looking projected financial information that is based on current estimates and forecasts. Actual results could differ materially. to total risk-weighted assets.]



**NON-GAAP FINANCIAL MEASURES:**

In this document, we sometimes use information derived from consolidated financial data but not presented in our financial statements prepared in accordance with U.S. generally accepted accounting principles (GAAP). Certain of these data are considered "non-GAAP financial measures" under the U.S. Securities and Exchange Commission rules. These non-GAAP financial measures supplement our GAAP disclosures and should not be considered an alternative to the GAAP measure. The reasons we use these non-GAAP financial measures and the reconciliations to their most directly comparable GAAP financial measures are posted to the investor relations section of our website at www.ge.com. [We use non-GAAP financial measures including the following:

- Operating earnings and EPS, which is earnings from continuing operations excluding non-service-related pension costs of our principal pension plans.
- GE Industrial operating & Verticals earnings and EPS, which is operating earnings of our industrial businesses and the GE Capital businesses that we expect to retain.
- GE Industrial & Verticals revenues, which is revenue of our industrial businesses and the GE Capital businesses that we expect to retain.
- Industrial segment organic revenue, which is the sum of revenue from all of our industrial segments less the effects of acquisitions/dispositions and currency exchange.
- Industrial segment organic operating profit, which is the sum of segment profit from all of our industrial segments less the effects of acquisitions/dispositions and currency exchange.
- Industrial cash flows from operating activities (Industrial CFOA), which is GE's cash flow from operating activities excluding dividends received from GE Capital.
- Capital ending net investment (ENI), excluding liquidity, which is a measure we use to measure the size of our Capital segment.
- GE Capital Tier 1 Common ratio estimate is a ratio of equity

# Topics

Essential Reliability Services that hybrid power plants may provide (beyond time shifting):

**Voltage Regulation**

- Reactive Capability
- Dynamic voltage response

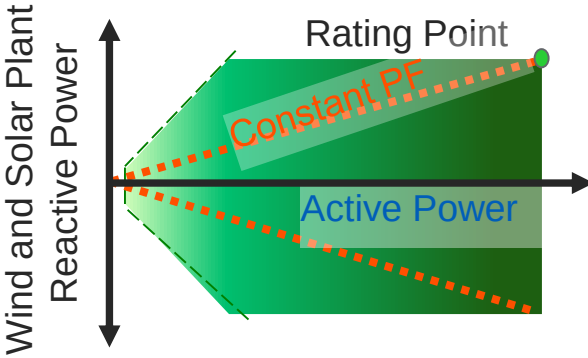
**Active Power Control**

- Frequency Regulation
- Primary Frequency Response
- Fast Frequency Response

**Black Start**

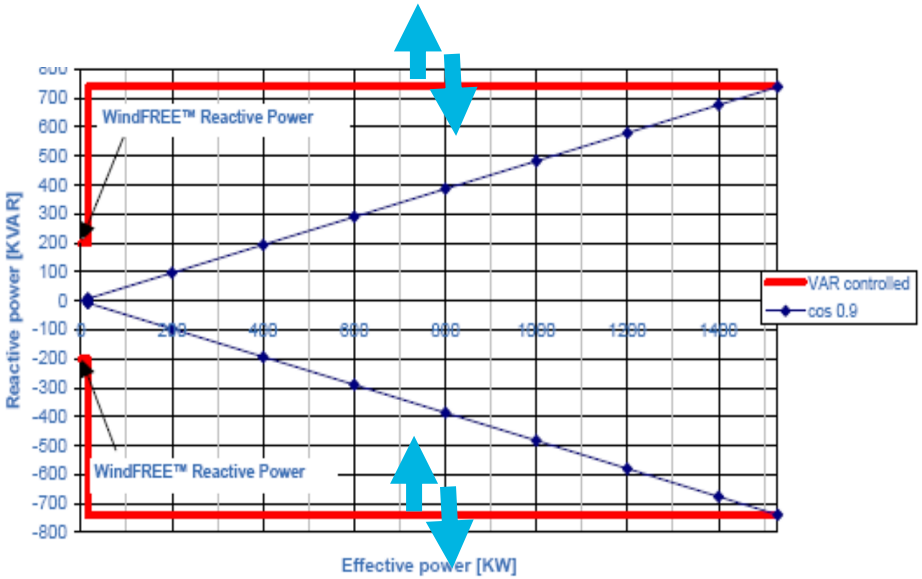
# Voltage Regulation and Reactive Power Control

# Hybrid Reactive Power Capability

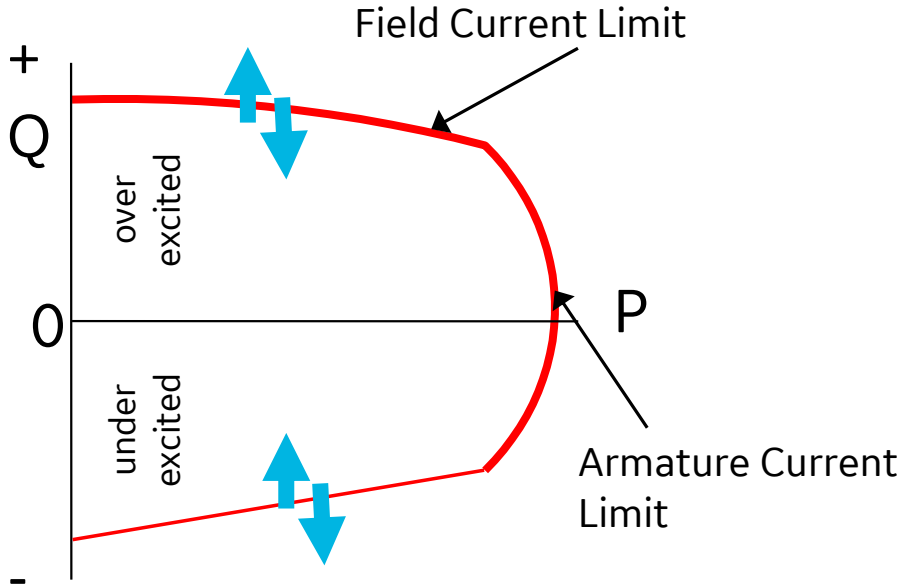



- Wind, Solar & BESS Steady-state PF range - +/-0.90 at converter/inverter, +/-0.95 at POI
- Conventional up to 0.80pf at machine terminals (typically 0.85pf)
- Can be extended by BESS when needed
- Both constrained by voltage (terminal, collector, auxiliary), unlocked by BESS

Wind Turbine Reactive Capability




Synchronous Machine Reactive Capability



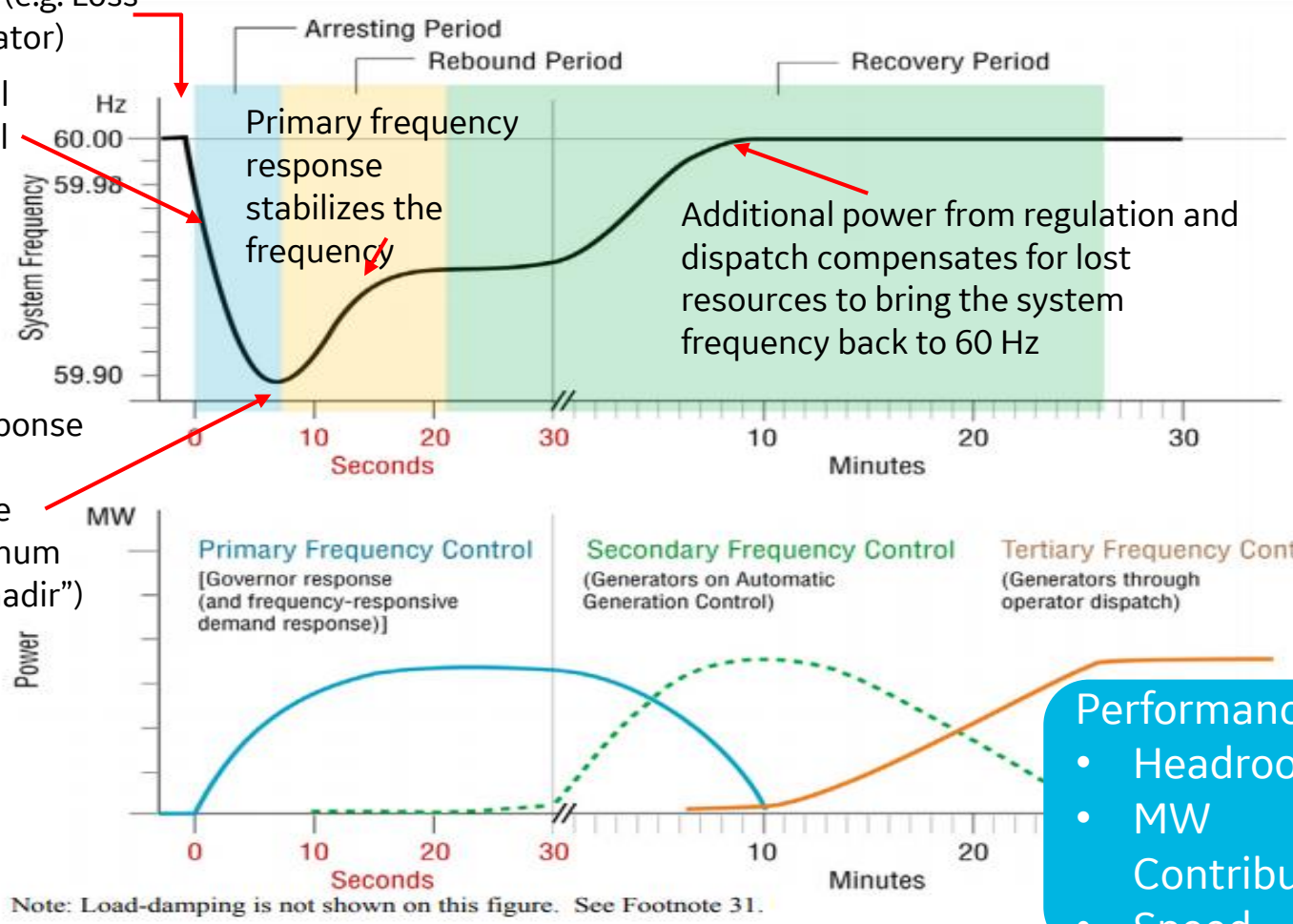
# Active Power Control

# Frequency Response – Physical and Controls

Disturbance – (e.g. Loss of large generator)

Synchronous Inertial Response sets initial slope

Fast frequency response and initial primary frequency response establish the minimum frequency point ("nadir")



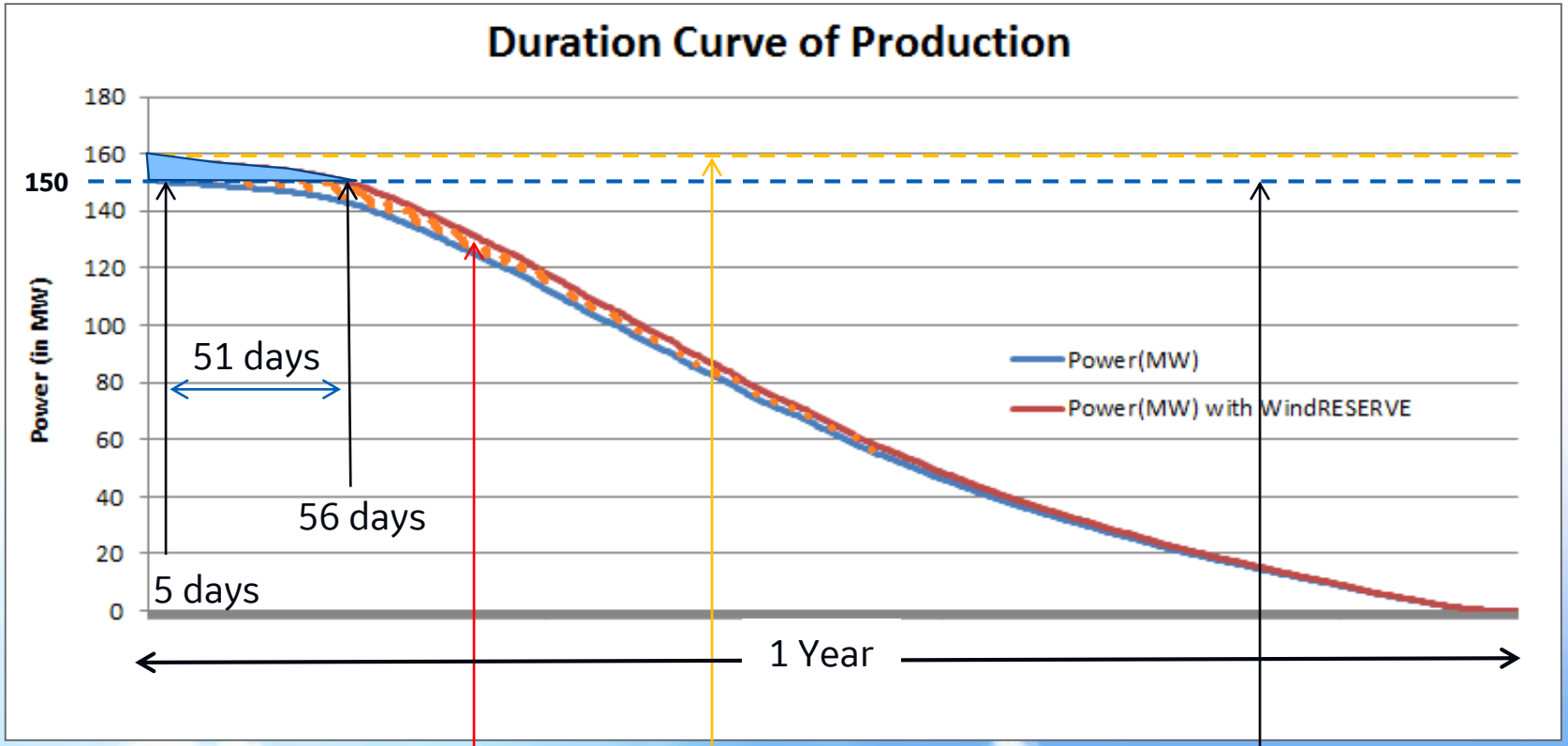

Performance:
- Headroom
- MW Contribution
- Speed

Courtesy J. Eto, J. Undrill, M. O'Malley et al, "Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation", 2010

Annotations by M. Ahlstrom, Nextera

https://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf

# WindRESERVE and Hybrids



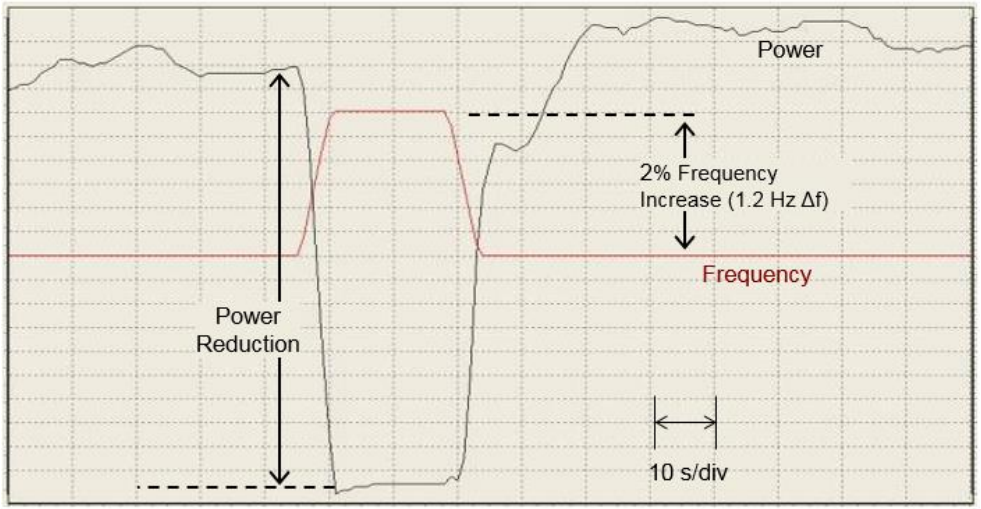

Increased AEP!

With permission may be used as

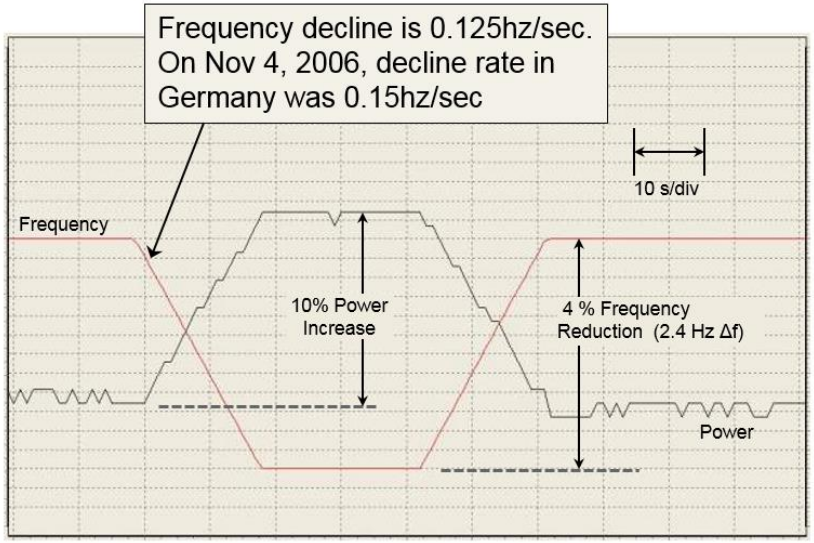
1. spinning reserve
2. extra power

Can ensure power output does not go above black dotted line (e.g. NMC) unless otherwise explicitly permitted

# Primary Frequency Response (Droop)




Field Test: Over-Frequency Response




Field Test: Under-Frequency Response

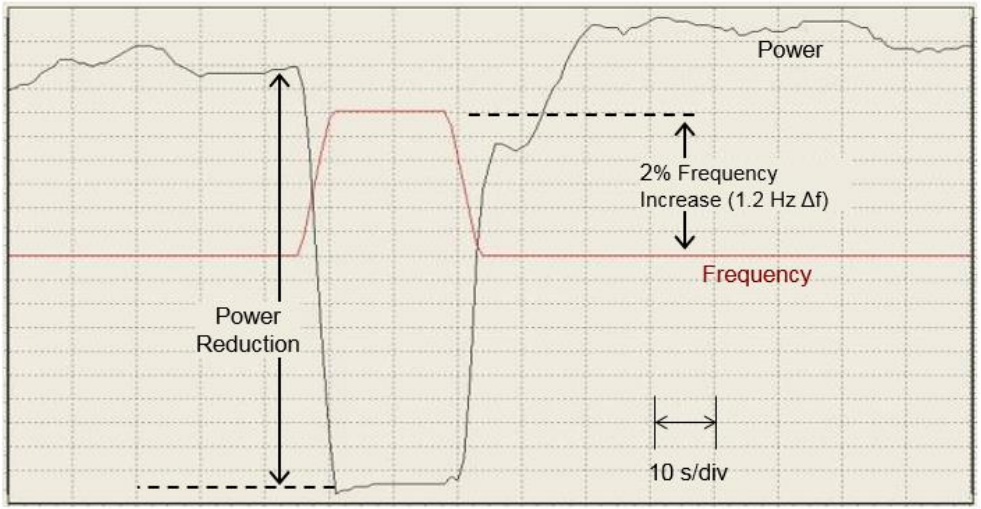
PFR is faster than regulating reserves and directly responds to frequency (like governor response with droop on thermal plants)

IBRs have provided PFR in Texas, Ireland, Canada for >7-8 years

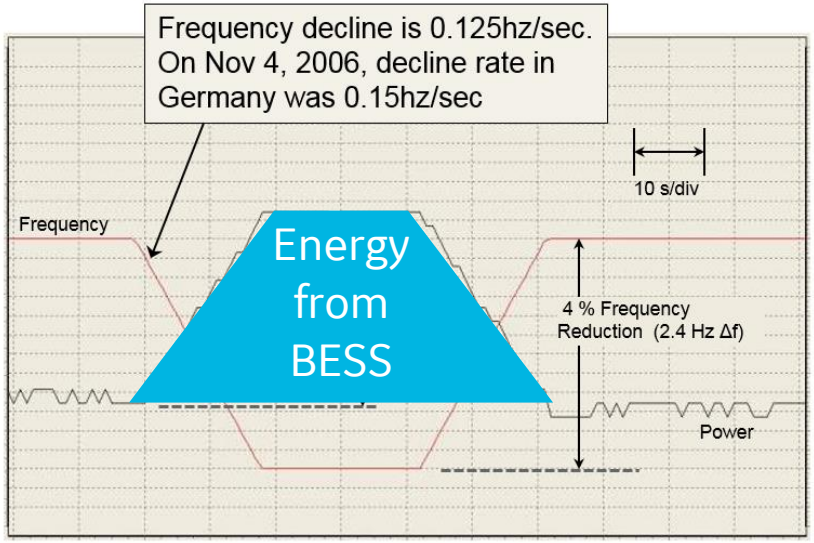
In the US, FERC requires this capability for new (BES connected) generators

**IBRs have the capability to provide PFR in both directions. Under-frequency response requires headroom (pre-curtailment has opportunity cost).**

# Primary Frequency Response with Hybrids




Field Test: Over-Frequency Response




Field Test: Under-Frequency Response

Speed and profile may be shaped by BESS beyond Wind/Solar capability alone

Battery ratings dictate magnitude and duration

**IBRs have the capability to provide PFR in both directions. Under-frequency response requires headroom (little or no opportunity cost with BESS/Hybrids).**

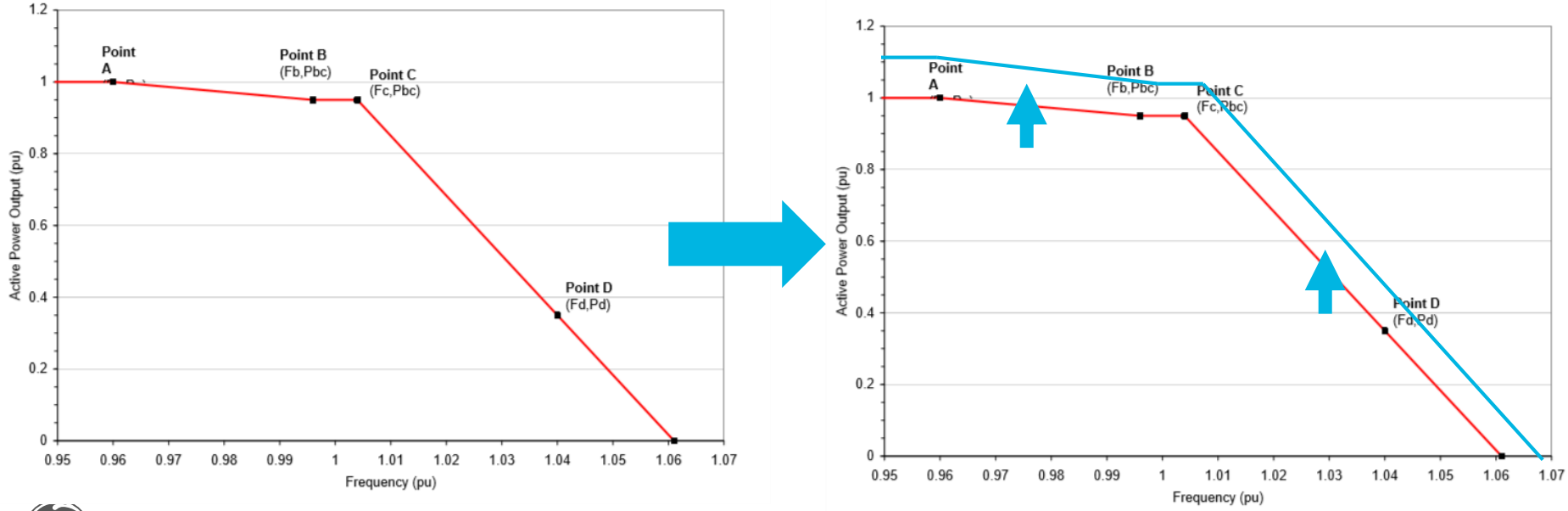
# Primary Frequency Response with Hybrid Wind/Solar

Today's State-of-the-art Wind Plants:

- Provide over-frequency response with no opportunity cost
- Provide under-frequency response with opportunity cost: pre-curtailment

Next-generation with Hybrid wind plants :

- Provide under-frequency response without opportunity cost
- As fast (or slow) as the grid needs

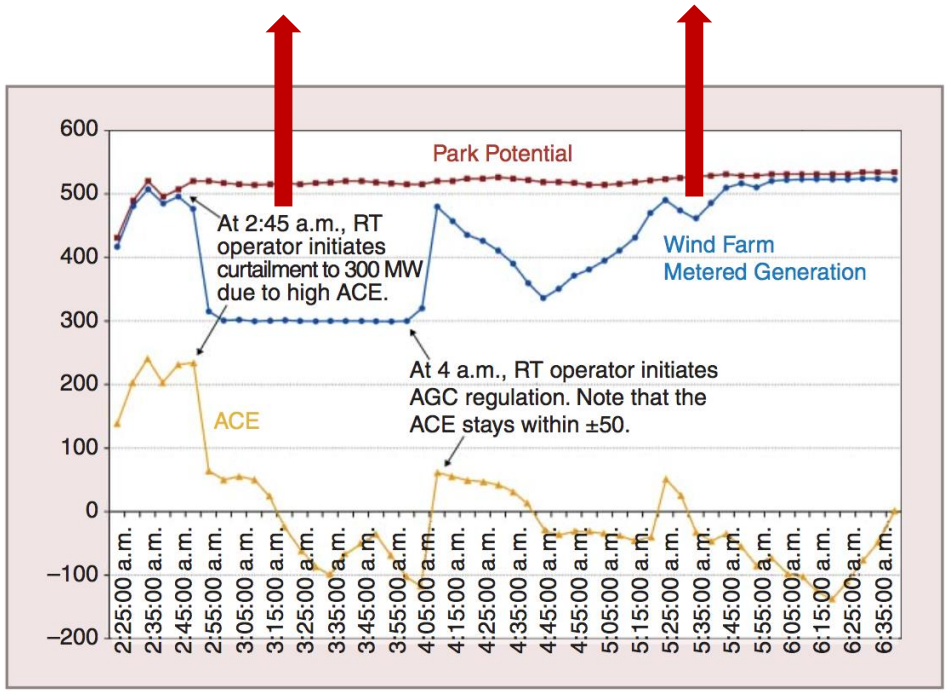


# Hybrid plants can provide regulating (secondary) reserves with increased headroom

ISOs in the US typically dispatch wind to set points at 5 minute intervals, using short-term forecasts.

About 6 years ago, Xcel/PSCO went one step further and had wind provide regulating (also called secondary, or AGC) reserve. Wind responds to a 4 second AGC signal that helps maintain frequency.

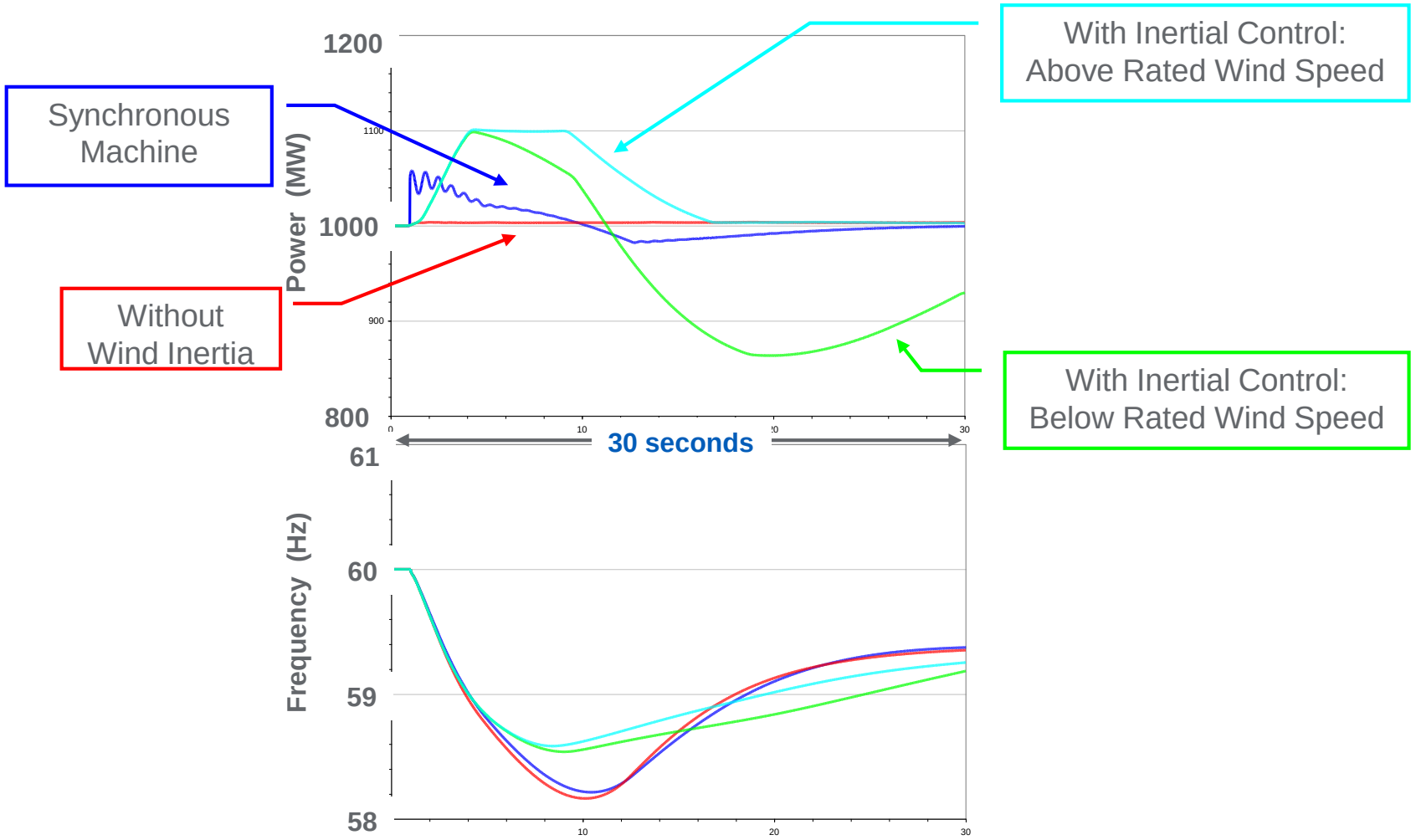
PSCO now has 1678 MW providing regulating reserve. In 2016, 23% of electricity in PSCO was served by wind.



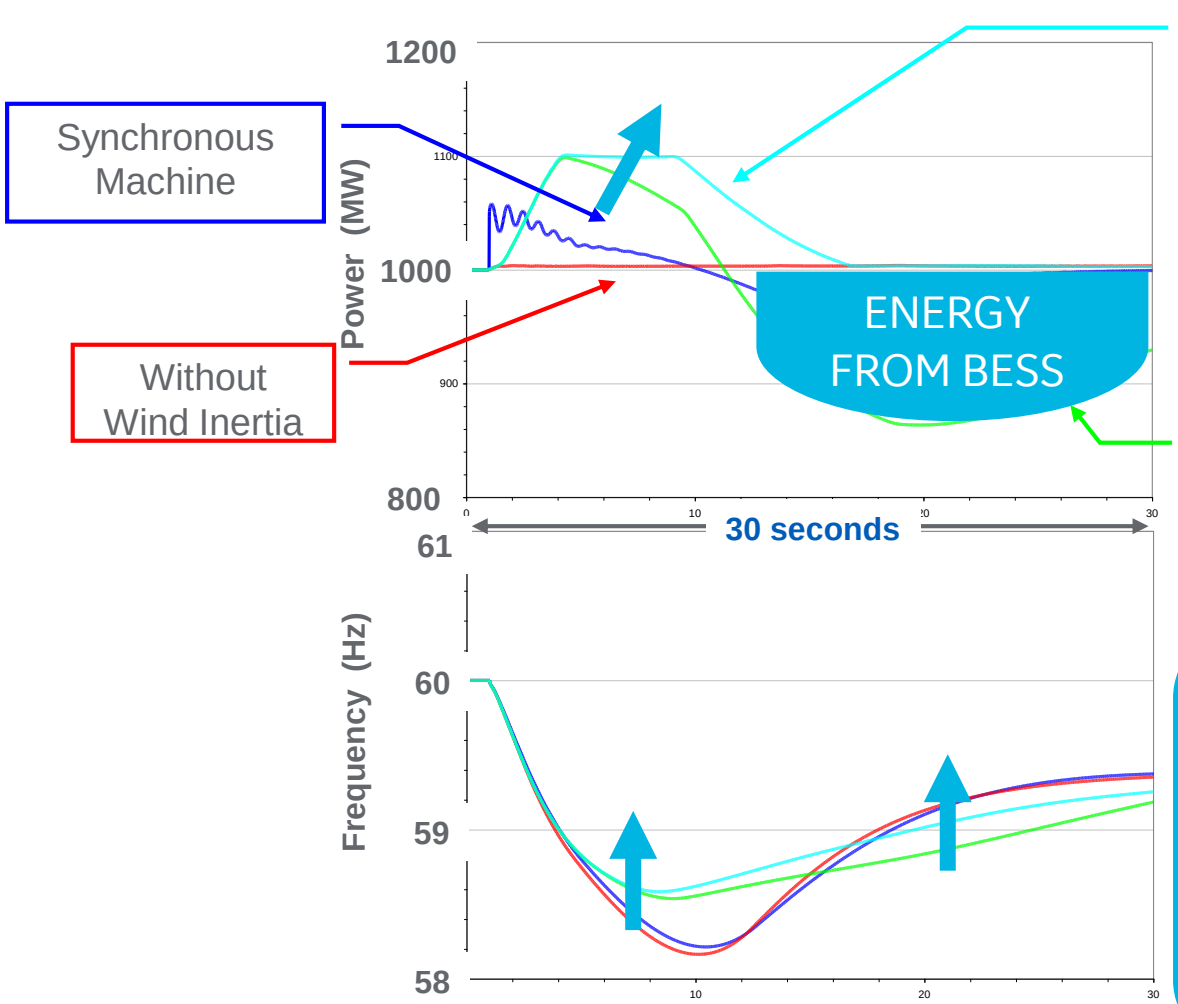

Source: Xcel/PSCO, Feb. 2012

# Hybrid impact on Fast Frequency Control

# Wind Fast Frequency Response vs. Conventional



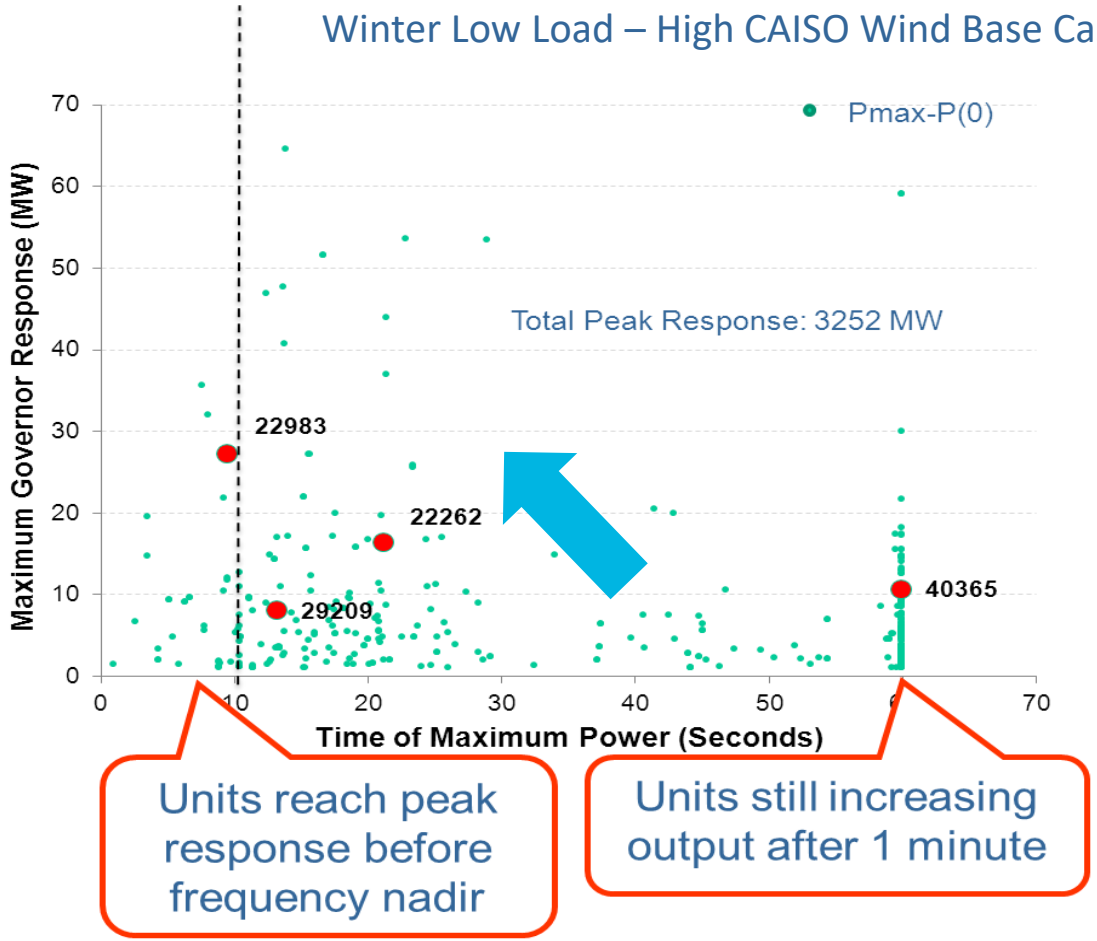
# Wind Fast Frequency Response with Hybrid

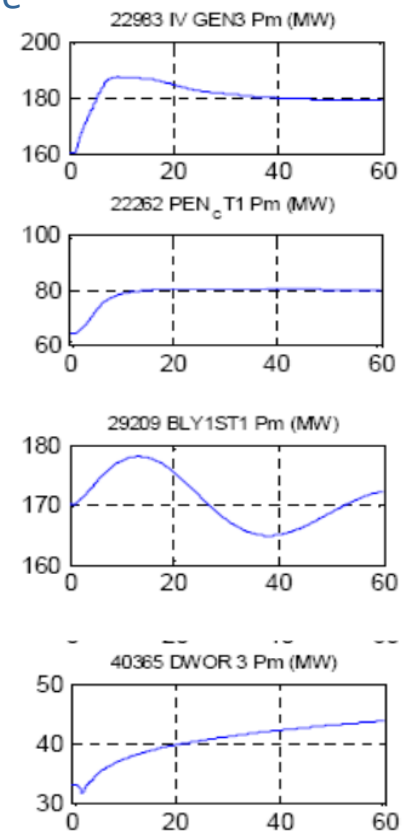



Hybrid BESS turbines increase FFR capability on wind *and solar* and stretch payback from ~10 sec to ~10 min

# PFR widely varies… Hybridizing may help

Performance:
- Headroom increases with storage
- MW Contribution can increase
- Speed can increase




* Courtesy of CA Wind Integration Study, 2012

# Grid Forming Batteries

BESS projects are usually not Grid Forming

Key GE Grid Forming BESS Projects:

- Metlakatla Power & Light 1MW/1.4MWh- 1995 [1]
- Vernon CA 5MW/2.5MWh- 1996 [2]
- Battery Energy Storage System of 30MW/22MWh- IID 2017 [3]

Projects under design/execution

- Inverter rating optimizations
- Large drives fed from BESS



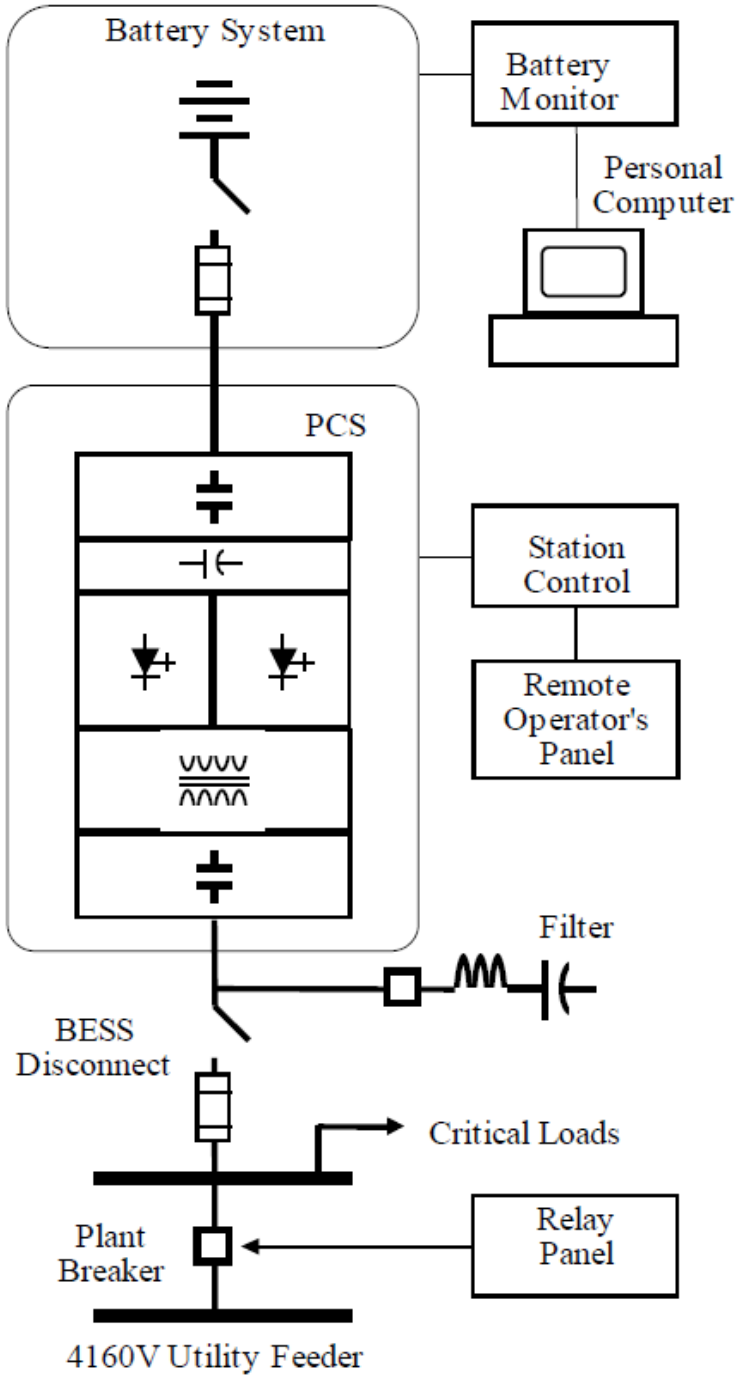

***Imperial Irrigation District (IID)***
***30MW, 20MWh BESS project -2017***

# Twenty years ago…

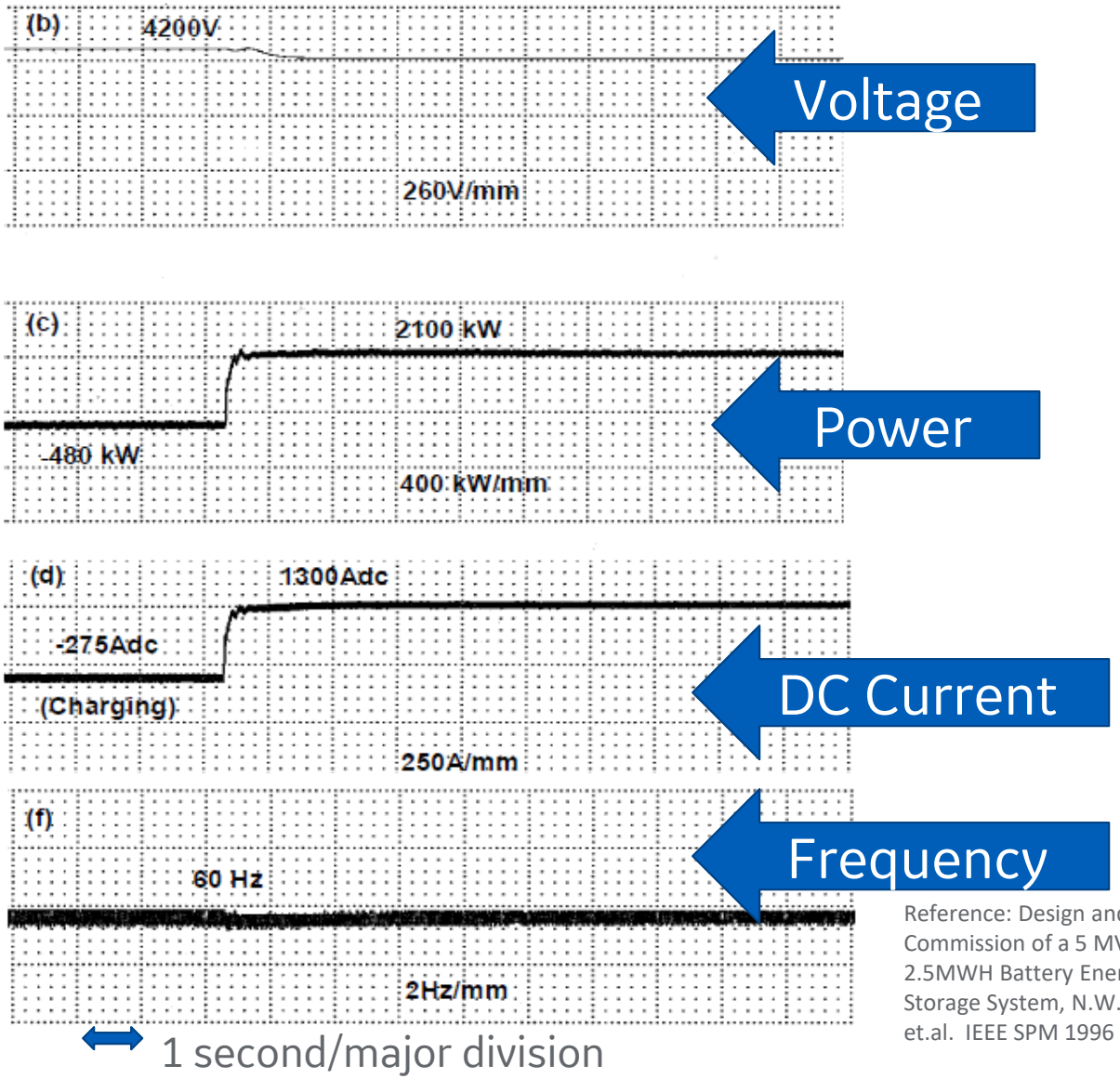
SUMMARY OF SYSTEM RATINGS FOR GNB VERNON

| | | |
|---|---|---|
| Base Voltage | 4160 Vrms L-L | |
| Nominal Current Rating | 348 Arms | |
| Nominal Power Rating | 2500 kVA<br>5000 kVA | continuous<br>for 10 sec. |
| Nominal DC Voltage Rating | 756 Vdc<br>(660 - 900 Vdc range) | |

Reference:
Design and Commissioning of a 5 MVA, 2.5MWH Battery Energy Storage System, N.W. Miller, et.al. IEEE SPM 1996

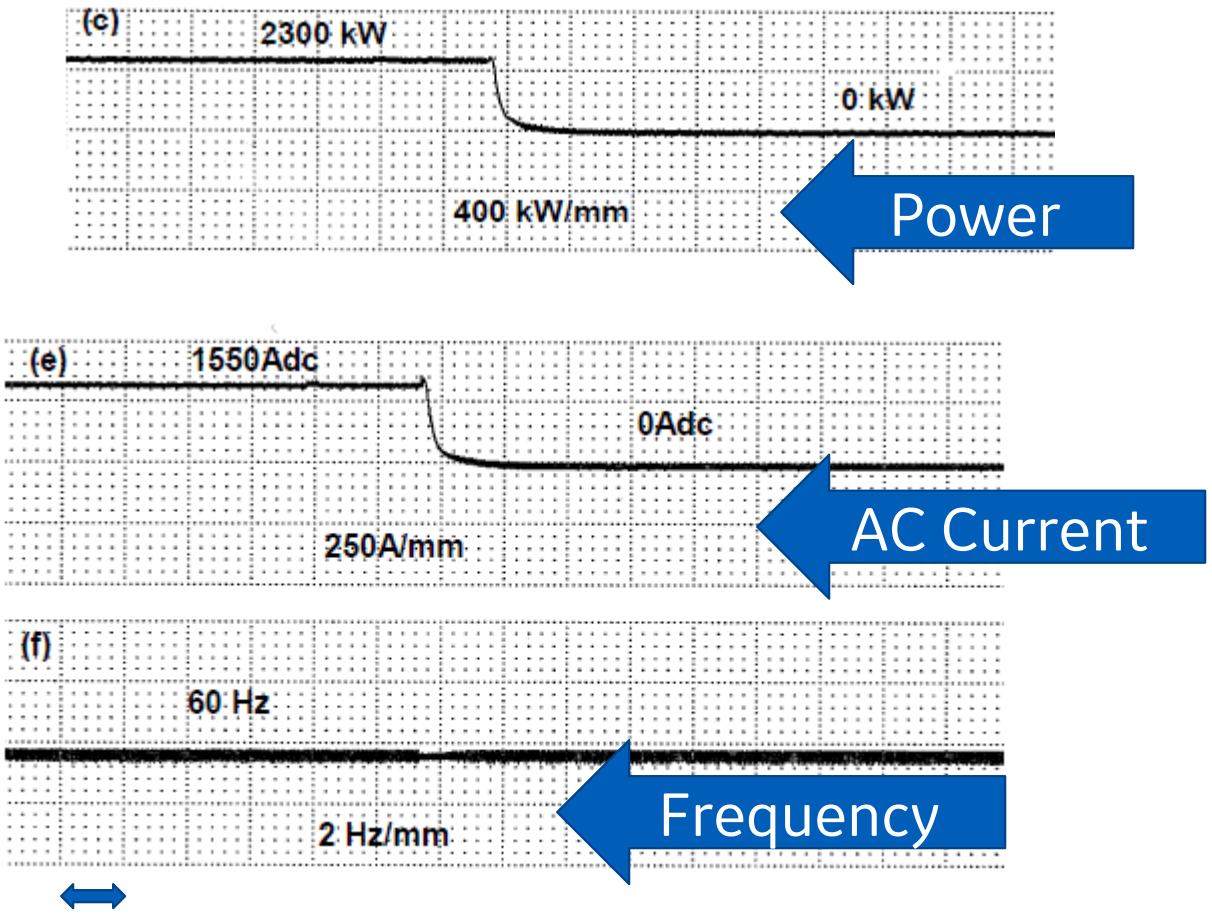


# Trip to “zero” inertia island




Reference: Design and Commission of a 5 MVA, 2.5MWH Battery Energy Storage System, N.W. Miller, et.al. IEEE SPM 1996

# Resync “zero” inertia island to grid

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# Summary

Hybrid power plants with BESS can (in addition to time shifting):

- Extend the voltage regulation capability of power plants
- Enhance the primary and fast frequency response of power plants
- Blackstart

Controls and coordination of battery and resource capability is key to unlocking enhanced performance

**Advanced IBR grid-friendly technology is available and widely used today! Incentives (markets) and sound requirements are key to unlocking this capability and achieving higher penetration.**


Thank You!
Jason MacDowell
jason.macdowell@ge.com