The Challenges of Integrating Lithium Ion Battery Storage Arrays in MISO

PJM Primary Frequency Response Senior Task Force

October 9, 2017

IPL is a regulated investor-owned electric utility engaged primarily in generating, transmitting, distributing, and selling electric energy to approximately 490,000 retail customers in the city of Indianapolis and neighboring areas within the state of Indiana. IPL is a transmission system owner member of MISO. IPL owns and operates the IPL Advancion Energy Storage Array, the Harding Street Station Battery Energy Storage System ("HSS BESS").

First Grid-scale Lithium Ion Battery in the MISO Footprint

Placed in service May 20, 2016

Highlights

- Lithium Ion Technology
- 20 MW or Flexible 40 MW Lithium ion battery array
- Provides frequency control continuously; It is the leading state of the art frequency control solution
- Moves from a neutral state to full injection/withdraw in less than 1 second
- Always available; Always Charged
- Can qualify to provide all ancillary services in the MISO tariff; tested annually
- Provides 5 MWs capacity – can deliver 5 MWs continuously over 4 hours of the peak (IPL does not include the HSS BESS as a load modifying resource in its FRAP)
- For IPL the device is a transmission asset intended to be part of our rate base
- An integral component of grid resiliency
- All in cost $26 million (2015-2016); constructed in 12 months. Costs and time to construct have declined since then.

Design of the Facility

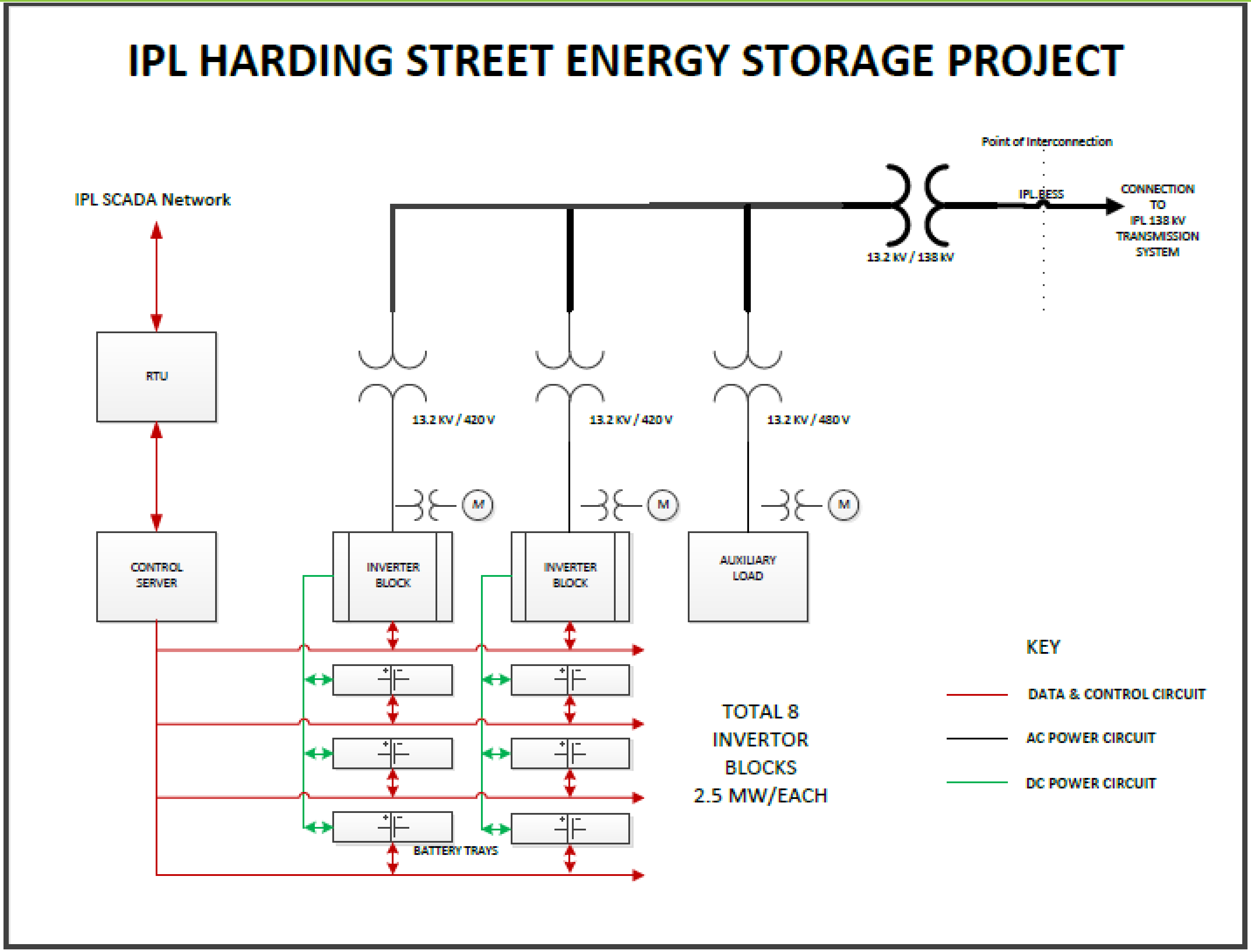
Battery Arrays are designed to fit the specific purpose they will serve; design differences can change some of the operating characteristics.

- Array server monitors and controls entire system; and is connected to the server in each core
- The HSS BESS is designed to autonomously contribute to frequency control; reacting at its full directed capacity in less than one second
- There are 8 2.5 MW cores with a total of 244 nodes
- The system is monitored and controlled through using the AES Advancion software with imbedded SCADA and HMI; Monitors over 20 thousand data points within each core
- Node = 20 battery trays with 20 wafer batteries each. Total of 97,600 lithium ion battery cells

IPL HARDING STREET BESS

The Harding Street BESS will provide reliability benefits to the grid through frequency regulation

Diagram


IPL HARDING STREET ENERGY STORAGE PROJECT
Point of Interconnection
IPL SCADA Network
IPL BESS
CONNECTION TO IPL 138 KV TRANSMISSION SYSTEM
13.2 KV / 138 KV
RTU
13.2 KV / 420 V
13.2 KV / 420 V
13.2 KV / 480 V
M
M
M
CONTROL SERVER
INVERTER BLOCK
INVERTER BLOCK
AUXILIARY LOAD
KEY
DATA & CONTROL CIRCUIT
AC POWER CIRCUIT
DC POWER CIRCUIT
TOTAL 8 INVERTOR BLOCKS 2.5 MW/EACH
BATTERY TRAYS

Exterior View

Interior View of Battery Room

Batteries on the grid

Modular, scalable arrays with high availability from current technology

BATTERY CELLS BATTERY PACKS

BATTERY MODULES

ADVANCION NODES

ADVANCION ARRAY

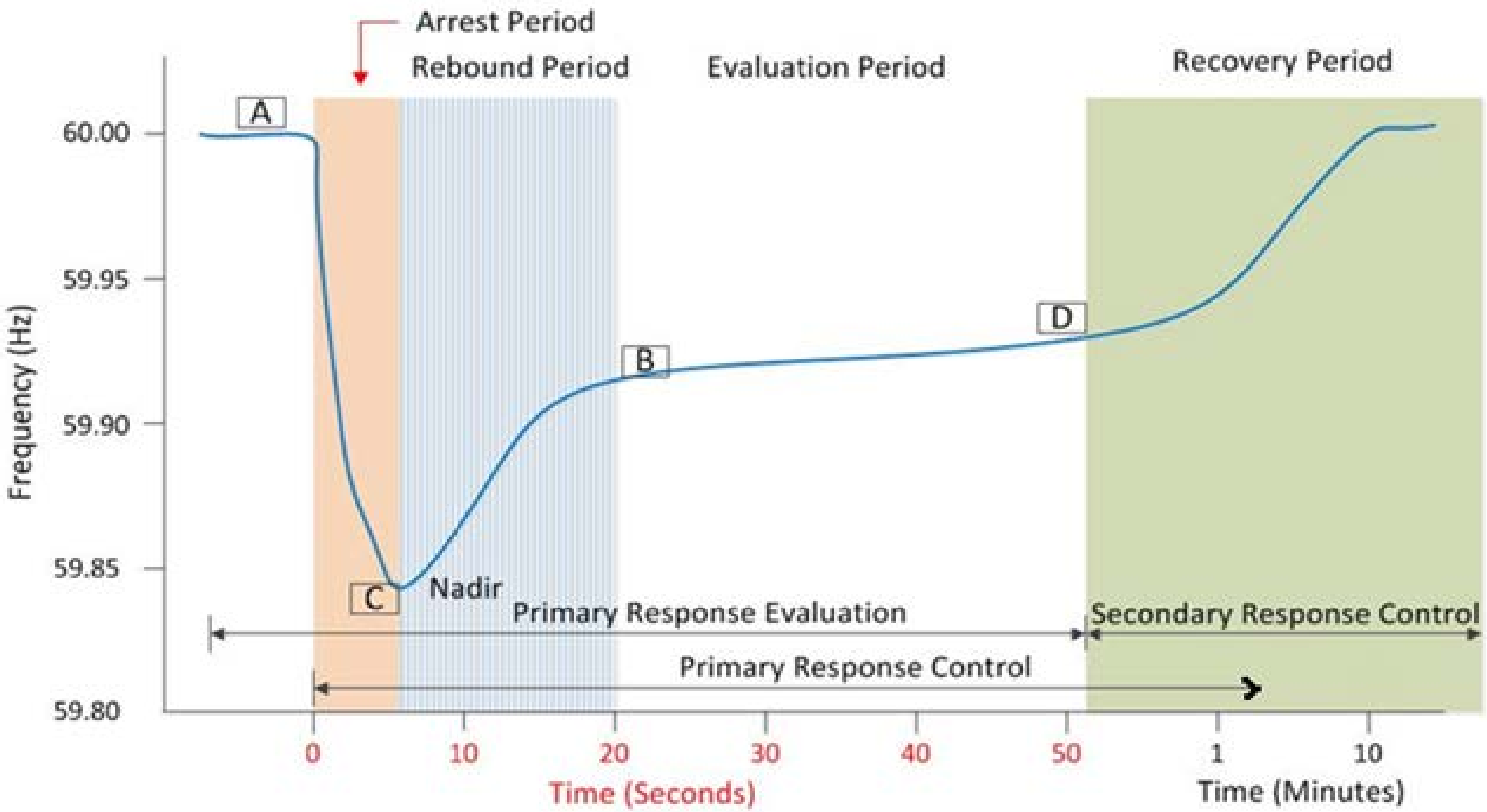
The Secret Sauce

Over 20,000 data points for each core are captured every 2 seconds; data is used for monitoring, analysis, and can provide critical actual performance information in any granularity down to 2 seconds nearly instantaneously at the end of the desired time period.

Highlights

- The Vendor Proprietary operating software is the key to efficient and safe operation and the ability to modify instructions to adapt to evolving system needs.
  - Optimizes performance and battery life
  - Manages the State of charge
  - Programmed change from one service to next; can change within 1 second
  - Provides real time information to inform maintenance needs
  - Modular design
- Battery packs are readily available from many manufacturers to your specifications
- Fewer providers of inverters but still readily available
- Construction of the device regardless of MW capacity occurs in less than 12 months

Primary Frequency Response



Source: NERC Guidelines Primary Frequency Response

Primary Frequency Response

Frequency Response in the Eastern Interconnection is declining

PFR is an Essential Reliability Service

- The automatic reaction to deviations in frequency of the interconnected transmission system to assist with controlling frequency to NERC standards
- Unmitigated deviations can damage consumer electronics, electric motors and more
- Severe unmitigated deviations can lead to generation failure and ultimately brown or blackouts
- BAL003-1 assigns PFR Compliance Responsibility to Balancing Authorities
- The observed decline in PFR in the Eastern Interconnection is in part due to the increase of reliance upon renewable generation; retirement of traditional baseload generation; economic dispatch of all resources (fewer PFR providing resources always available).

Frequency Control Continuum

Control	Ancillary Service	Dispatched or Automatic	Purpose	NERC Standard
Primary Control	Primary Frequency Control (aka Frequency Response)	Automatic	To arrest in 10-60 seconds the degradation of frequency following an event	FRS-CPS1 BAL003-1
Secondary Control	Regulation, Spinning Reserves	Dispatched	To manage the difference between scheduled generation and load with actual.	CPS1-CPS2 DCS-BAAL
Tertiary Control		Manual and Dispatched	To correct the imbalance created by the event.	BAAL-DCS
Time Control	Time Error Correction	Automatic	To regulate system frequency in a manner that keeps synchronous clocks running accurately.	TEC

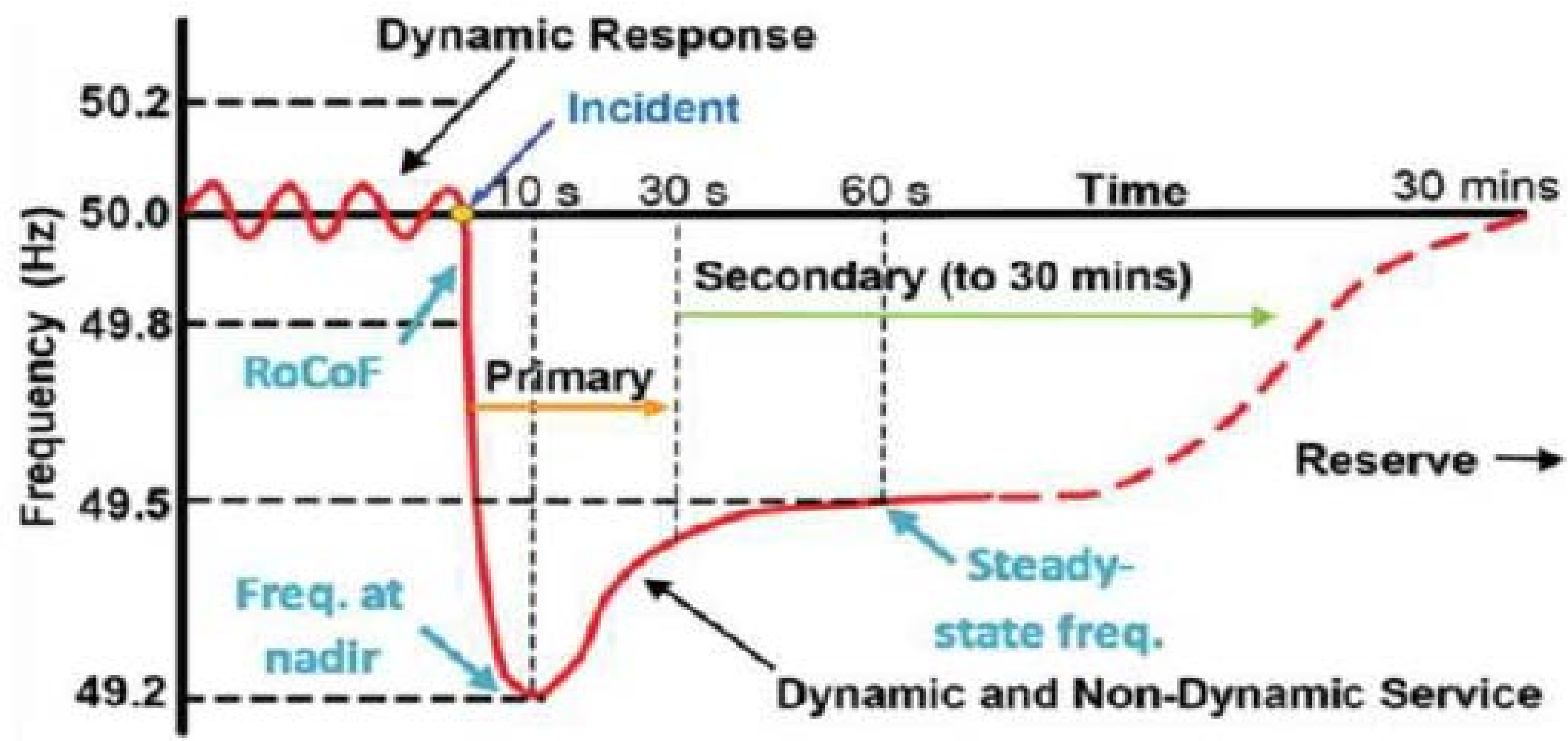
Inertia

- ***Inertial Response(mechanical) is a property of large synchronous generators, which contain large synchronous rotating masses like baseload coal generators. For these generators, coal is burned, which produces steam, which spins a turbine, which generates electricity, which is connected straight to the electric grid. The generation plant works with the help of a heavy, rotating mass that has inertia. If you suddenly stop burning coal, the turbine will keep spinning – for a while. The continuation of the spinning acts to overcome the immediate frequency control.***

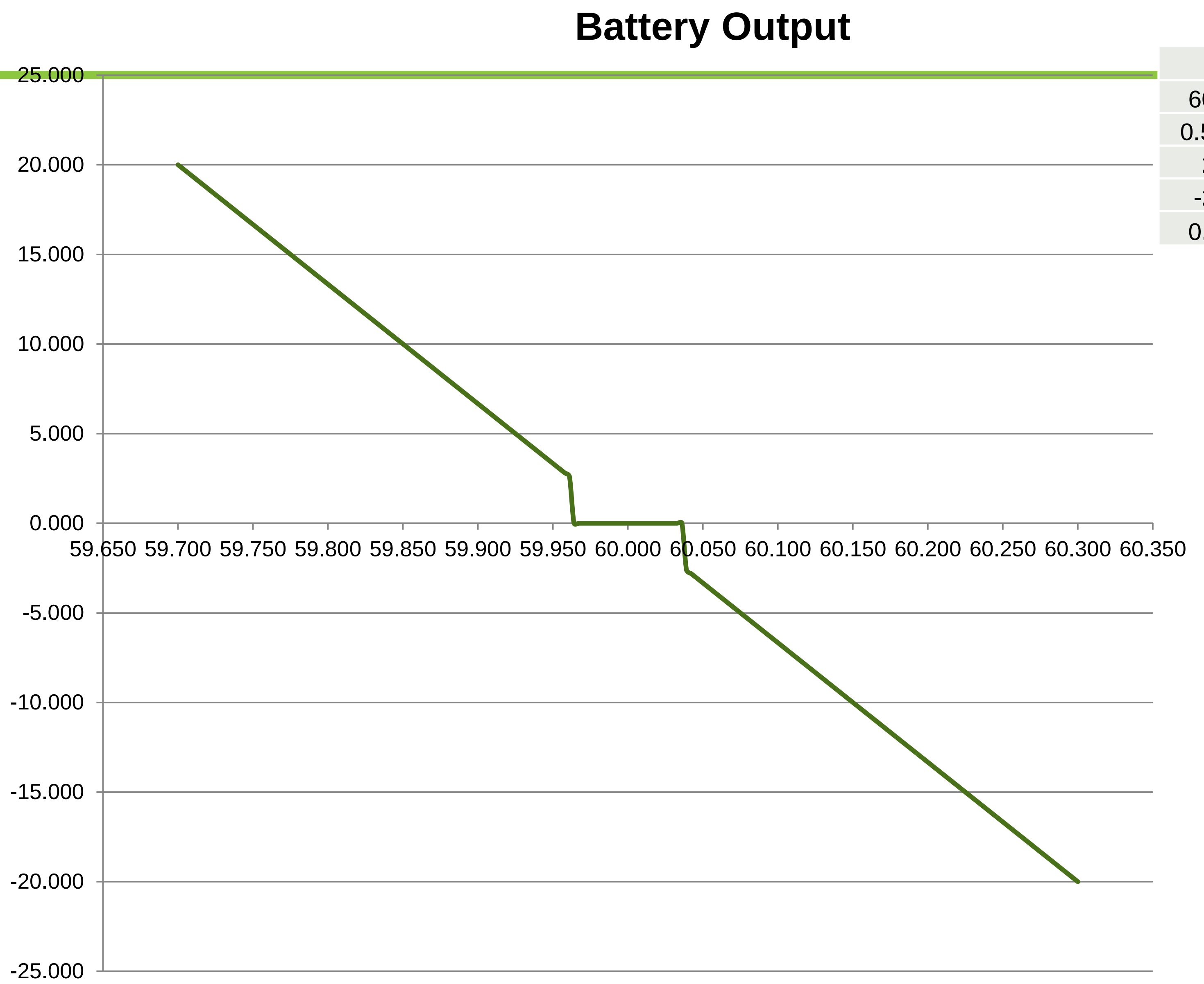
- ***The term synthetic inertial response is used to describe the same service, but provided by non-mechanical resources.***

- ***The graph the next slide illustrates the use of inertial response (dynamic response) in the period before the event causing the need for PFR.***

Inertia



Grid Inertial Response
Source: J Schmutz "Primary Frequency Control Provided by Battery", EEH Power Systems Laboratory Zurich, 2013



Input Variables	
60.000	System Frequency
0.500%	Droop Governor
20.00	Battery Outout
-20.00	Battery Input
0.0360	Dead band +/-

Harding Street Application Servic	IPLH-INS-AES-GEN-SO-8[illegible]
Revision #: 03	09 Feb 2017
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Figure 1. Droop Curve for Harding Street.

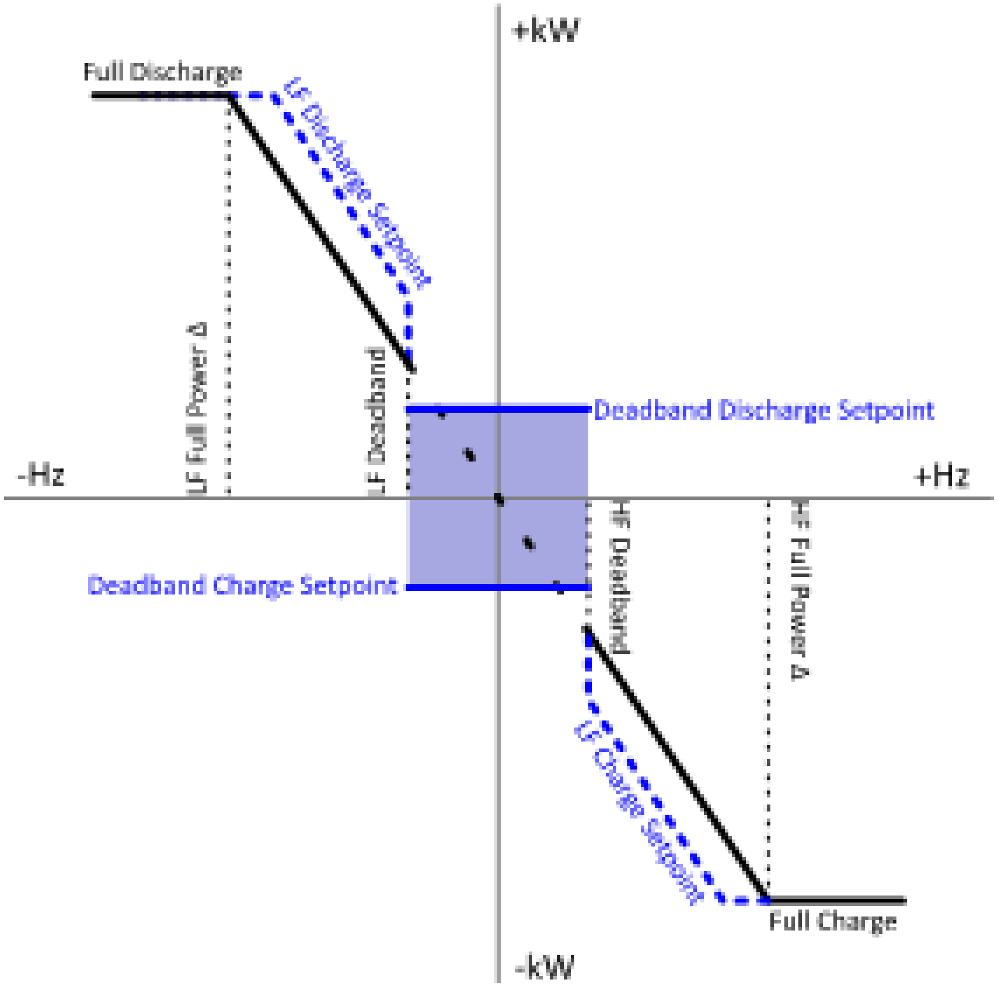
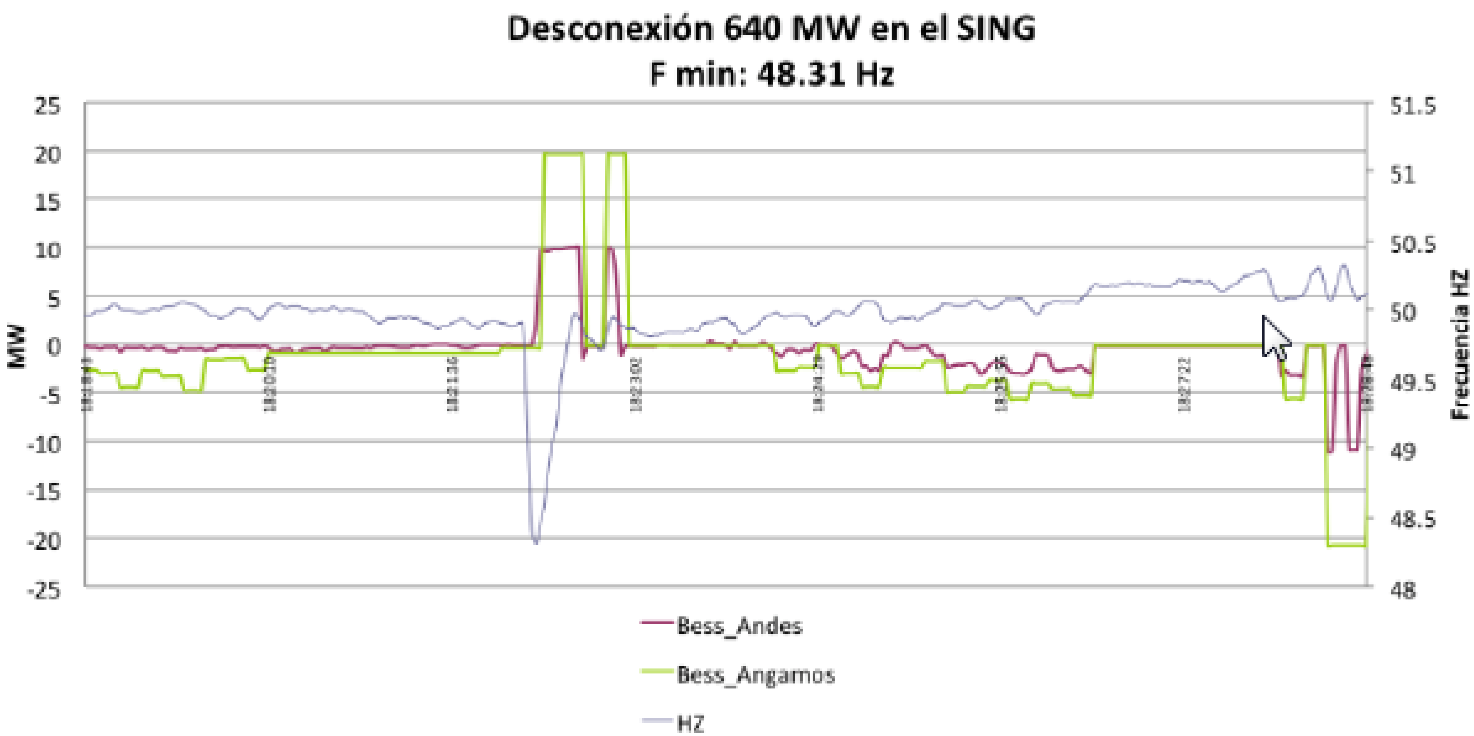


Figure 2. SOC Management Regions.

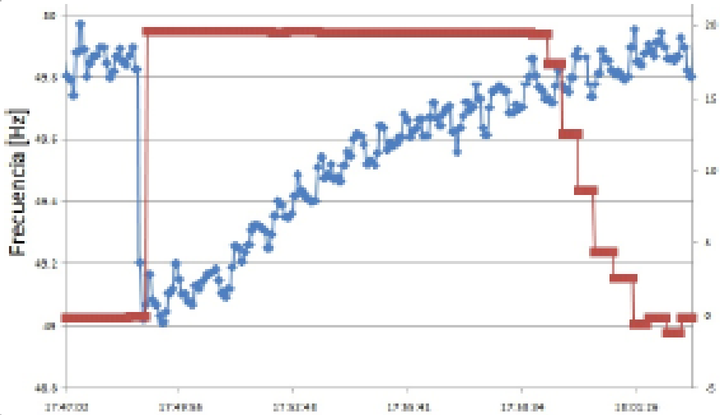
Actual Performance: Event from May 2013, when Storage Units Autonomously Responded to Frequency Deviation

Actual Performance: Event from May 2013, when Storage Units Autonomously Responded to Frequency Deviation



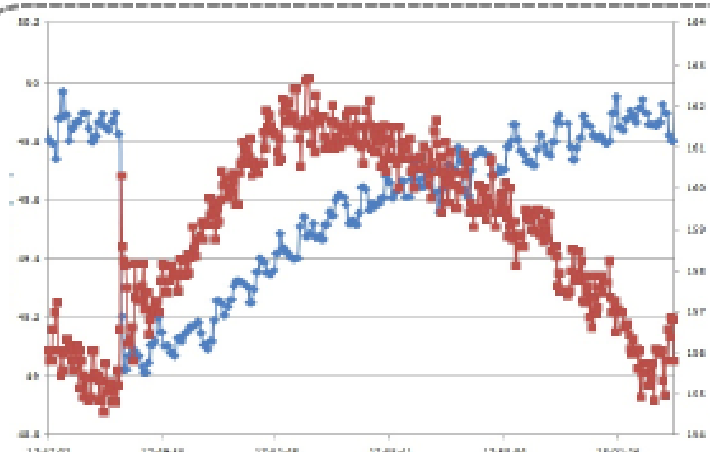
The AES units BESS_Andes and BESS_Angamos both responded immediately and this rapid injection of power helped stabilize the system frequency so that the other thermal units could replace the lost power without tripping.

Actual Performance: Angamos Storage Resource’s Quick, Precise Response to Maintain Grid Frequency



Angamos BESS Response

- ✓ Angamos BESS responds with rapid increase of output from 0MW to 20MW
- ✓ Autonomous response according to programmed profile
- ✓ Output sustained until stability restored



Thermal Units

- ❖ Thermal unit responds with 4MW burst, then output drops off
- ❖ Gradually ramps up in oscillating manner to 7MW output increase over 4 minutes

June 6, 2017

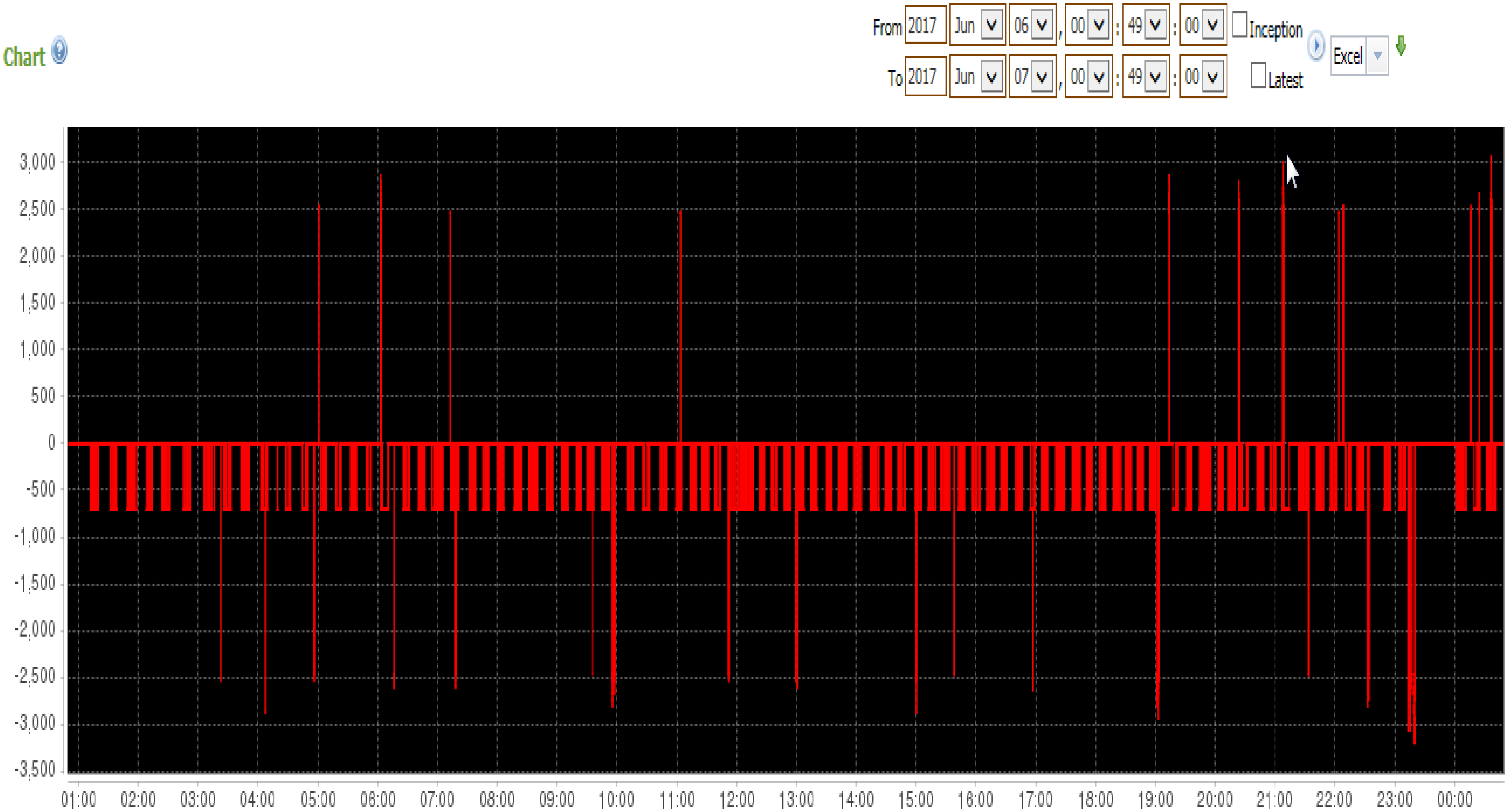


Chart
From 2017 Jun 06, 00 : 49 : 00
To 2017 Jun 07, 00 : 49 : 00
Inception
Latest
Excel
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
-2,000
-2,500
-3,000
-3,500
01:00
02:00
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July 4, 2017

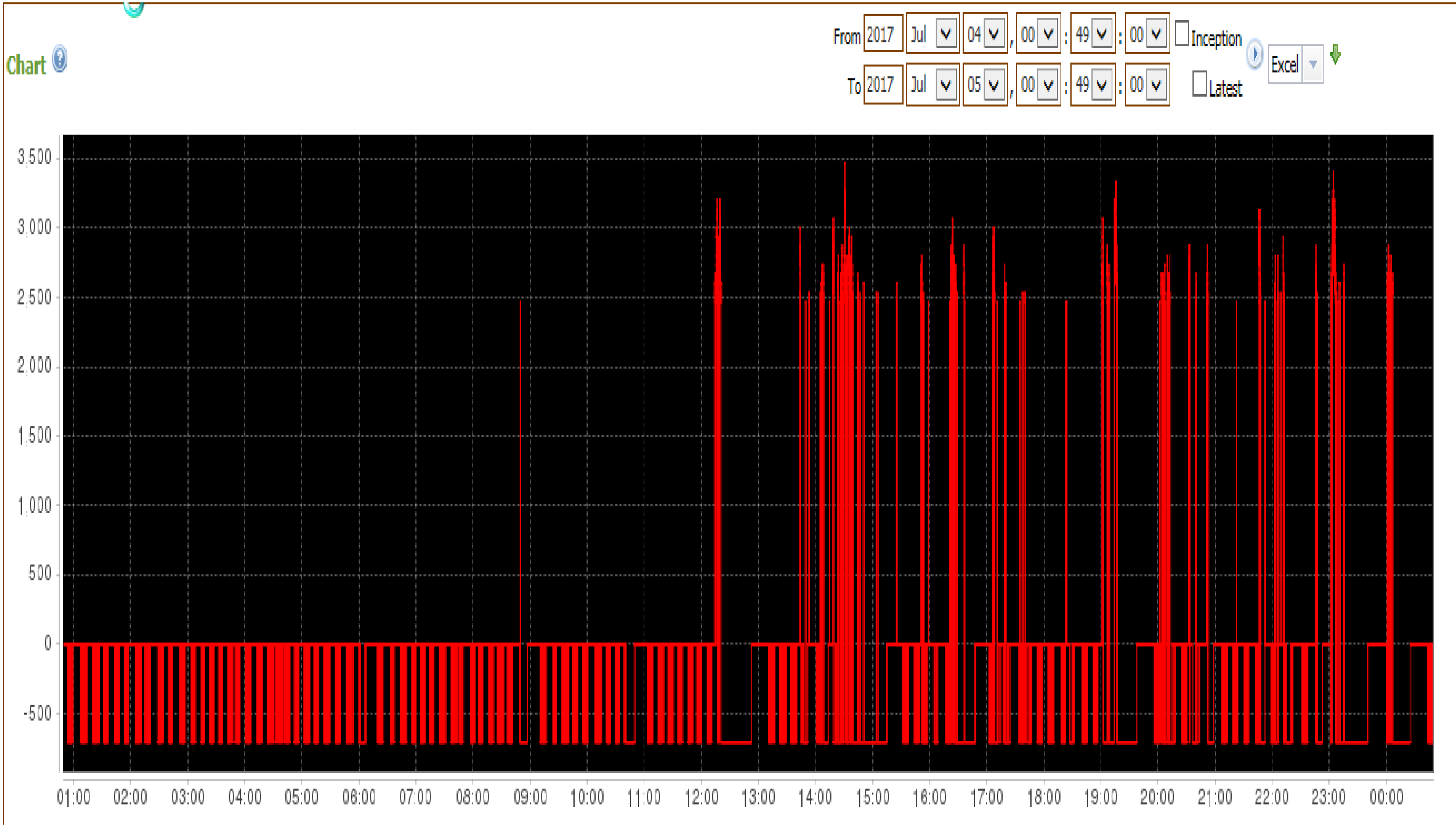


Chart
From 2017 Jul 04 , 00 : 49 : 00 Inception
To 2017 Jul 05 , 00 : 49 : 00 Latest
Excel
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-500
01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00 00:00

State of Charge Management

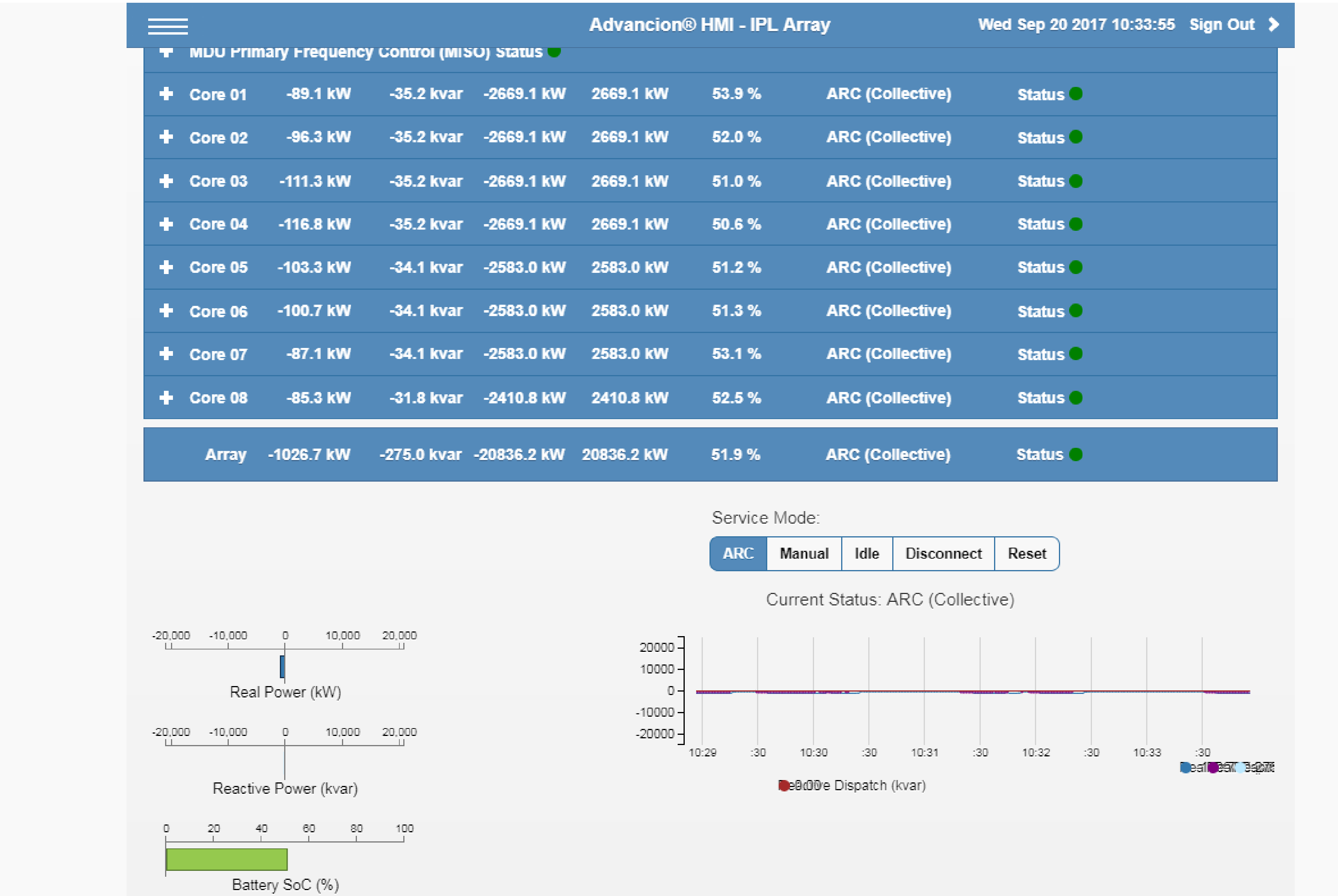
The Advancion software is key to performance

- State of Charge of the nodes is optimized to adhere to characteristics of lithium ion batteries; desired performance of no less than 97% EAF; charge need to perform programmed service(s); optimal battery life.

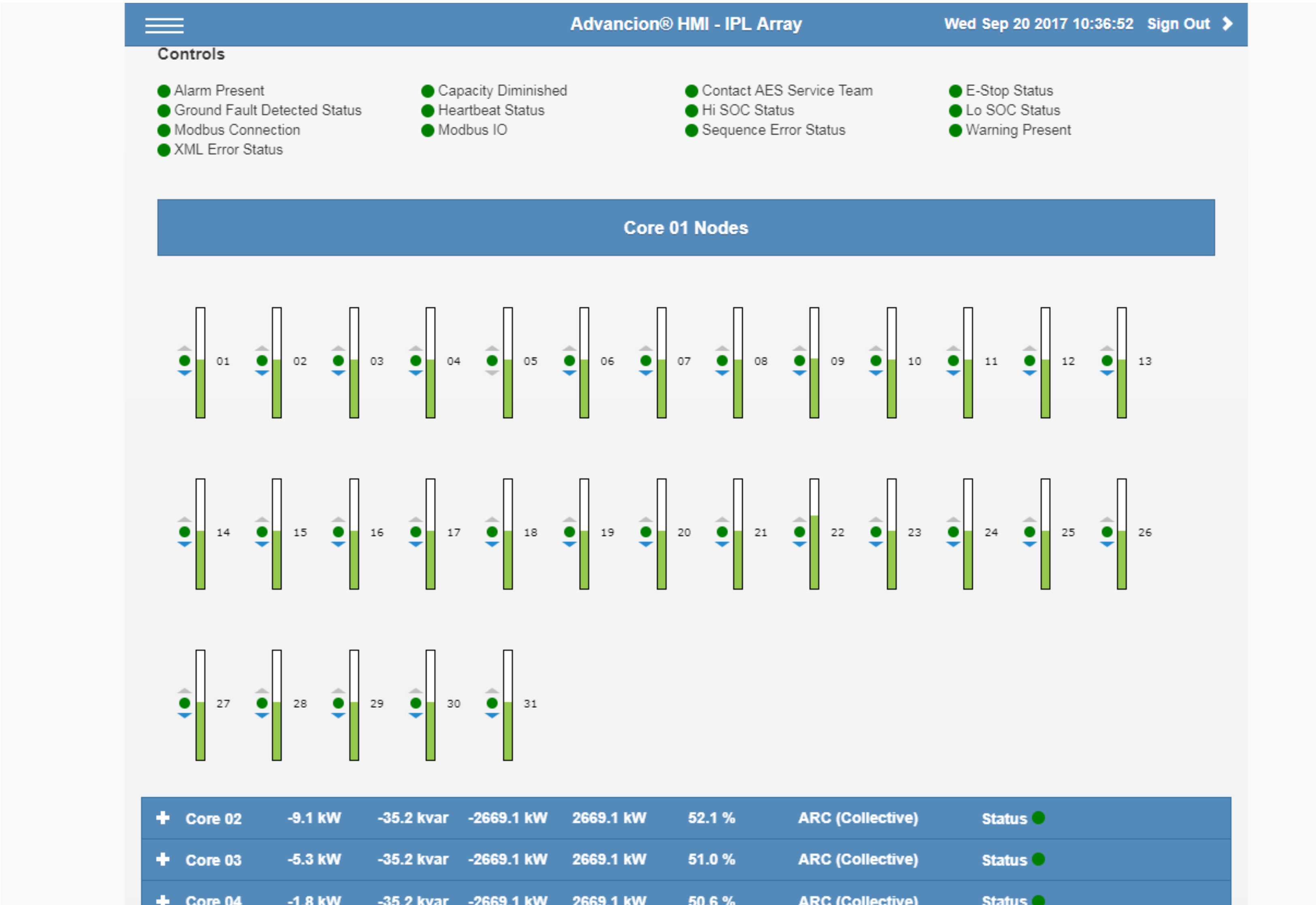
- Always topping off to programmed optimal charge – like talking on your cell phone while plugged in.

- Designed to be on continuously; reading and reacting to frequency fluctuations every 2 seconds autonomously. Minimizes use of lifetime estimated cycles – 10 years if operated appropriately. Similar in concept to 25 year life LEDs – designed to be on continuously but if you turn them on and off they do not last 25 years….something less.

Human Machine Interface



Core One



Advancion® HMI - IPL Array
Wed Sep 20 2017 10:36:52
Sign Out
Controls
Alarm Present
Ground Fault Detected Status
Modbus Connection
XML Error Status
Capacity Diminished
Heartbeat Status
Modbus IO
Contact AES Service Team
Hi SOC Status
Sequence Error Status
E-Stop Status
Lo SOC Status
Warning Present
Core 01 Nodes
01 02 03 04 05 06 07 08 09 10 11 12 13
14 15 16 17 18 19 20 21 22 23 24 25 26
27 28 29 30 31
Core 02 -9.1 kW -35.2 kvar -2669.1 kW 2669.1 kW 52.1 % ARC (Collective) Status
Core 03 -5.3 kW -35.2 kvar -2669.1 kW 2669.1 kW 51.0 % ARC (Collective) Status
Core 04 -1.8 kW -35.2 kvar -2669.1 kW 2669.1 kW 50.6 % ARC (Collective) Status

ADDENDUM

FERC Questions

Questions indicate FERC does not understand the use of the technology

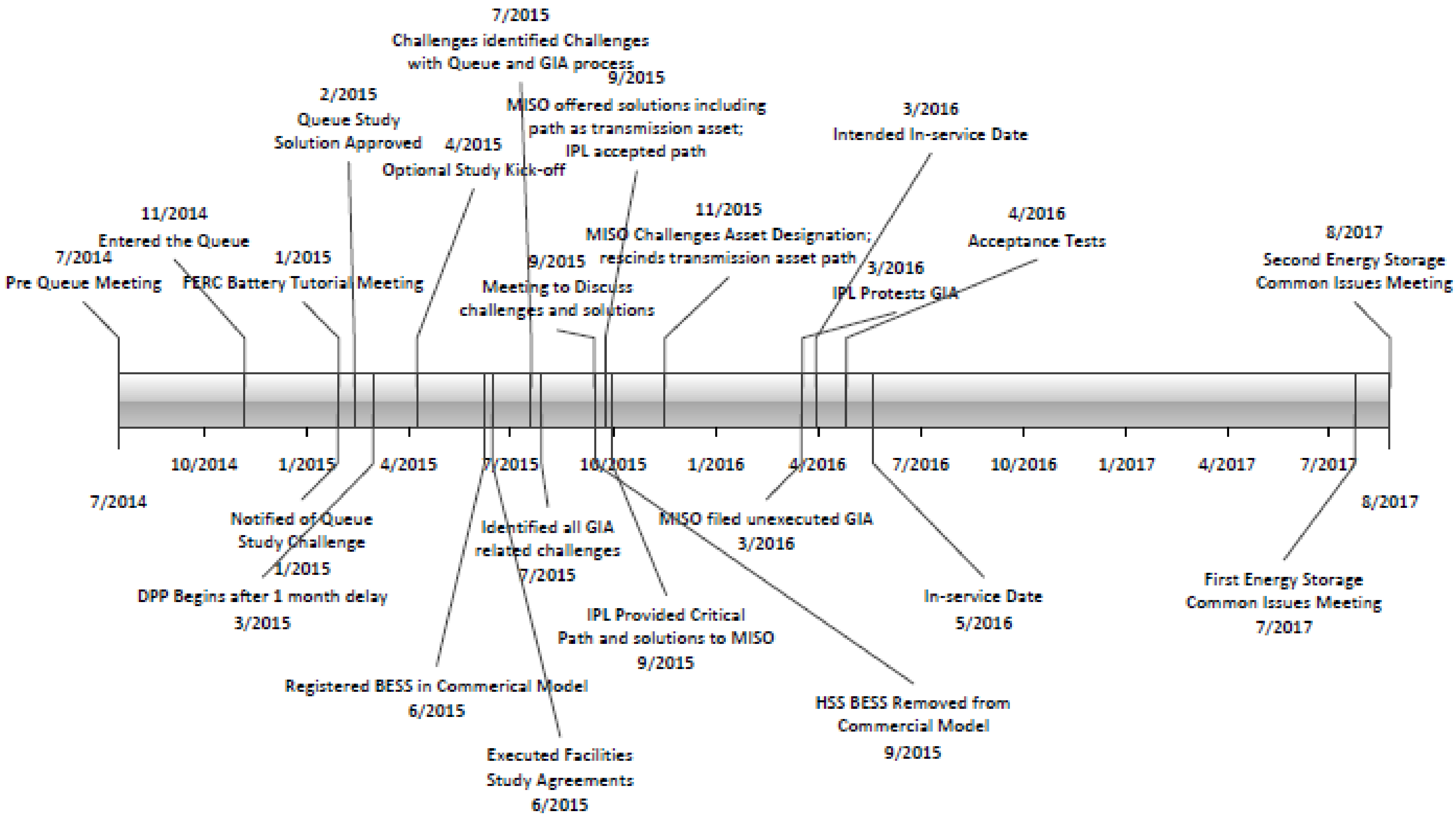
1. Operational challenges to providing PFR?
   - None
   - however it does not make sense to reduce one ancillary service to provide another or to use the droop designed for baseload generators
2. Impacts of proposed requirements on SOC
   - Reduces grid benefits of devices designed to provide essential reliability and other ancillary services; could reduce efficiency; different service will have different optimal SOC
3. Minimum requirements for droop, deadband, and timely and sustained response might be more appropriate
   - All in same interconnection should use same deadband
   - Droop however might need to approach zero slope
   - Timing of response is instantaneous; no challenges for sustainability for historical US experience in duration

FERC Questions

Questions indicate FERC does not understand the use of the technology

4. Risks associated with requiring electric storage resources to provide PFR
   - Reduction in grid benefits
   - Reduction in designed intent for provision of other ancillary services
5. Describe the relationship between electric storage resources being online and the provision of primary frequency response
   - Always n line always reacting to frequency deviations – agnostic to cause
   - Only resources always online are storage and “must run”
6. Is it possible t turn off the battery?
   - Yes, but not designed to shut down – reduces financial life and not at all necessary; can idle
7. Minimum set point? No; reaction dictated by droop and deadband; no limits
8. Several questions related to SOC – see slides on that topic

HSS BESS TIMELINE: 7/17/2014 through 8/24/2017



Identified Issues

1. Technology knowledge is essential. The category of stored energy resources includes many different technologies with different operating characteristics and benefits.

2. Understanding of the system impacts in real-time. Fear of the unknown.

3. Determine what information is useful to real-time operators

4. Protocols needed for autonomous resources

5. To address fast resources contribution to Regulation either autonomously or dispatched; determine the MWs useful to the system.

6. Policy maker education

Identified Issues

7. Understanding of State of Charge Management
8. Capacity Accreditation
9. Remove tariff and business practices barriers to capacity auction participation
10. Clarify jurisdictional and tariff conditions relative to BTM Energy Storage and Grid Scale energy storage
11. Clarify the brightline for state vs. FERC jurisdiction
12. Adapt market rules to address services dispatch and services provided autonomously

Identified Issues

13. Review and potentially modify study practices for interconnection of energy storage
14. Determine appropriate interconnection conditions for ESR by technology
15. Review Net Zero concepts and develop a similar but more efficient process that allows existing resources to add batteries without undue delay
16. Develop an appropriate interconnection process, more expedient than generation process for ESR
17. If to be studied in interconnection queue but is a transmission asset; develop a rational path from the queue to MTEP

Identified Issues

18. Develop a path and process for ESR to provide congestion relief
19. Create an expedited path in MTEP for ESR
20. Fully develop a participation model for all existing and planned ESR
21. Develop compliance with FERC Order 755 for fast resources in MISO
22. Develop an equitable means to compensate fast resources for benefits of their speed and performance
23. Clarify market participation by transmission assets per FERC Policy

Identified Issues

25. Review and modify security constrained economic dispatch models to address ability of some ESR to both inject and withdrawal; consider optimization over a longer period of time

26. Specifically address the autonomous provision of frequency control across the continuum and payment for services rendered.

DPP Considerations going forward

Definitive Planning Process Considerations

- Studies conducted with Generators may not capture the appropriate impacts if device is for frequency and/or voltage control
- Currently studied together with generators for system impacts at full capacity injection and full capacity withdrawal regardless of purpose
- HSS BESS is not a generator, does not inject or withdrawal at full capacity unless there is a Primary Frequency Response event. Injection or withdrawal is equal to the duration of the event, typically in durations of less than one minute.[1]
- There is no aspect of the studies performed in DPP for generators that addresses the provision of frequency response by generators and none for resources providing only frequency control
- Should the provision of essential reliability services even be a part of the DPP?

1 The HSS BESS is providing frequency control in conformance with NERC guidelines for PFR. Although the Array responds to all frequency deviations across the continuum, it is currently set to respond as if just for PFR.