



PMU-based application for frequency response analysis and baselining

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Frequency Response

FERC defines in RM13-11:

“*Frequency response* is a measure of an Interconnection’s ability to stabilize frequency immediately following the sudden loss of generation or load, and is a *critical component of the reliable operation* of the Bulk-Power System, particularly during disturbances and recoveries.”

- ▶ The frequency response measure (FRM) can be computed from the single event frequency response data (SEFRD).
- ▶ FRM is expressed in MW/0.1Hz



Regulatory Landscape

▶ WECC

- Initial efforts to develop a Frequency Response Standard started in early 2000's
- WECC FRR White Paper was approved in 2004
- Two attempts to develop a WECC FRR Criterion failed in late 2000s

▶ NERC

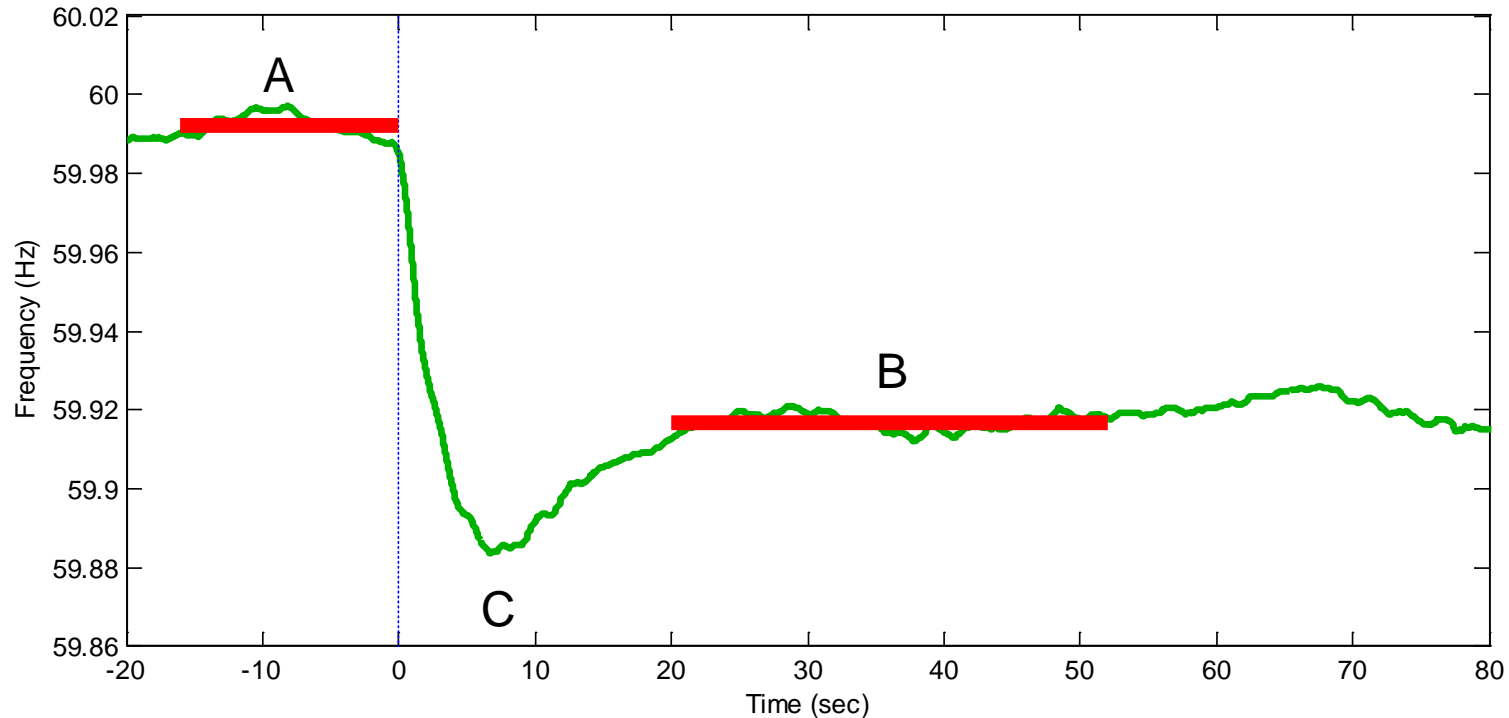
- FERC Technical Conference on Frequency Response in 2010
- NERC Frequency Response Initiative led to the development of NERC BAL-003-1 Frequency Response Standard
- **FERC approved BAL-003-1 Reliability Standard, implementation date is April 1, 2015**

- ▶ Design Event should not result in under frequency load shedding (UFLS)

Table 11: Recommended Resource Contingency Protection Criteria

Interconnection	Resource Contingency	Basis	MW
Eastern	Largest Resource Event in Last 10 Years	August 4, 2007 Disturbance	4,500
Western	Largest N-2 Event	2 Palo Verde Units	2,740'
ERCOT	Largest N-2 Event	2 South Texas Project Units	2,750'

- ▶ Western Interconnection Frequency Response Obligation (IFRO) is about 950 MW per 0.1 Hz at settling frequency (point B)
- ▶ IFRO is prorated among Balancing Authorities (BAs) based on annual load and generation
- ▶ BAs are responsible for providing frequency response,
 - BA frequency response measure (FRM) is measured as change in BA interchange over the delta frequency between initial and settling values
- ▶ Formation of Reserve Sharing Groups is permitted



F_A = pre-disturbance frequency (average from -16 to 0 sec)

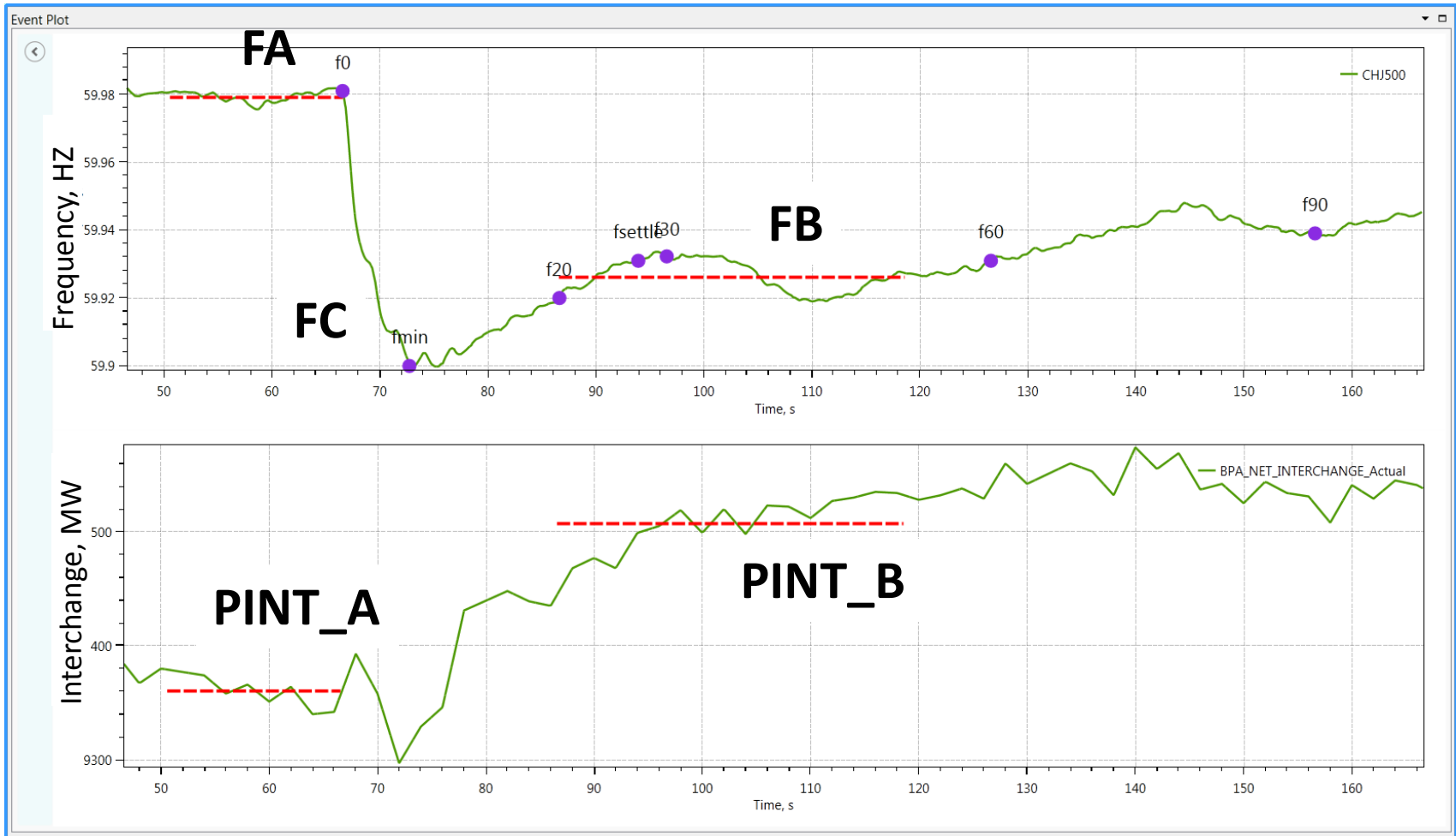
F_B = settling frequency (average from 20 to 52 sec)

F_C = minimum (nadir) frequency

NERC FRM: Frequency difference between Point A and Point B

LBNL Metrics: Frequency difference between Point A and Point C*

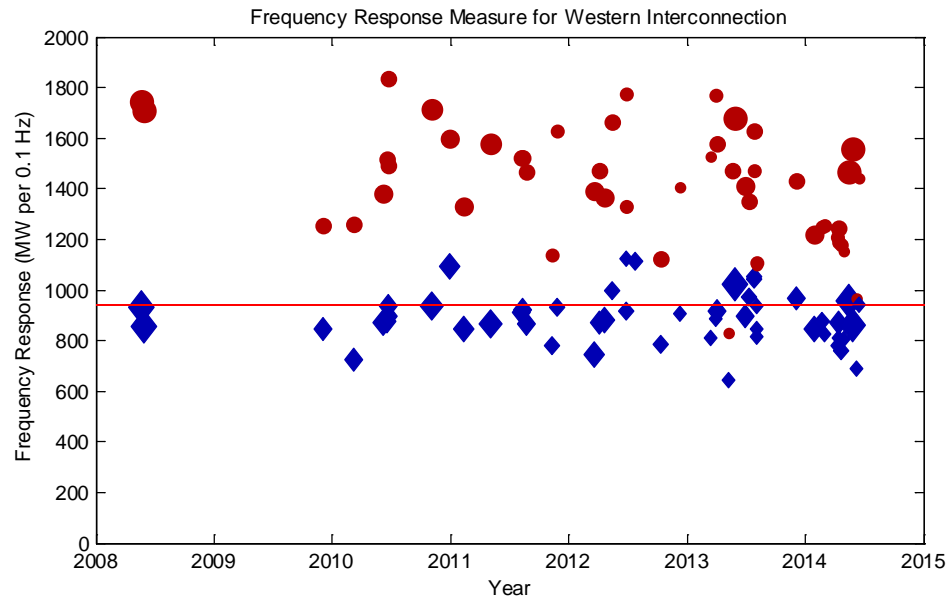
BA Frequency Response Measure Calculation



$$BA\ FRM = (PINT_B - PINT_A + BA\ GEN\ LOSS) / (FA - FB)$$

Western Interconnection Performance

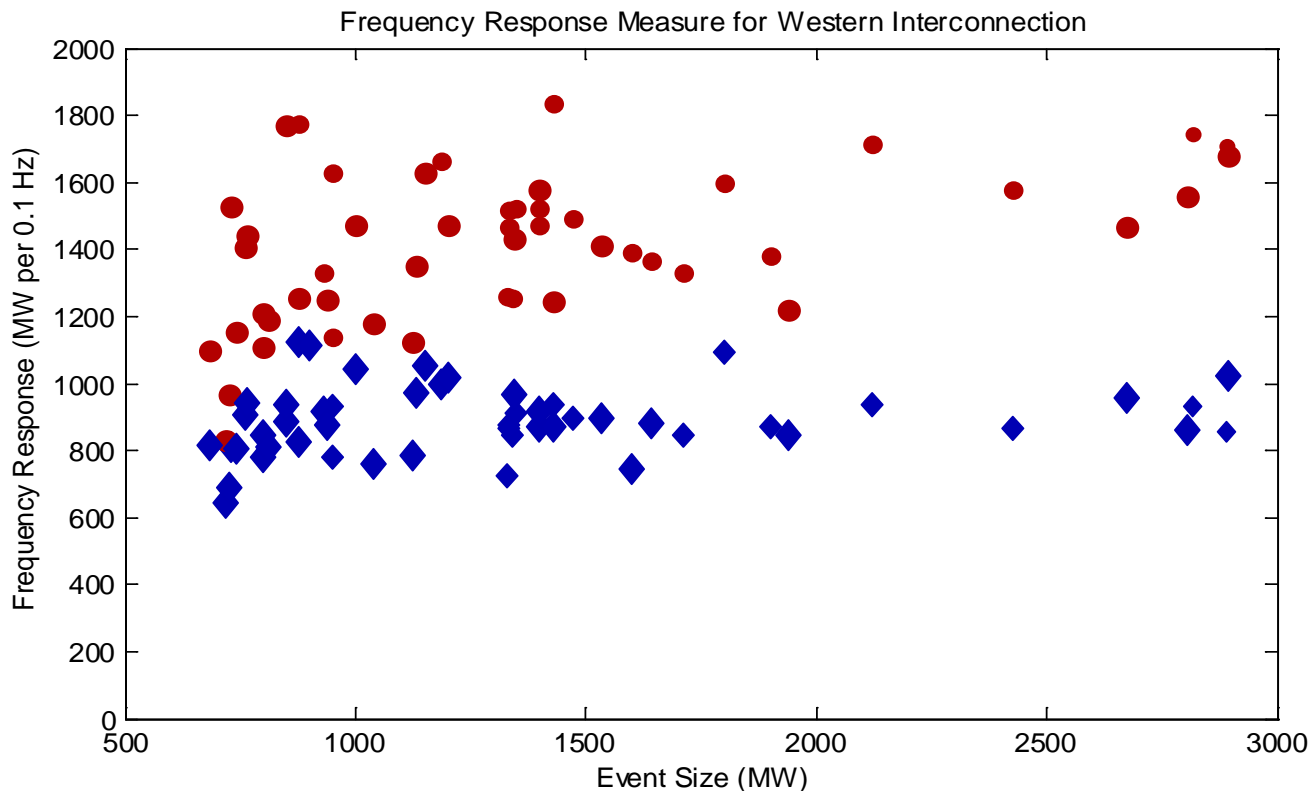
WECC IFRO ~950 MW per 0.1 Hz, WECC IFRM is trending ~ 1,400 to 1,600 MW per 0.1 Hz
Response at nadir: required ~580 MW per 0.1 Hz, actual is about 800 MW per 0.1 Hz



- ▶ Red dots – frequency response measured at point B (settling) using NERC FRM methodology
- ▶ Blue diamonds – frequency response is measured at point C (nadir)

Western Interconnection Performance

Response versus size of event: Small events do not extrapolate well to large
Nadir measurement is more consistent, as it is driven by system physics



- ▶ Red dots – frequency response measured at point B (settling) using NERC FRM methodology
- ▶ Blue diamonds – frequency response is measured at point C (nadir)



Frequency Response Analysis Tool (FRAT)

- ▶ Developed under BPA guidance by PNNL
- ▶ Development is co-funded by US DOE and BPA
- ▶ **Frequency response monitoring**
 - **Interconnection**
 - **Balancing Authority**
 - ◆ Power Plant (*Under development*)
 - ▶ Individual Unit (*Under development*)
- ▶ Calculation NERC FRM using PMU and SCADA measurements
- ▶ Compliance reporting
- ▶ Baselining frequency response for interconnection and BA
- ▶ Supporting different data formats (csv, xml, OSIsoft PI, COMTRADE)
- ▶ Statistical Analysis

Database of Events

Event Plot

Events DataBase

Event Name	Date	Time	Disturbance	FRM NERC	FRM BPA
Intermountain Unit 1	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 2	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 3	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 4	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 5	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 6	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 7	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 8	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 9	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 10	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 11	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 12	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 13	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 14	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 15	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 16	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 17	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 18	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 19	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 20	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 21	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 22	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 23	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 24	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 25	04/29/14	5:23:00	740	1156.25	311.887
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Intermountain Unit 36	04/29/14	5:23:00	740	1156.25	311.887
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Intermountain Unit 46	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 47	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 48	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 49	04/29/14	5:23:00	740	1156.25	311.887
Intermountain Unit 50	04/29/14	5:23:00	740	1156.25	311.887

Event Characteristics

Event Description: Intermountain IPP Unit 1

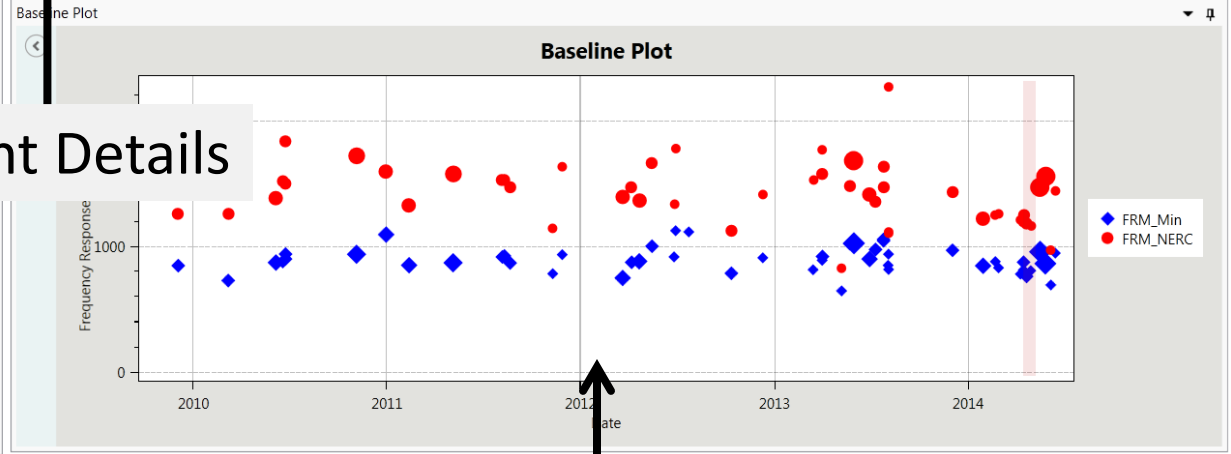
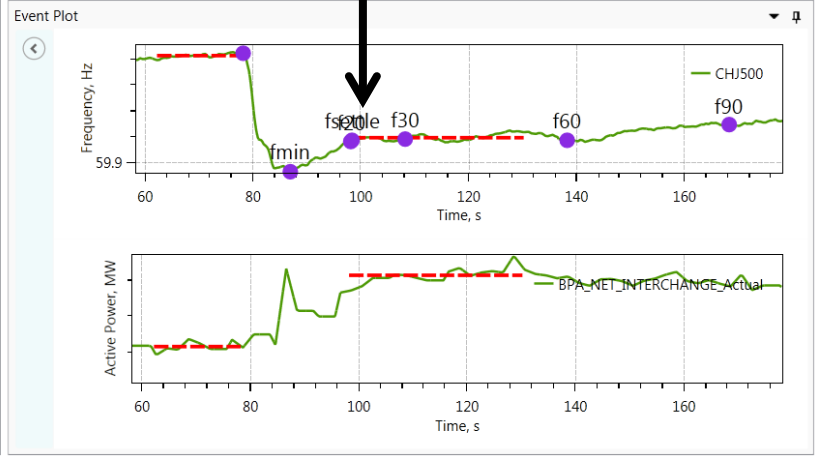
Date: 4/29/2014 Time: 5:23:00

Day: Tuesday

Disturbance Si: 740

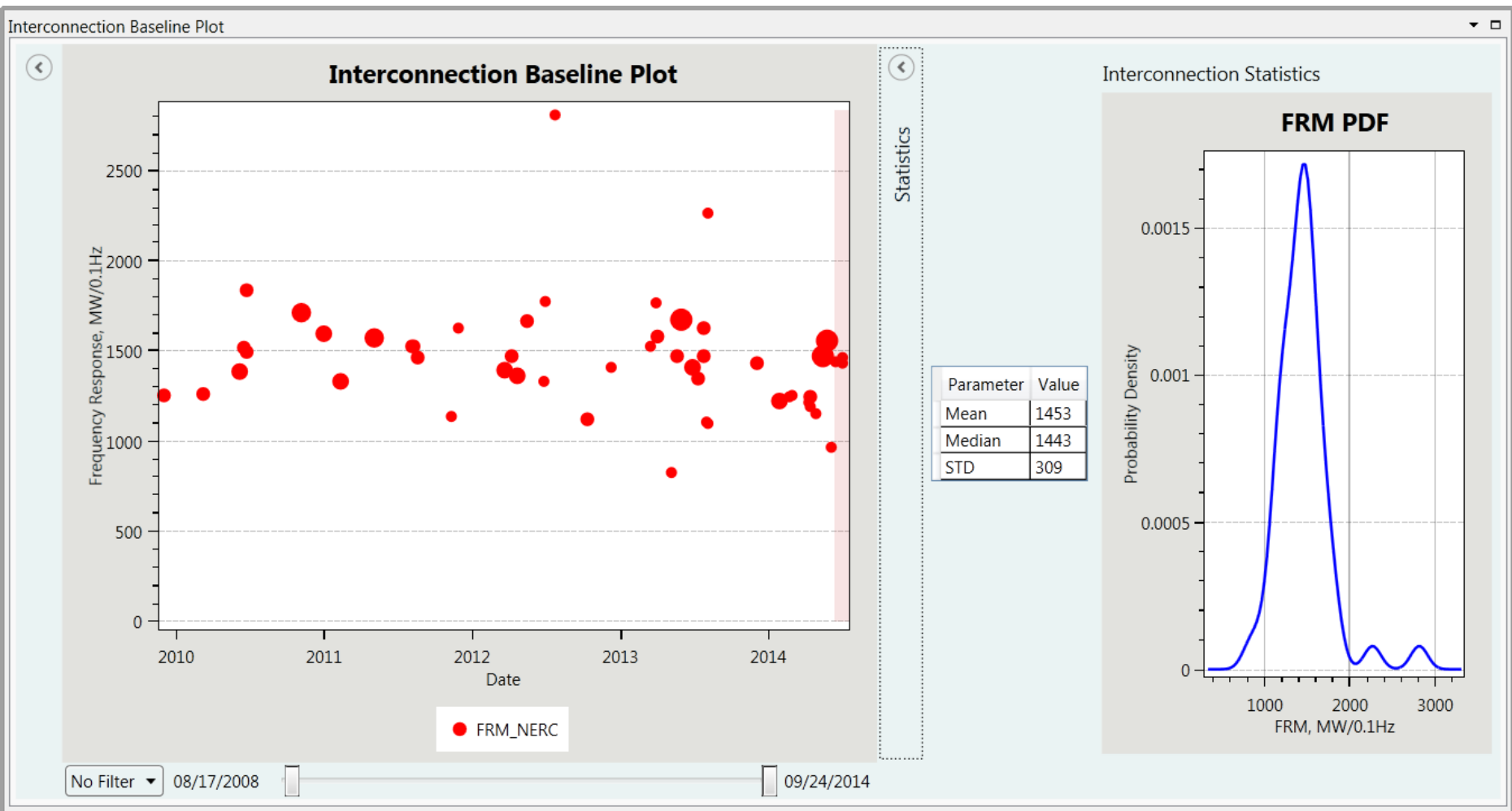
Qualifying I: Comments:

- Load/Generation
- Time/Frequency
- NERC Performance
- Additional Performance Indexes



Event Details

Performance Baseline



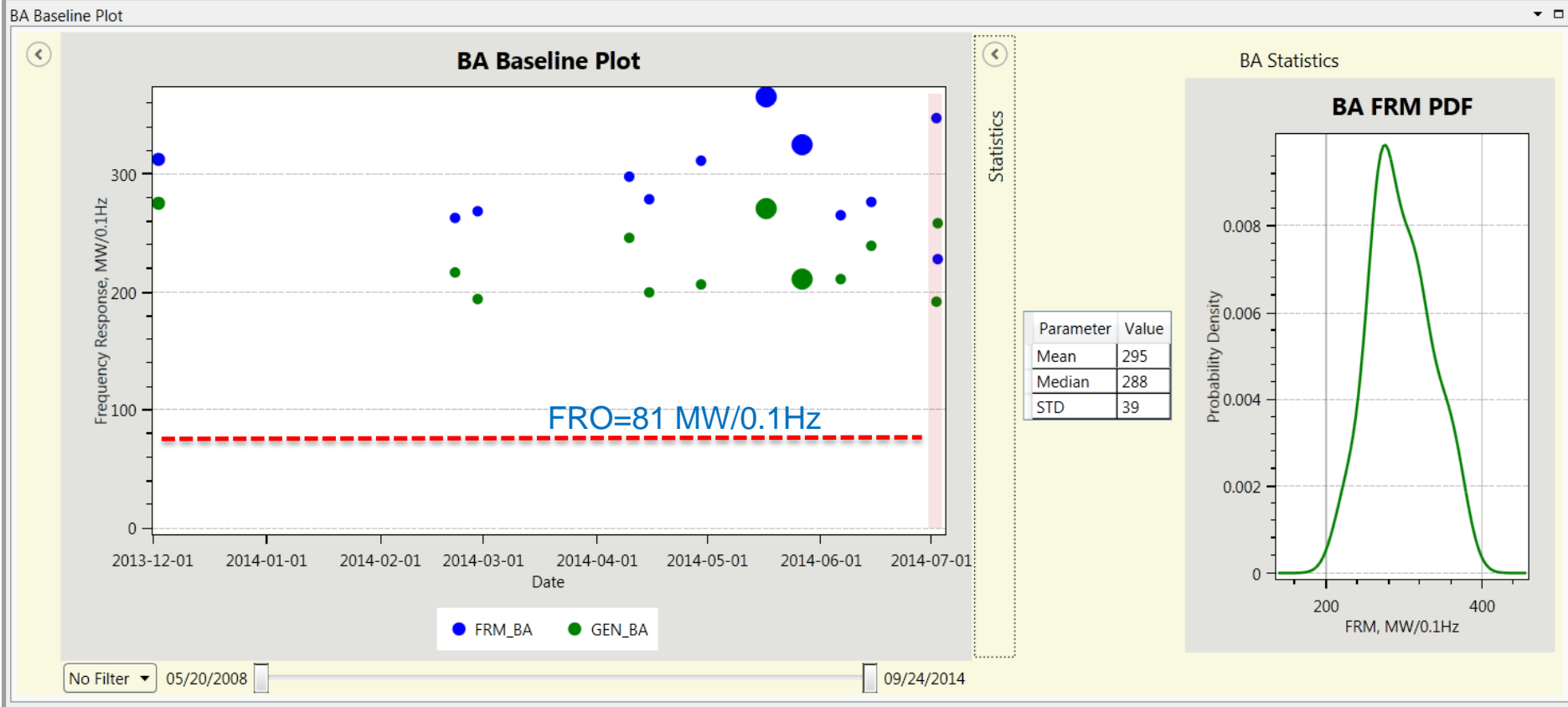


Balancing Authority Performance

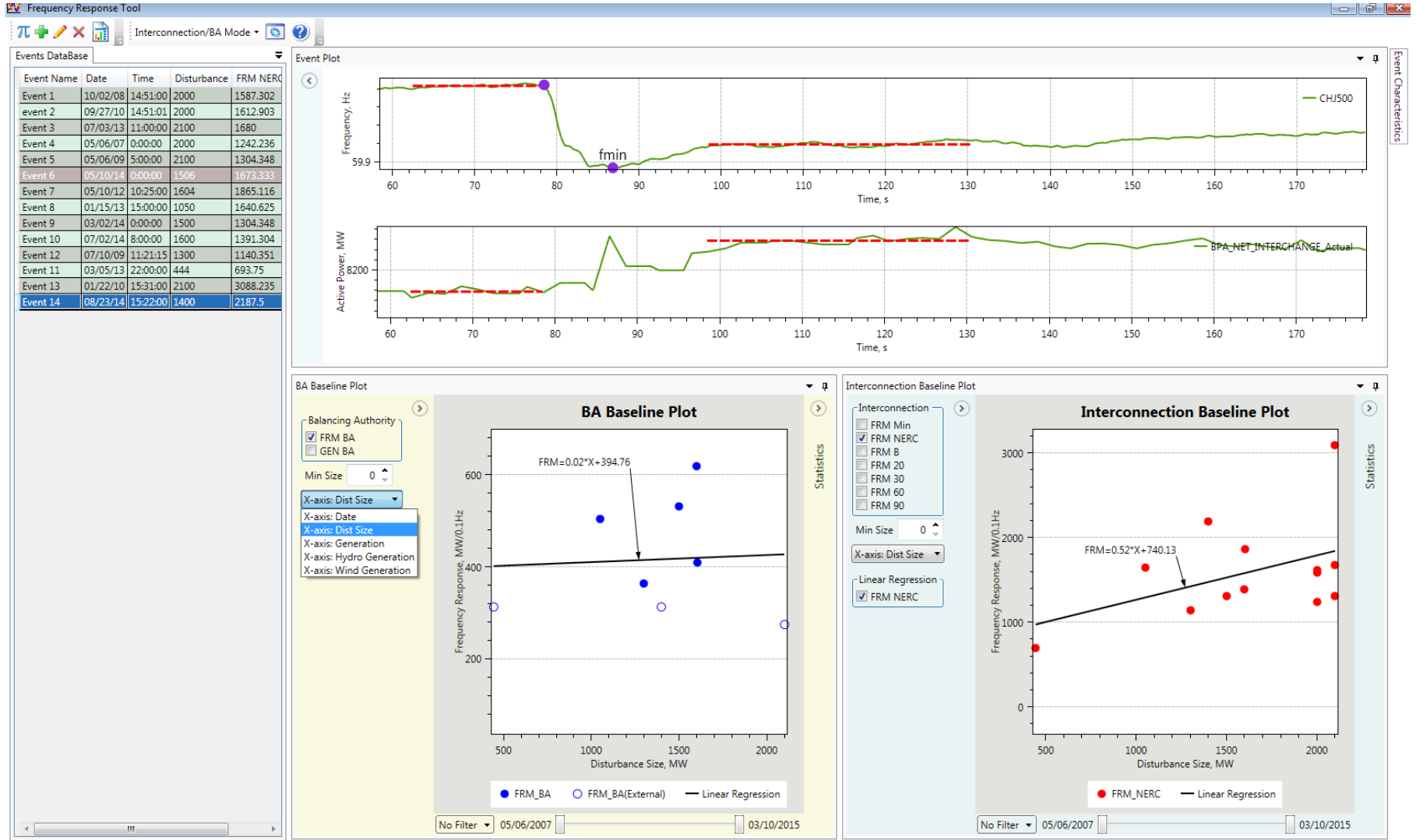


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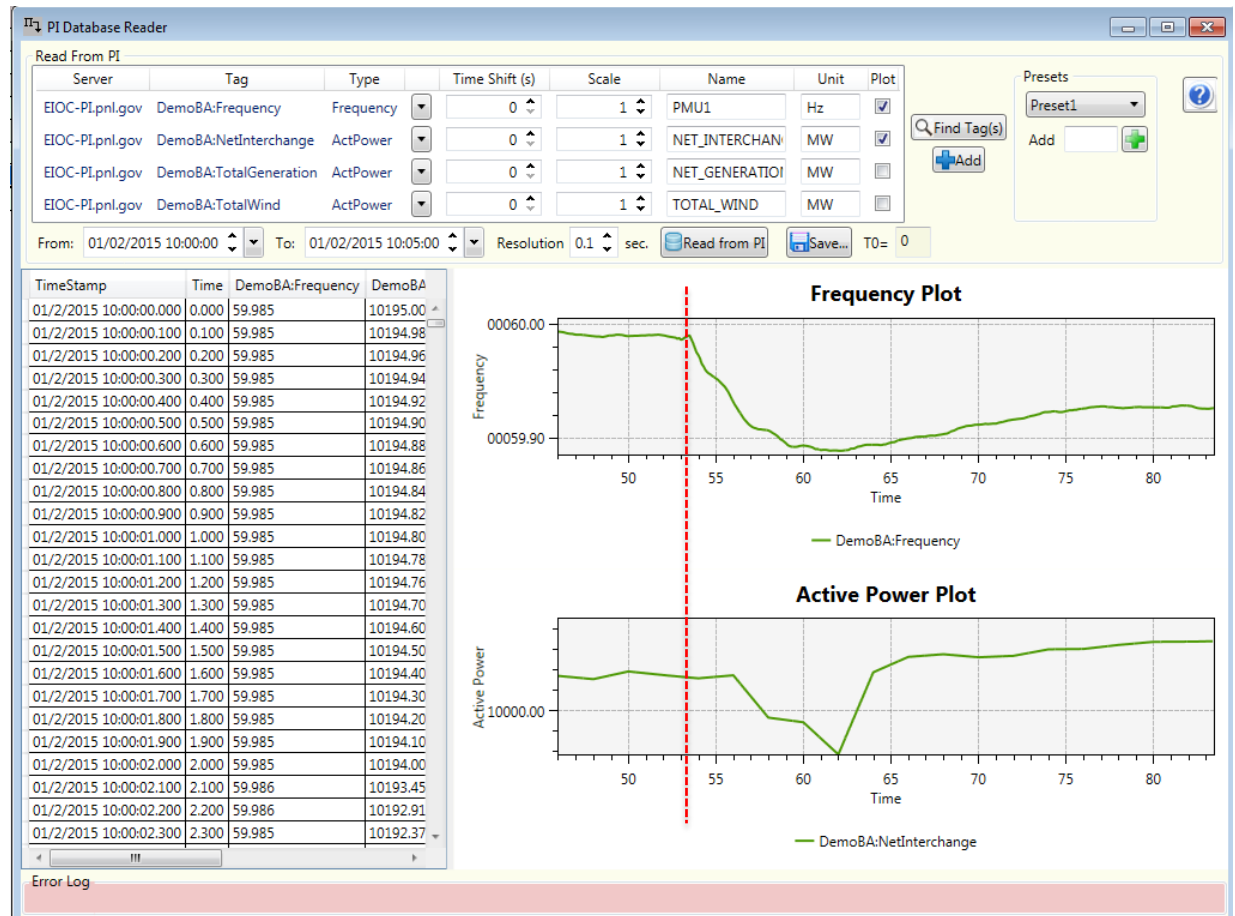
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Interchange response is measured for compliance with NERC BAL-003-1
Generation response is calculated to determine how much frequency response to acquire



- ▶ Read information from PI server
- ▶ Configurable presets
- ▶ Time-series aligning



Report

 Add Event Plot
 FR Report
NERC FRS1

3/10/2015 3:52:38 PM

Frequency Response Analysis Report

Event Name	Event Date	Event Time	Disturbance Size	Load Loss	Time of Load	FRM NERC	FRM BA	Gen Response BA
Event 1	10/2/2008	14:51:00	2000	1000	5	1587.302	0	0
Event 2	9/27/2010	14:51:01	2000	444	10	1612.903	0	0
Event 3	7/3/2013	11:00:03	2100	0	0	1680	0	0
Event 4	5/6/2007	0:00:00	2000	500	11	1242.236	0	0
Event 5	5/6/2009	5:00:00	2100	0	0	1304.348	0	0
Event 6	5/10/2014	0:00:00	1506	0	0	1073.333	-216.13	246.667
Event 7	5/10/2012	10:25:00	1604	650	5	1865.116	409.52	260.349
Event 8	1/15/2013	15:00:00	1050	700	5	1640.625	504.66	398.667
Event 9	3/2/2014	0:00:00	1500	100	0	1304.348	531.81	441.433
Event 10	7/2/2010	8:00:00	1600	0	0	1391.304	619.88	529.079
Event 11	7/10/2009	11:21:15	1300	0	0	1140.351	363.38	273.039
Event 12	3/5/2011	22:00:03	444	0	0	693.75	312.08	213.455
Event 13	1/22/2010	15:31:21	2100	0	0	3088.235	274.37	192.643
Event 14	8/23/2014	15:22:00	1400	0	0	2187.312	312.36	208.523

Interconnection Baseline Plot

Frequency Plot

Event: "Event 1"

Event Characteristics Table				
Event Name	Event Date	Event Time	Disturbance Size	Load Loss
Event 1	10/2/08	14:51:00	2000	1000
Initial Time	62.15	Initial Frequency	59.979	
Frequency point A NERC	59.98	Frequency point B NERC	59.854	FRM NERC
Minimum Time	9.517	Minimum Frequency	59.773	FRM Min

Active Power Plot

Frequency Plot

Event2: "event 2"

Event Characteristics Table				
Event Name	Event Date	Event Time	Disturbance Size	Load Loss
event 2	9/27/2010	14:51:01	2000	444
Initial Time		Initial Frequency		
Frequency point A NERC		Frequency point B NERC		
Minimum Time		Minimum Frequency		

Active Power Plot

Frequency Plot

March 25, 2015

15



Power Plant / Single Unit Performance (under development)

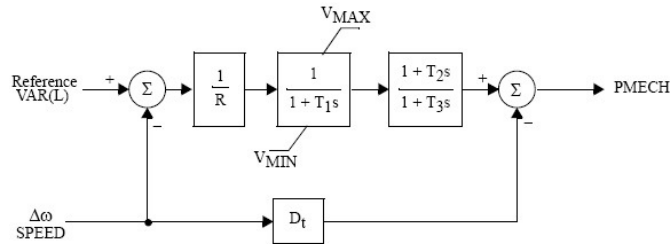


Pacific Northwest
NATIONAL LABORATORY

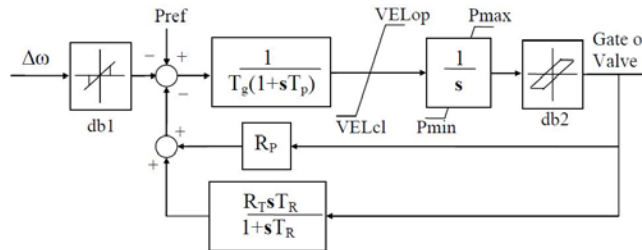
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- ▶ Compare measurement based response vs. model based
- ▶ Generic models of units
 - TGOV (steam)



- IEEEG3 (hydro)



- ▶ Computation of unit FRM

Frequency Response Tool
Single Unit Mode

Event Name	Date	Time	Disturbance	F
Event 1	10/02/08	14:51:00	2000	15
event 2	09/27/10	14:51:01	2000	16
Event 3	07/03/13	11:00:00	2100	16
Event 4	05/06/07	0:00:00	2000	12
Event 5	05/06/09	5:00:00	2100	13
Event 6	05/10/14	0:00:00	1506	16
Event 7	05/10/12	10:25:00	1604	18
Event 8	01/15/13	15:00:00	1050	14
Event 9	03/02/14	0:00:00	1500	13
Event 10	07/02/14	8:00:00	1600	13
Event 12	07/10/09	11:21:15	1300	11
Event 11	03/05/13	22:00:00	444	66
Event 13	01/22/10	15:31:00	2100	30
Event 14	08/23/14	15:22:00	1400	23

Unit Characteristics

Unit Info
 Gen Name: Hydro 0
 Gen Type: Hydro
 F Signal: CHJ500.F P Signal: JDA1.P

Speed Governor Parameters

Pmax	900	Pmin	200
Permanent Droop	0.05	Temporary Droop	0.5
Deadband 1	0.01	Deadband 2	0
Tg	0.5	Tp	0.03
Opening Velocity	0.1	Closing Velocity	-0.1
Tr	1	Tw	2
Pref	878.75	Fnominal	60

Model Diagram

Frequency Response Characteristics

Initial Time	52.293	Initial Frequency	59.99
FA	59.994	FB	59.926
PA	878.085	PB	888.881
FRM	15.684		

Event Plot

Frequency response analysis tool

- ▶ Received high reviews from NERC Resource Subcommittee
 - ▶ Presented at CIGRE, WECC and ERCOT working groups, and IEEE conferences
 - ▶ BPA maintains the database of Western interconnection events going back to 2008
 - ▶ Released under an open source license
-
- FRAT web page: <https://svn.pnl.gov/FRTool>
 - dnkosterev@bpa.gov
 - pavel.etingov@pnnl.gov