Pacific Northwest
NATIONAL LABORATORY

Field Demonstration of an Automated Generator Evaluation Tool at BPA

April 16, 2024

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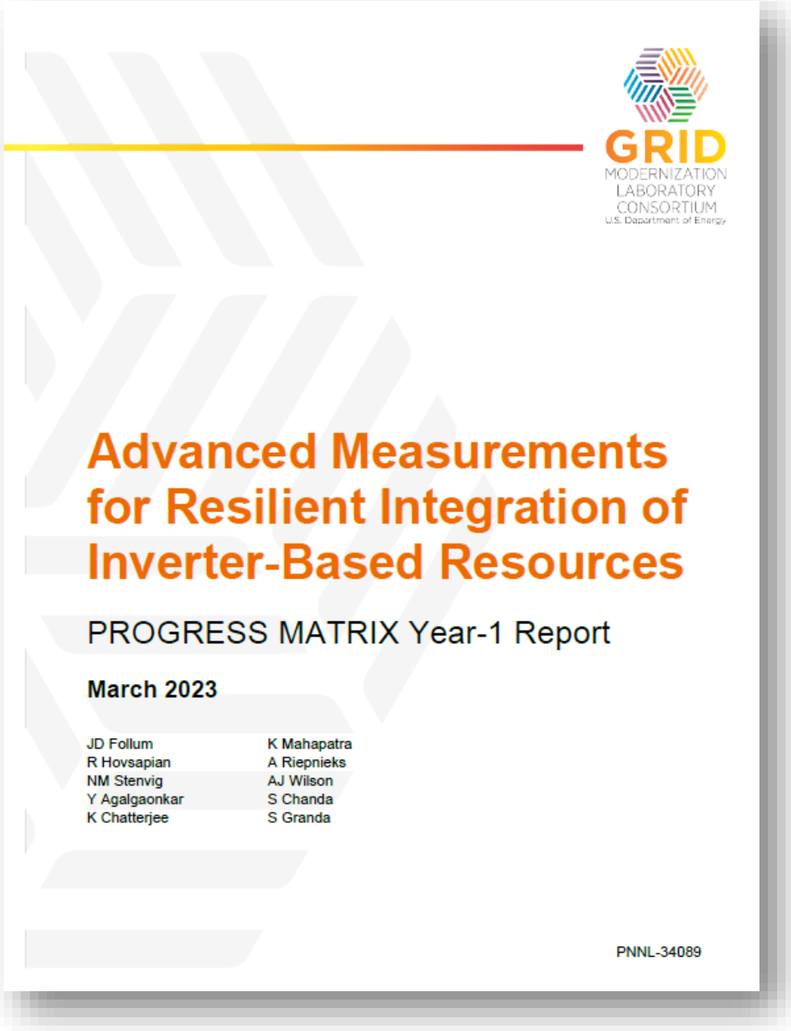
U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

PNNL-SA-196973

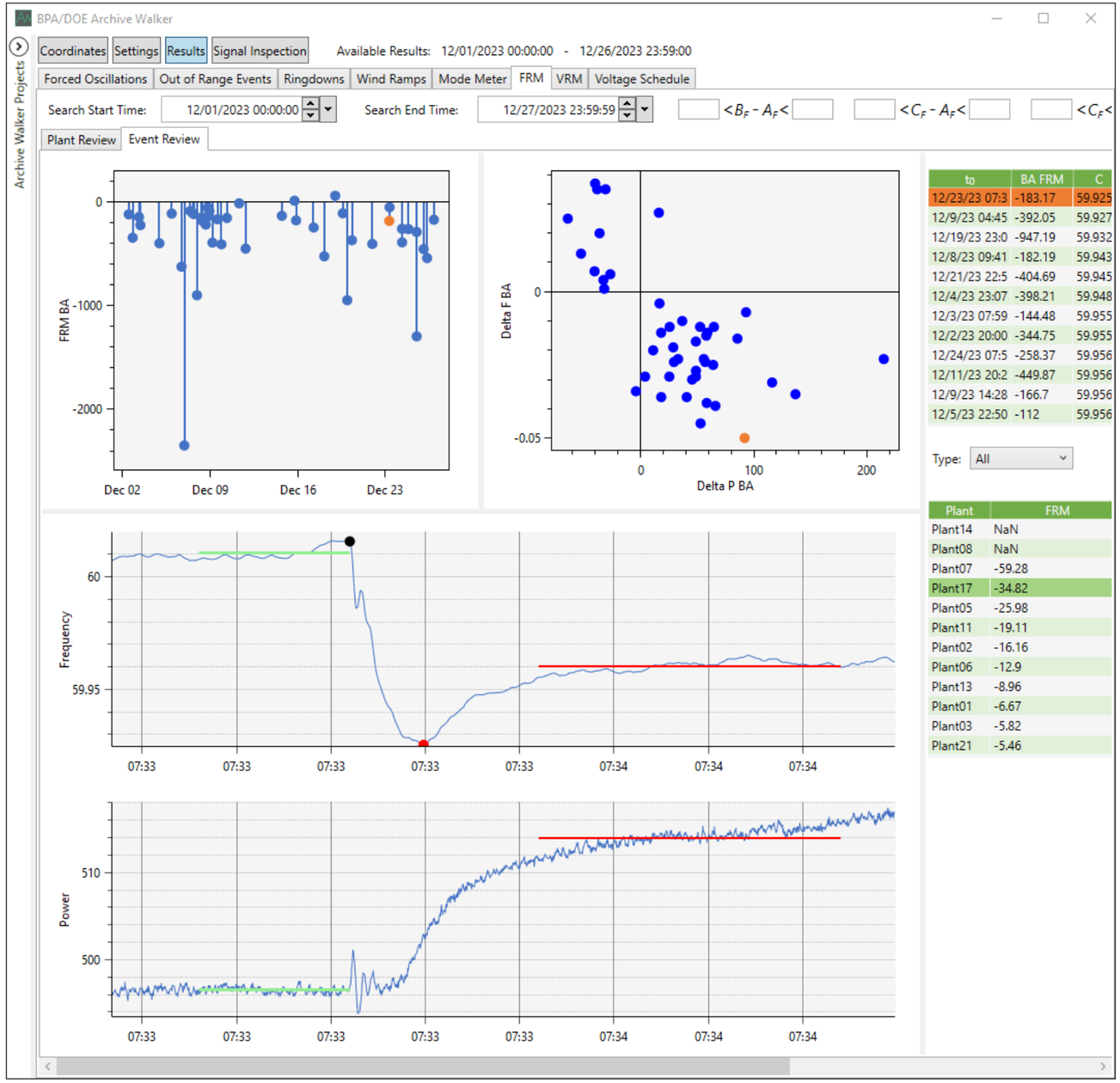
Background

- Multi-lab team partnered with utilities to develop advanced measurement capabilities for resilient integration of inverter-based resources (IBRs)
- PNNL partnered with BPA to address one of their needs
  - All generators must meet requirements to interconnect with BPA's system
  - Ongoing performance verification is time consuming, and increasingly so as new IBR plants come online
- The resulting Generator Scorecard tool was demonstrated at BPA



Capabilities

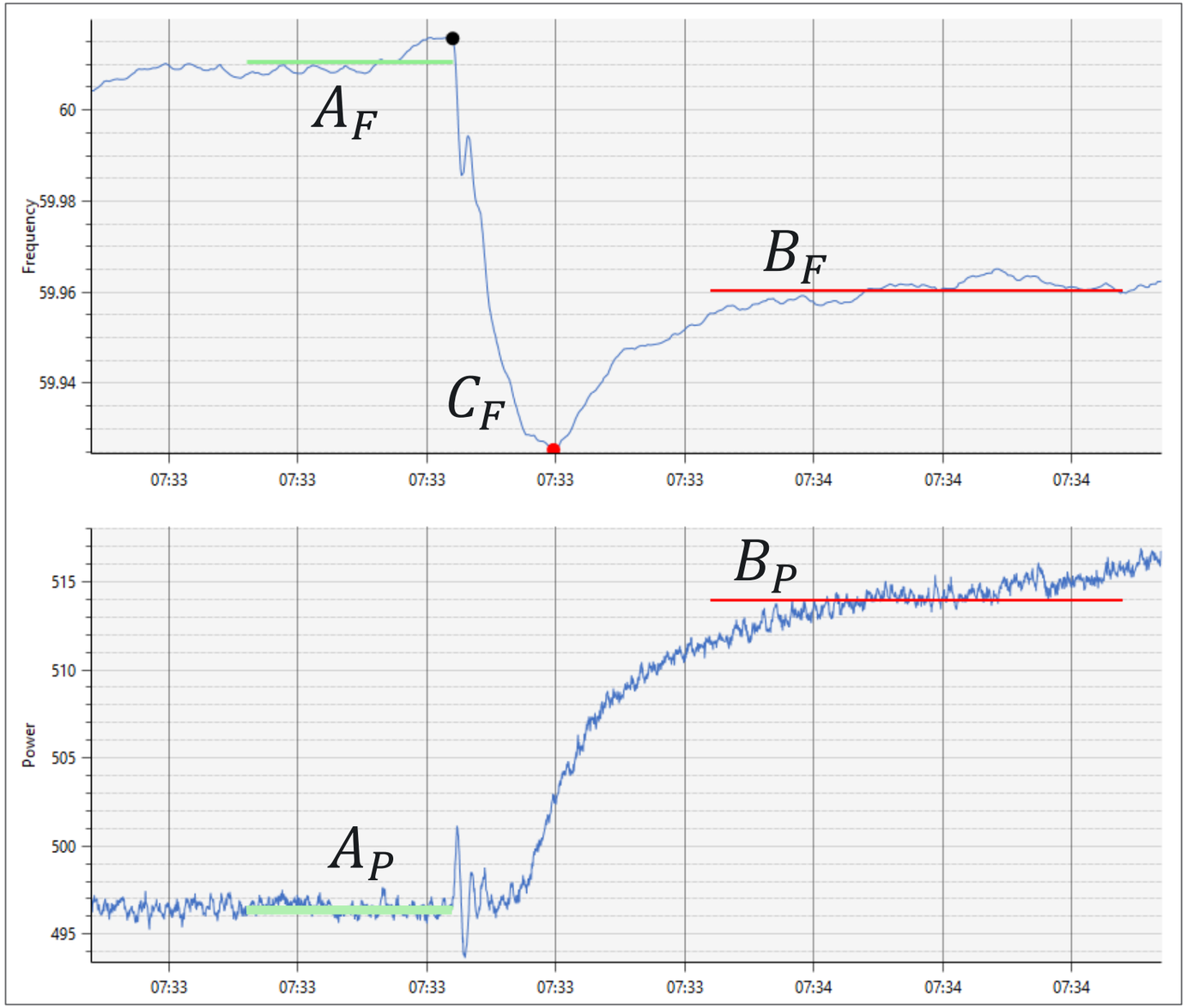
- Analyzes long records of archived or incoming PMU data
- Detects frequency and voltage excursions
- Automatically performs frequency and voltage response analysis
- Tracks adherence to the assigned voltage schedule
- Summarizes performance in easy to interpret visualizations



Frequency Response Measure (FRM)

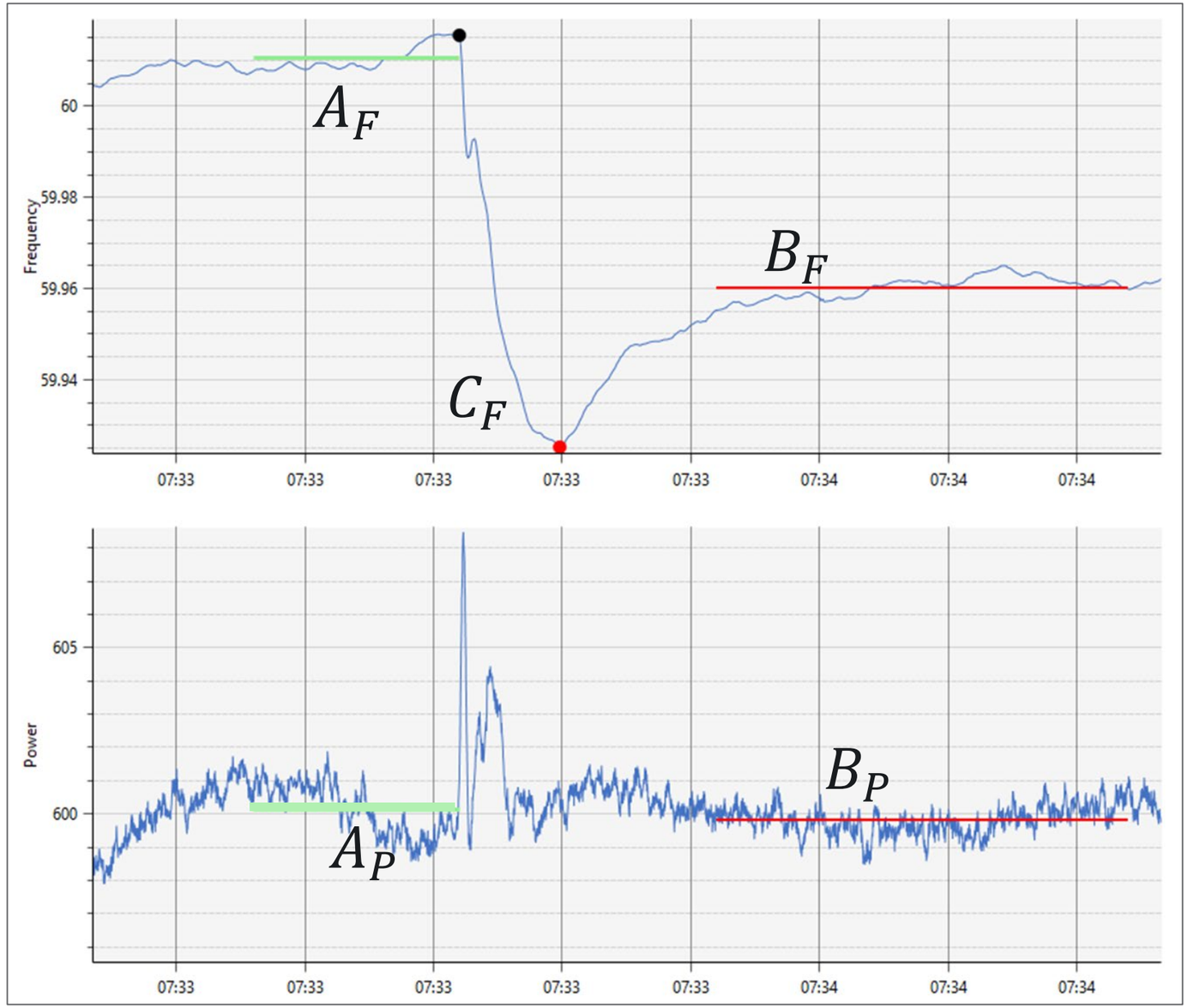
Measure of a plant's change in active power in response to a change in frequency

$$FRM = \frac{B_P - A_P}{10(B_F - A_F)} \text{ in } \frac{MW}{0.1Hz}$$



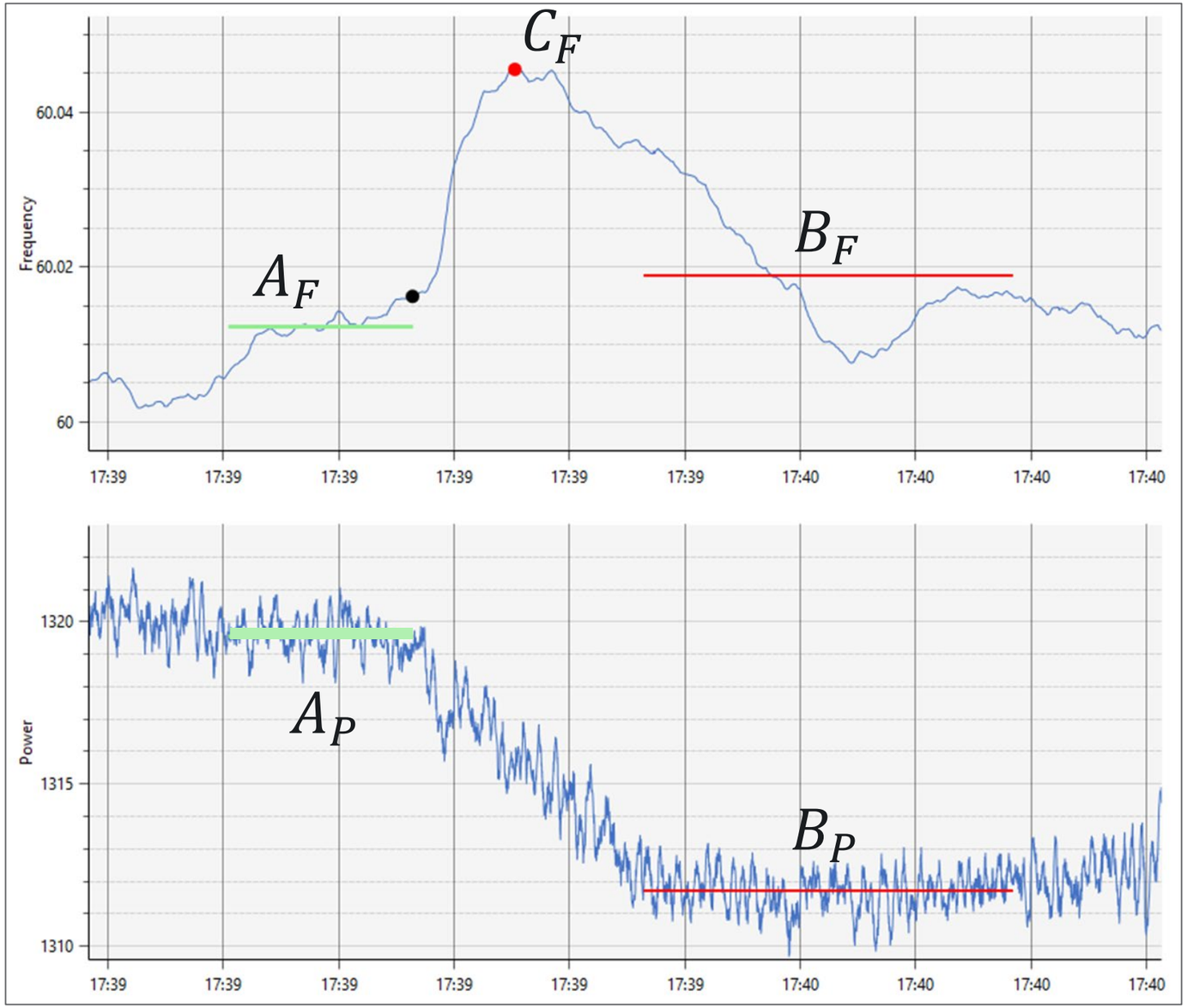
Frequency Response Measure (FRM)

- Plants operating without headroom are unable to respond, even if frequency control is active
- Under-frequency excursions may not provide enough information



Frequency Response Measure (FRM)

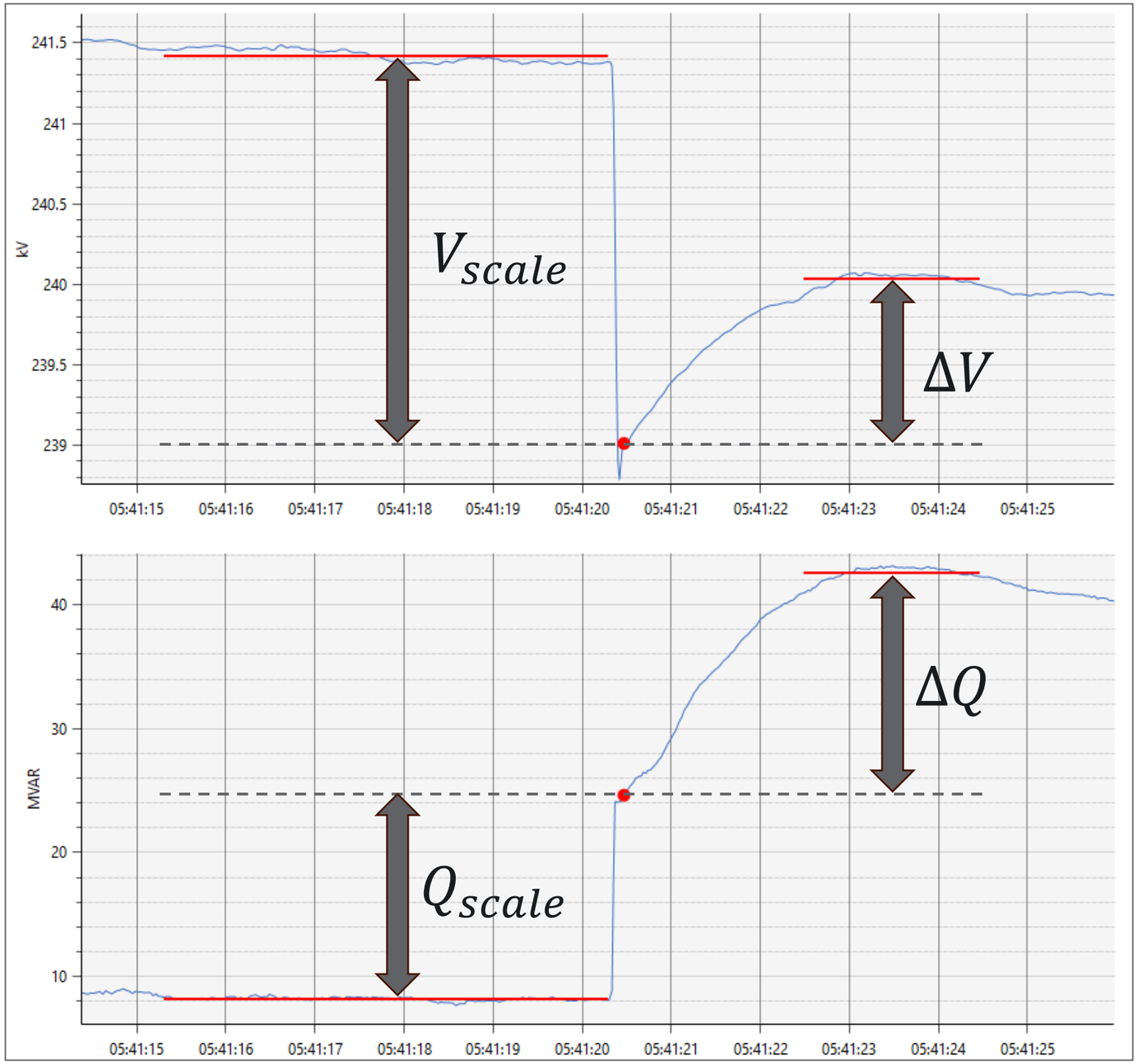
- Over-frequency excursions allow evaluation of plants operating without headroom
- Signatures of pumped storage motors turning off were specifically sought



Voltage Response Measure (VRM)

Measure of a plant's change in reactive power in response to a change in voltage magnitude

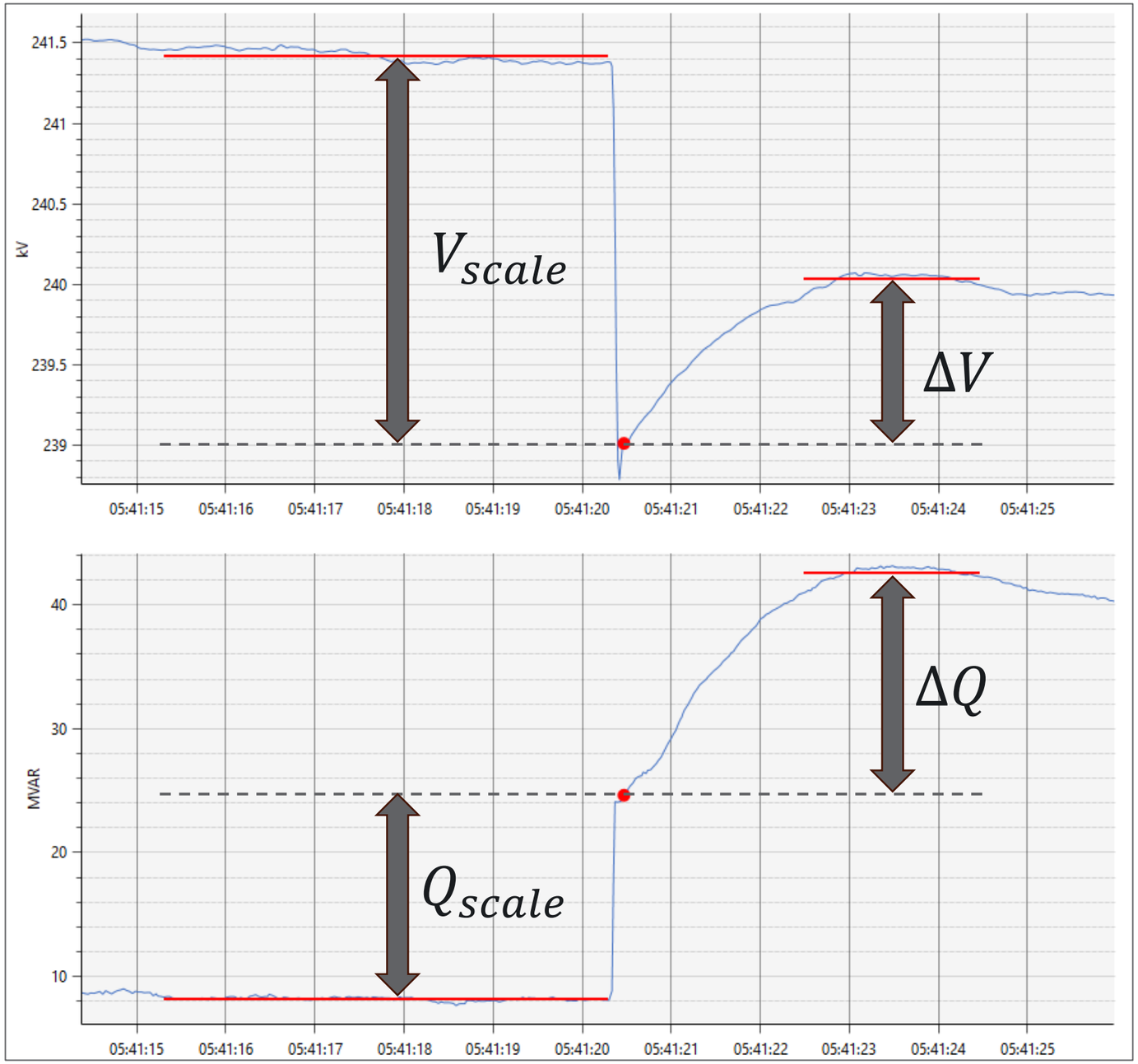
$$VRM = \frac{\Delta V}{\mathrm{V}_{scale}} \times \frac{\Delta Q}{Q_{scale}}$$



Voltage Response Measure (VRM)

- Detector targets capacitor switching events
- Scaling provides consistency across kV levels

$$VRM = \frac{\Delta V}{\mathrm{V}_{scale}} \times \frac{\Delta Q}{Q_{scale}}$$



Voltage Schedule

- BPA bases their voltage schedules on three loading periods
- The schedule has a kV target with upper and lower bounds
- The tool reports the proportion of time the plant is off schedule

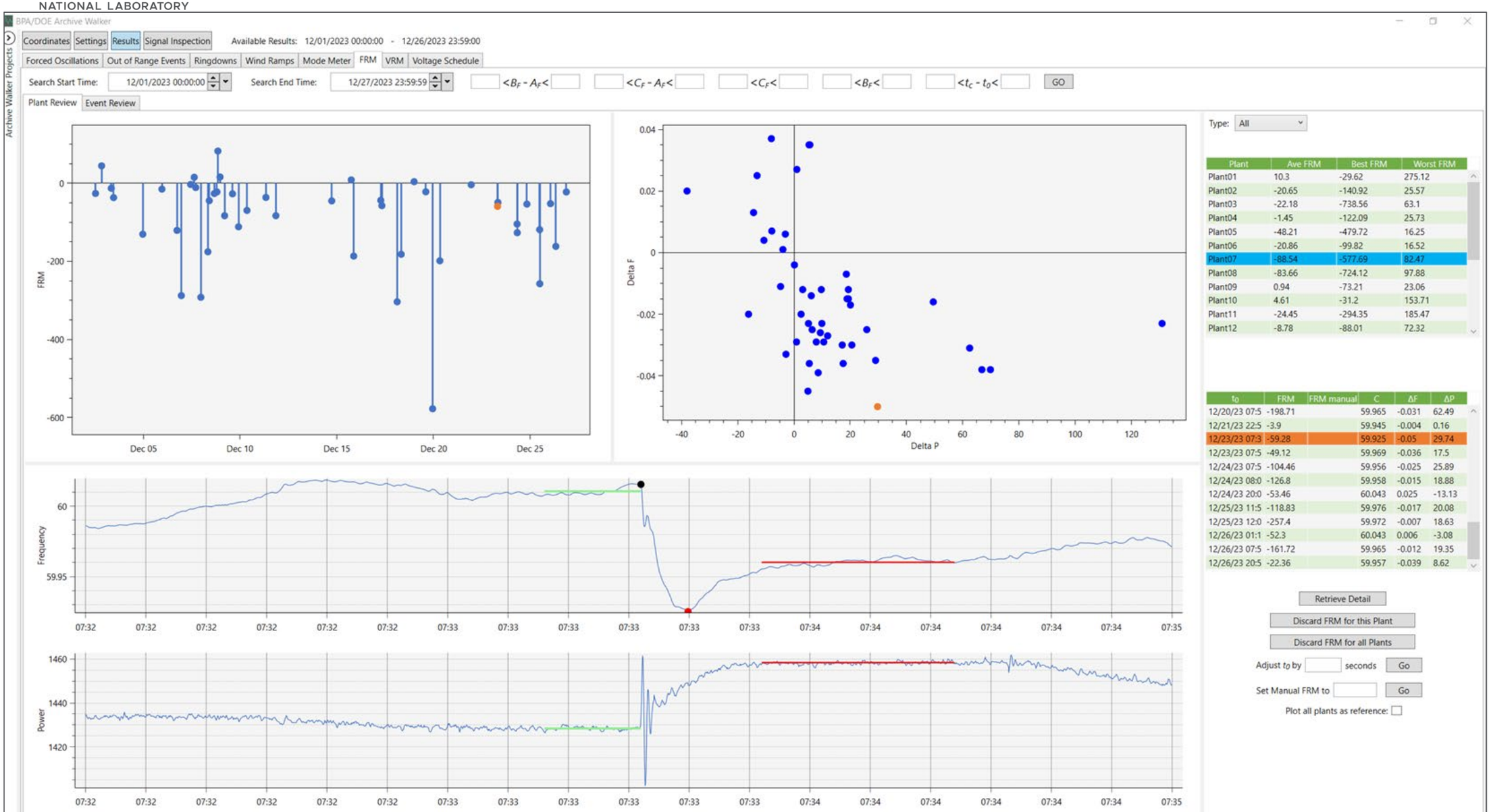
Follow-Up for Potential Performance Issues

- The Generator Scorecard provides an initial assessment
- Potential performance issues first reviewed by BPA internally
  - Check for straightforward explanation
    - Outage causing higher than normal voltages
    - Known limitations for certain operating conditions
  - Manual model-based analysis
  - Coordination between departments that may have insight
- For issues that need to be addressed, BPA's interactions with generator operator are cooperative
  - Informal conversation to check if the issue is known
  - Organizations collaborate to find a solution

Demonstration

- Deployed at BPA's synchrophasor laboratory
  - Many thanks to Tony Faris for setting up and running the tool
- Configured to evaluate 22 power plants
- Presented results are based on one month of archived PMU data

Frequency Response Measure (FRM)



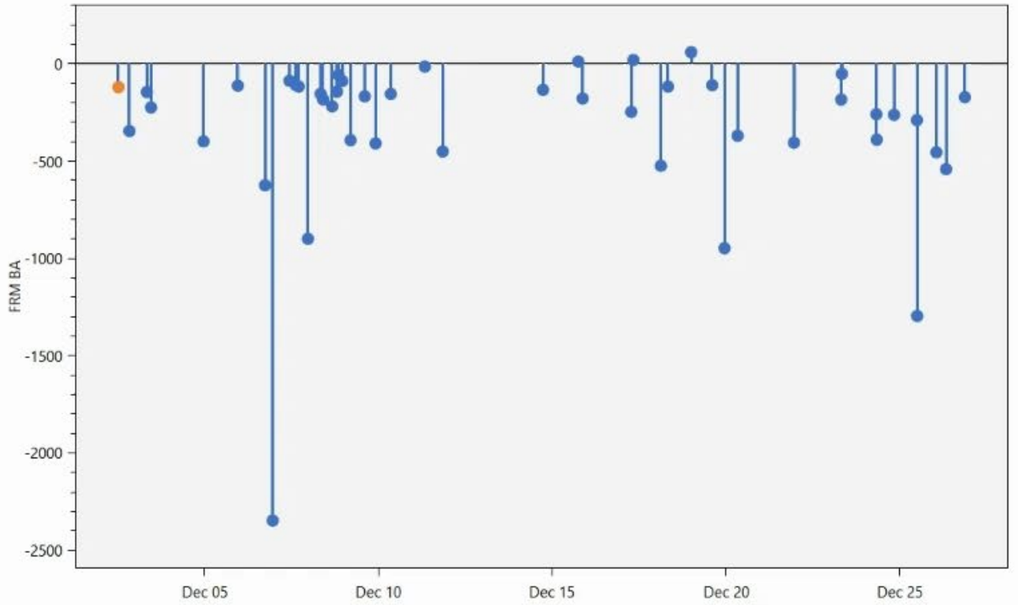
BPA/DOE Archive Walker

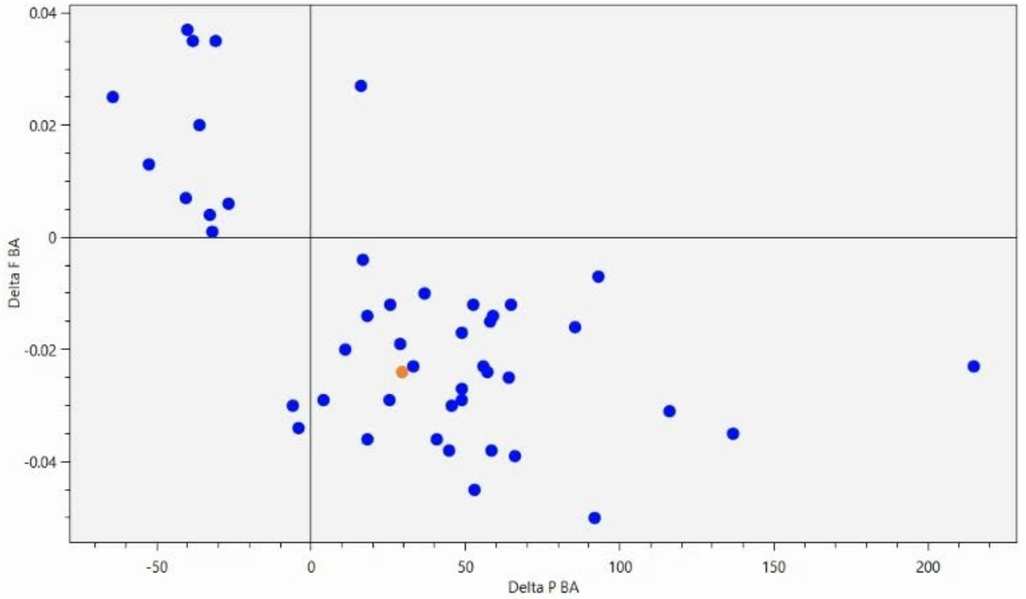
Coordinates | Settings | Results | Signal Inspection Available Results: 12/01/2023 00:00:00 - 12/26/2023 23:59:00

Forced Oscillations | Out of Range Events | Ringdowns | Wind Ramps | Mode Meter | FRM | VRM | Voltage Schedule

Search Start Time: 12/01/2023 00:00:00 Search End Time: 12/27/2023 23:59:59 $<B_F - A_F<$ $<C_F - A_F<$ $<C_F<$ $<B_F<$ $<t_c - t_0<$ GO

Plant Review | Event Review





to	BA FRM	C	ΔF	ΔP_{BA}
12/2/23 12:26	-119.38	59.973	-0.024	29.49
12/2/23 20:00	-344.75	59.955	-0.01	36.77
12/3/23 07:59	-144.48	59.955	-0.019	28.84
12/3/23 10:53	-223.9	59.96	-0.024	57.1
12/4/23 23:07	-398.21	59.948	-0.014	58.94
12/5/23 22:50	-112	59.956	-0.036	40.71
12/6/23 17:39	-623.84	60.046	0.007	-40.63
12/6/23 23:00	-2347.37	60.046	0.001	-32.04
12/7/23 10:32	-86.69	59.958	-0.029	25.38
12/7/23 15:00	-108.69	60.044	0.035	-38.32
12/7/23 16:54	-116.47	59.958	-0.045	52.96
12/7/23 23:15	-898.93	60.039	0.004	-32.84

Type: All

Plant	FRM	FRM manual	ΔP_{plant}
Plant01	3.73		-0.92
Plant02	-18.02		4.45
Plant03	NaN		NaN
Plant04	0.62		-0.15
Plant05	-14.82		3.66
Plant06	NaN		NaN
Plant07	-26.16		6.46
Plant08	NaN		NaN
Plant09	-7.26		1.79
Plant10	-14.2		3.51
Plant11	-18.95		4.68
Plant12	-5.44		1.34

Retrieve Detail

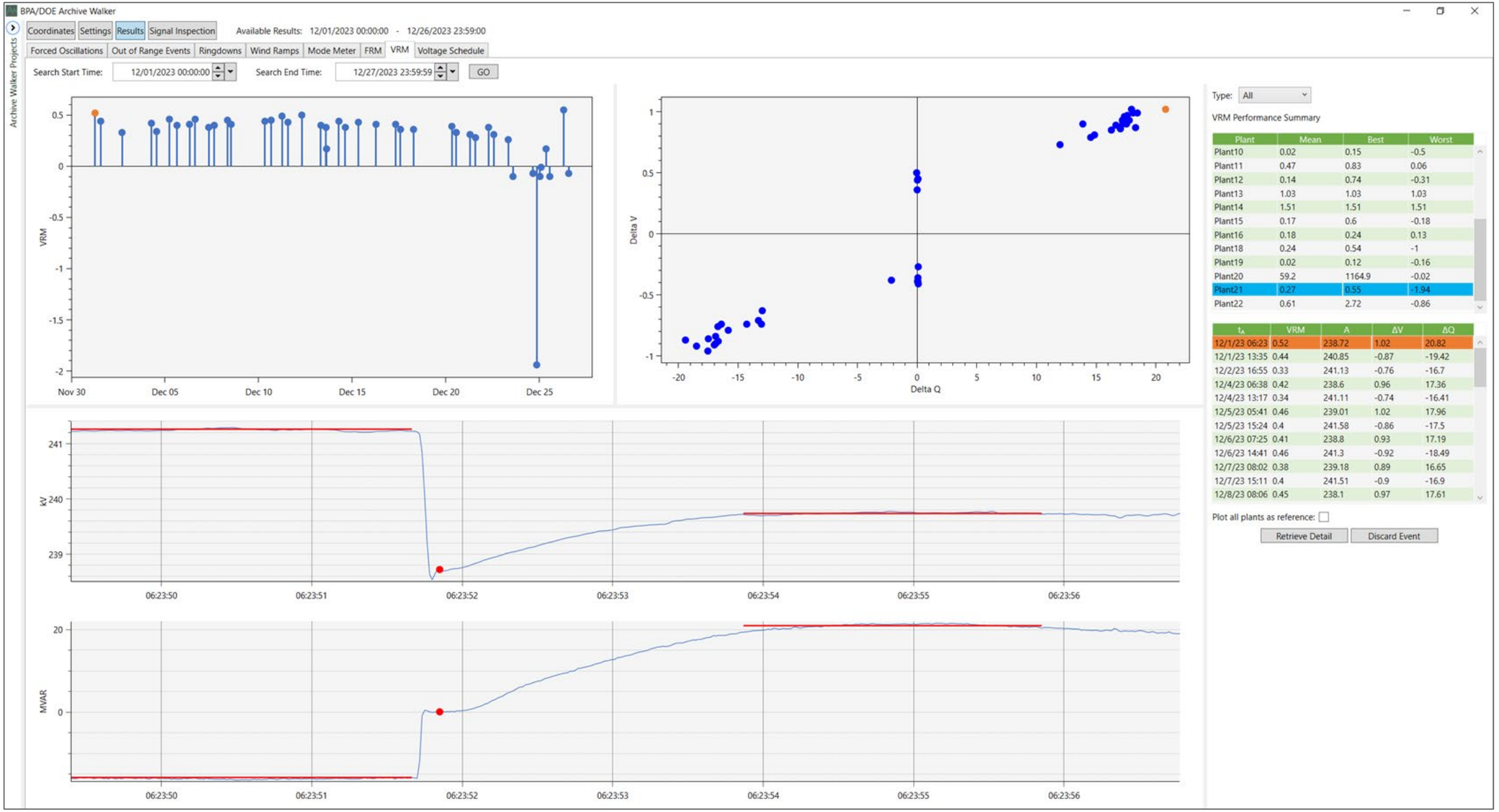
Discard FRM for this Plant

Discard FRM for all Plants

Adjust t_0 by seconds Go

Set Manual FRM to Go

Voltage Response Measure (VRM)



BPA/DOE Archive Walker

Archive Walker Projects

Coordinates | Settings | Results | Signal Inspection

Available Results: 12/01/2023 00:00:00 - 12/26/2023 23:59:00

Forced Oscillations | Out of Range Events | Ringdowns | Wind Ramps | Mode Meter | FRM | VRM | Voltage Schedule

Search Start Time: 12/01/2023 00:00:00 Search End Time: 12/27/2023 23:59:59 GO

Type:

VRM Performance Summary

Plant	Mean	Best	Worst

t_A	VRM	A	ΔV	ΔQ

Plot all plants as reference:

Retrieve Detail | Discard Event

Voltage Schedule

Plant	Low	Med	High	All
Plant01	0.15	0.12	0.17	0.15
Plant02	0.59	0.04	0.05	0.2
Plant03	0.26	0.02	0.01	0.08
Plant05	0.17	0	0	0.05
Plant06	0.59	0.68	0.91	0.79
Plant07	0	0	0	0
Plant08	0	0	0	0
Plant09	0.01	0.02	0.01	0.01
Plant12	0.33	0.25	0.38	0.35
Plant13	0.07	0	0	0.02
Plant17	0	0	0	0
Plant20	0	0	0	0
Plant19	0	0	0	0
Plant18	0.03	0.21	0.45	0.3
Plant16	0	0	0	0

BPA/DOE Archive Walker

Archive Walker Projects

Coordinates | Settings | Results | Signal Inspection

Available Results: 08/01/2023 00:01:00 - 08/14/2023 23:59:00

Forced Oscillations | Out of Range Events | Ringdowns | Wind Ramps | Mode Meter | FRM | VRM | Voltage Schedule

Search Start Time: 08/01/2023 00:01:00 Search End Time: 08/14/2023 23:59:00 Report by: Minute Overview Retrieve Detail 0% Cancel

Data Trends

Proportion of time off schedule by loading level

Plant	Low	Med	High	All

Detection Details

Next Steps

- Continue to integrate feedback from BPA
- Transition the final tool to BPA for continued use
- Work with partner to make the capabilities more broadly available under separate funding

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Thank you

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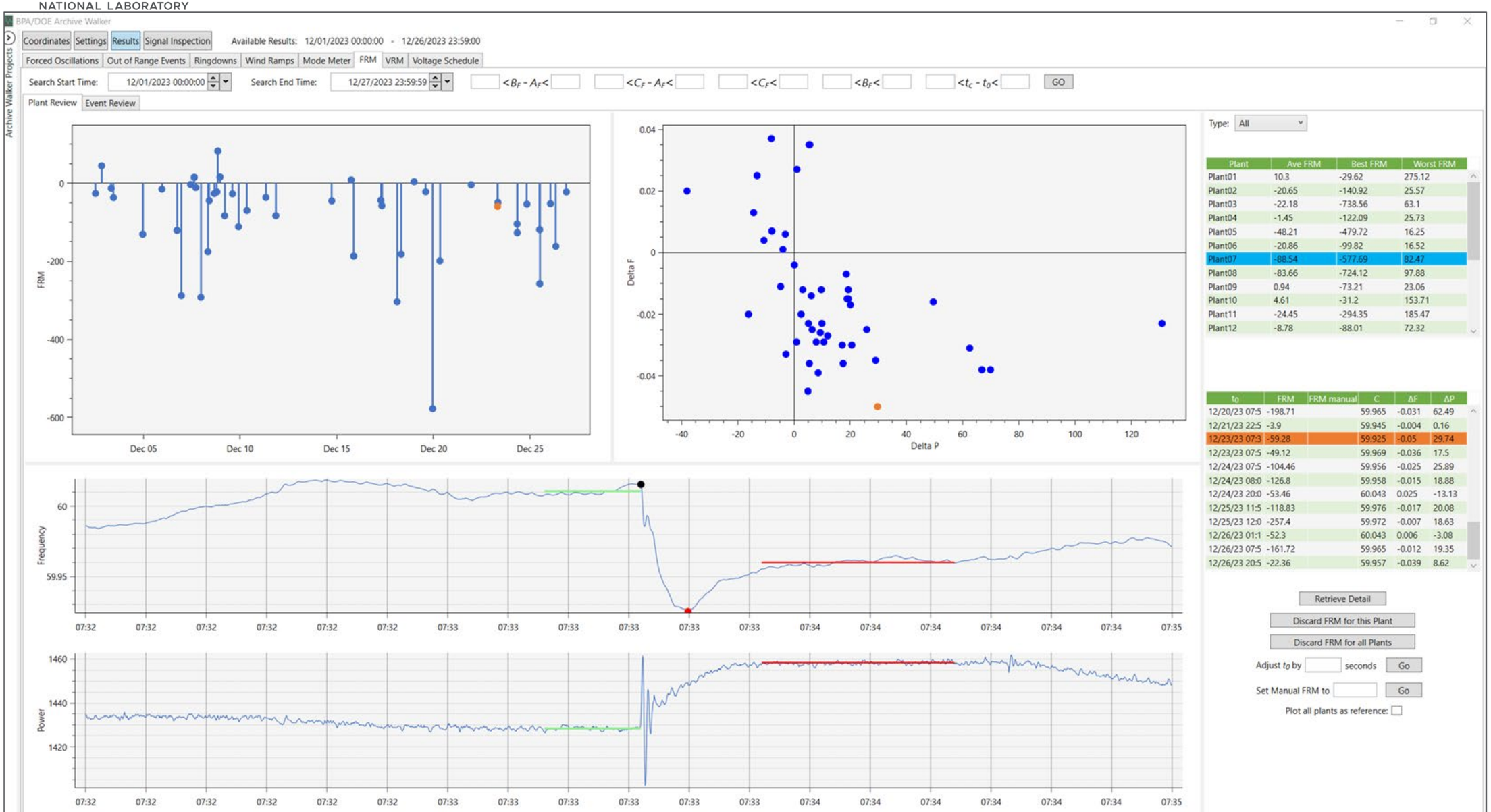
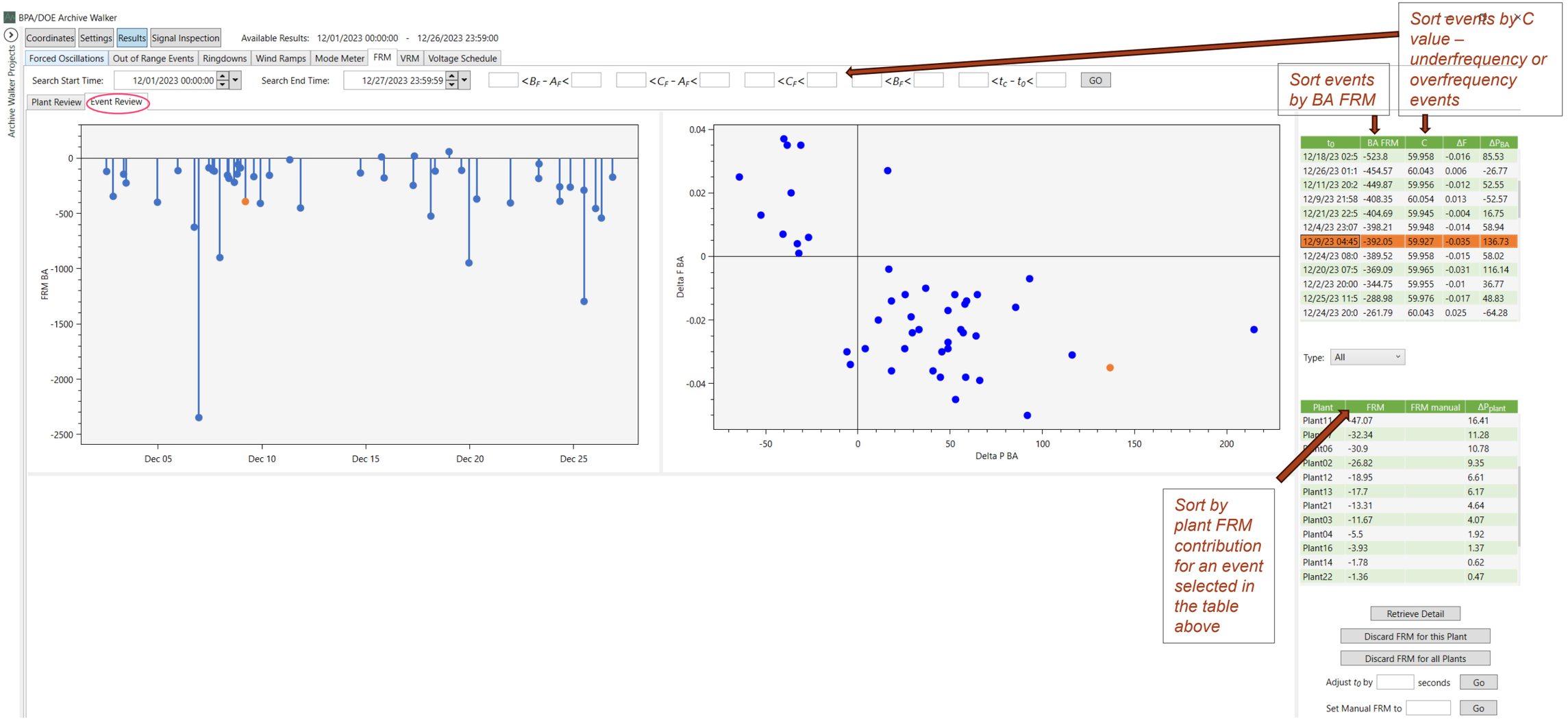
Extras

Frequency Response Measure (FRM)



FRM – Event Review

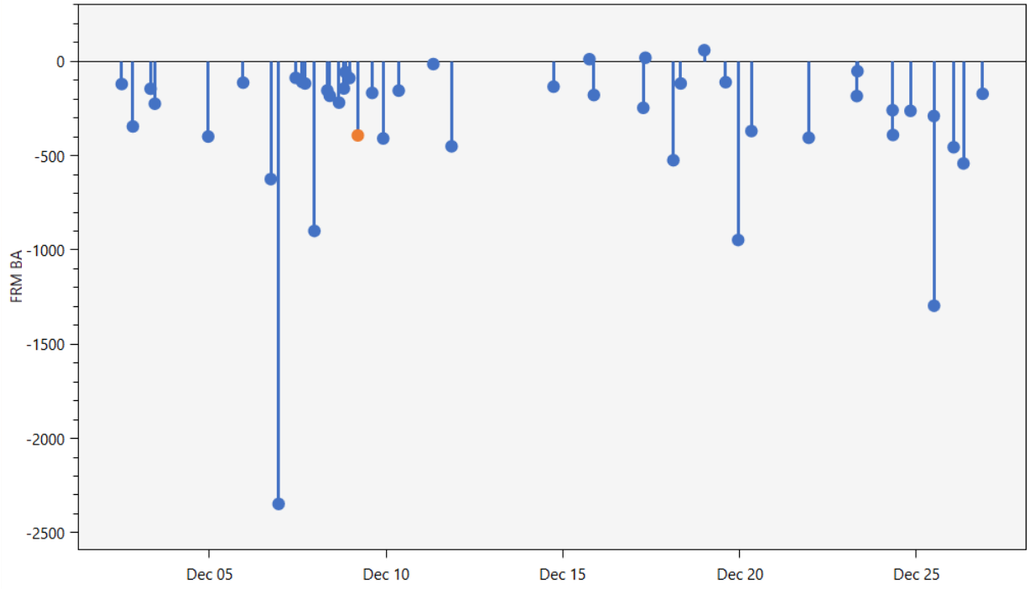


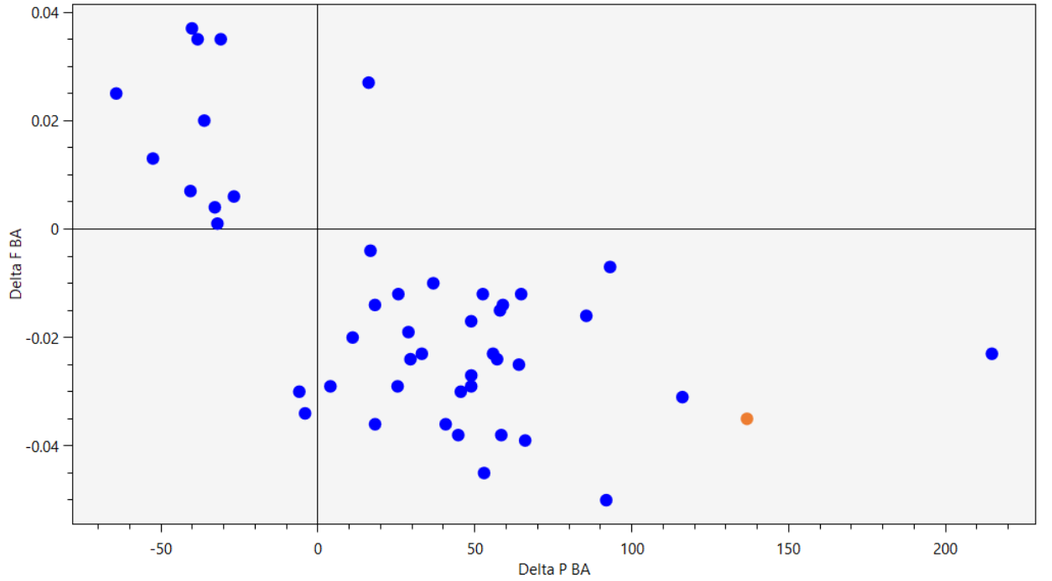
t_0	BA FRM	C	ΔF	ΔP_{BA}
12/18/23 02:5	-523.8	59.958	-0.016	85.53
12/26/23 01:1	-454.57	60.043	0.006	-26.77
12/11/23 20:2	-449.87	59.956	-0.012	52.55
12/9/23 21:58	-408.35	60.054	0.013	-52.57
12/21/23 22:5	-404.69	59.945	-0.004	16.75
12/4/23 23:07	-398.21	59.948	-0.014	58.94
12/9/23 04:45	-392.05	59.927	-0.035	136.73
12/24/23 08:0	-389.52	59.958	-0.015	58.02
12/20/23 07:5	-369.09	59.965	-0.031	116.14
12/2/23 20:00	-344.75	59.955	-0.01	36.77
12/25/23 11:5	-288.98	59.976	-0.017	48.83
12/24/23 20:0	-261.79	60.043	0.025	-64.28

Plant	FRM	FRM manual	ΔP_{plant}
Plant11	47.07		16.41
Plant[illegible]	-32.34		11.28
Plant06	-30.9		10.78
Plant02	-26.82		9.35
Plant12	-18.95		6.61
Plant13	-17.7		6.17
Plant21	-13.31		4.64
Plant03	-11.67		4.07
Plant04	-5.5		1.92
Plant16	-3.93		1.37
Plant14	-1.78		0.62
Plant22	-1.36		0.47

FRM – Event Review

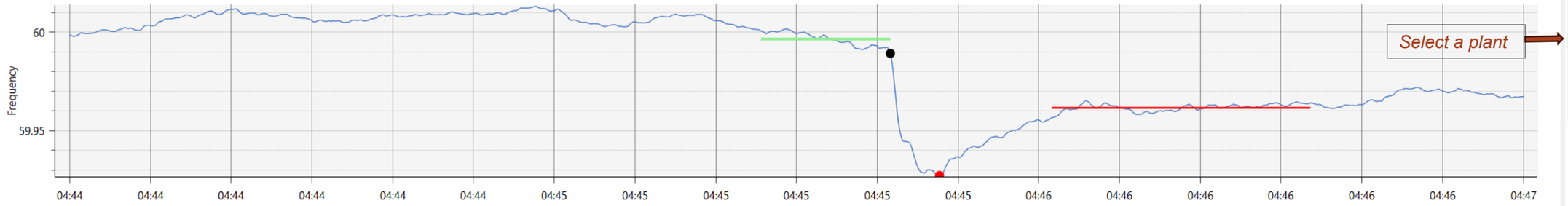
Plant Review | Event Review





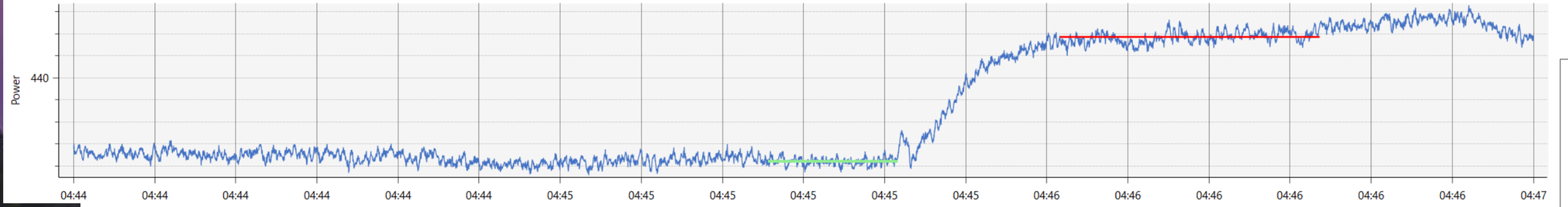
t_0	BA FRM	C	ΔF	ΔP_B
12/18/23 02:5	-523.8	59.958	-0.016	85.53
12/26/23 01:1	-454.57	60.043	0.006	-26.7
12/11/23 20:2	-449.87	59.956	-0.012	52.55
12/9/23 21:58	-408.35	60.054	0.013	-52.5
12/21/23 22:5	-404.69	59.945	-0.004	16.75
12/4/23 23:07	-398.21	59.948	-0.014	58.94
12/9/23 04:45	-392.05	59.927	-0.035	136.7
12/24/23 08:0	-389.52	59.958	-0.015	58.02
12/20/23 07:5	-369.09	59.965	-0.031	116.1
12/2/23 20:00	-344.75	59.955	-0.01	36.77
12/25/23 11:5	-288.98	59.976	-0.017	48.83
12/24/23 20:0	-261.79	60.043	0.025	-64.2

Type: All



Select a plant

Plant	FRM	FRM manual	ΔP_{plant}
Plant20	NaN		NaN
Plant15	NaN		NaN
Plant19	NaN		NaN
Plant07	-83.23		29.03
Plant08	-55.27		19.28
Plant05	-47.71		16.64
Plant11	-47.07		16.41
Plant17	-32.34		11.28
Plant06	-30.9		10.78
Plant02	-26.82		9.35
Plant12	-18.95		6.61
Plant13	-17.7		6.17



Retrieve Detail

Discard FRM for this Plant

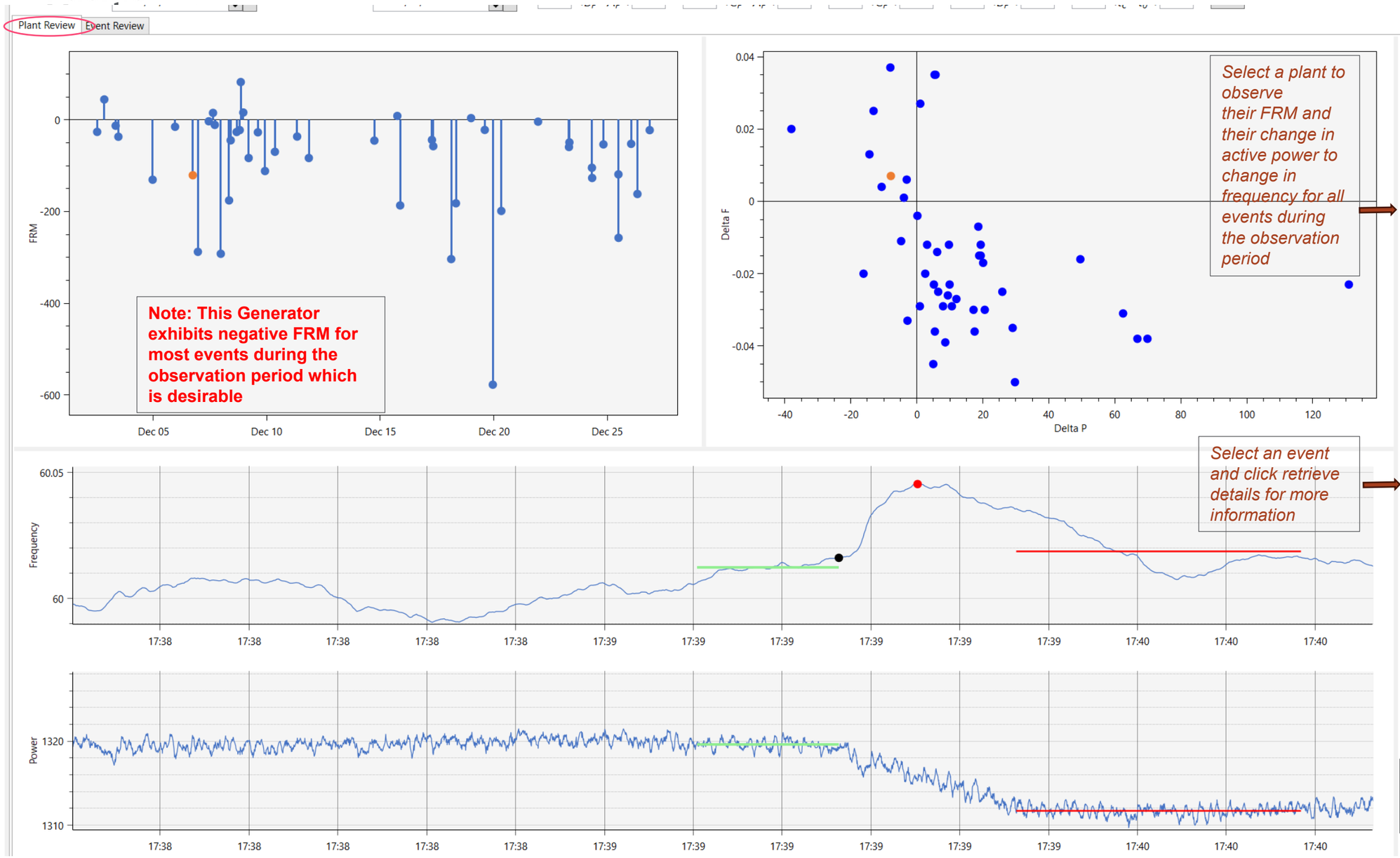
Discard FRM for all Plants

Adjust t_0 by seconds Go

Set Manual FRM to Go

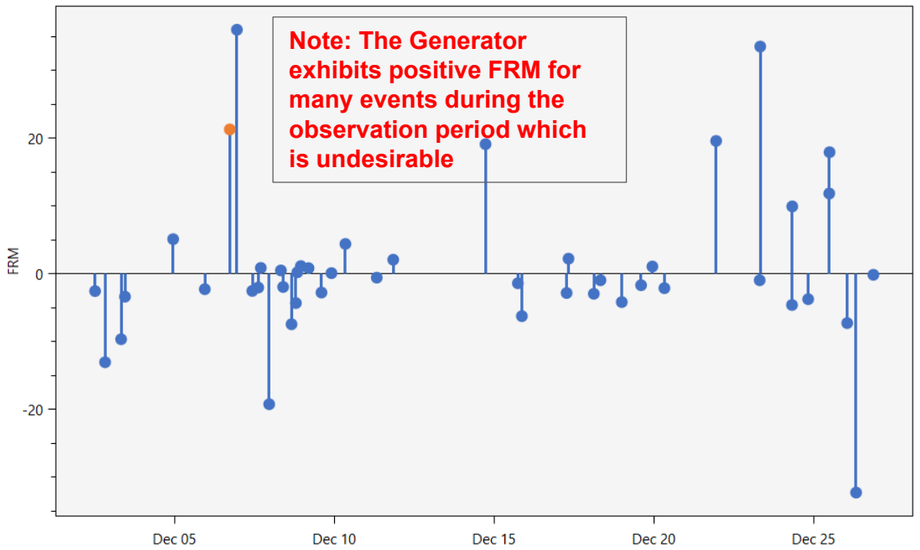
Note: Overall, the entire BA has satisfactory performance to frequency excursion events with delta f vs delta P being in the right quadrants, and FRM values being mostly negative.

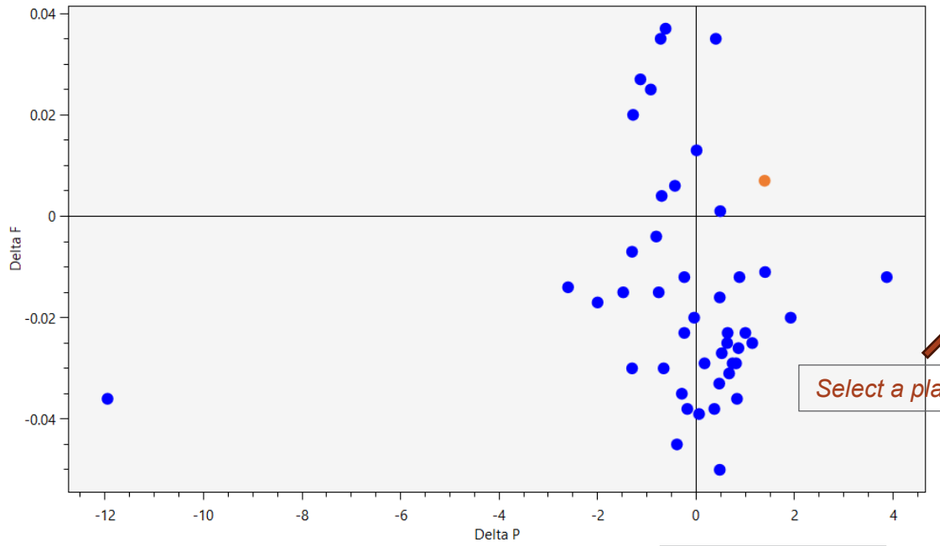
FRM – Plant Review



FRM – Plant Review

Plant Review | Event Review



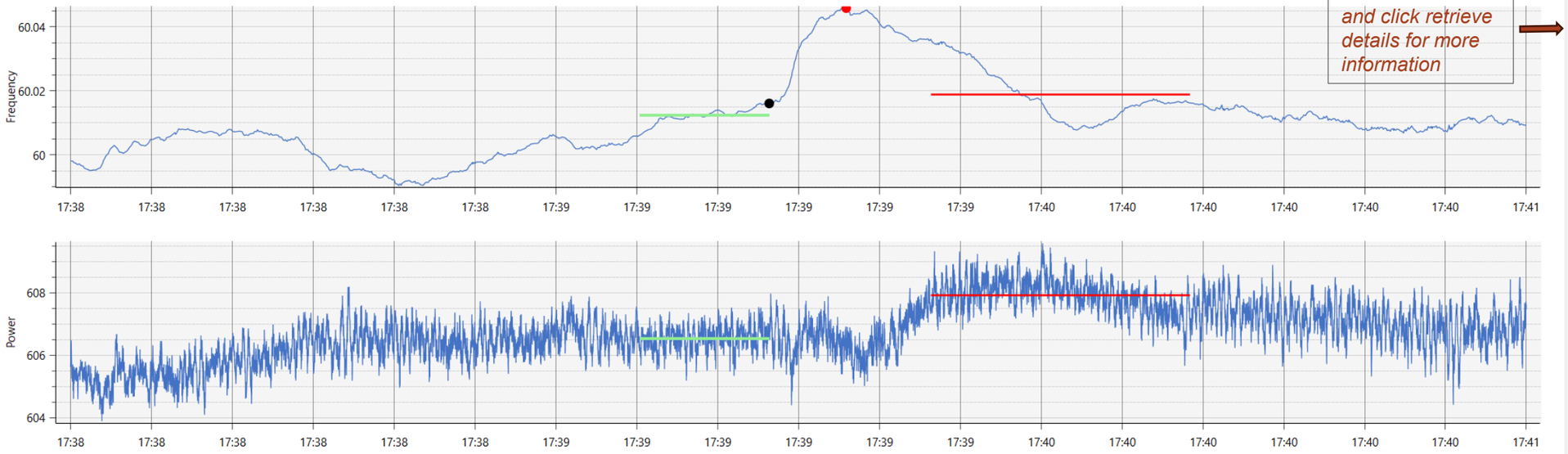


Sort plants by average FRM

Type: All

Plant	Ave FRM	Best FRM	Worst FRM
Plant02	-20.65	-140.92	25.57
Plant13	-16.37	-193.17	11.99
Plant16	-13.34	-206.78	22.01
Plant21	-10.31	-37.66	21.54
Plant12	-8.78	-88.01	72.32
Plant19	-4.85	-50.02	14.42
Plant15	-4.29	-41.15	8.74
Plant04	-1.45	-122.09	25.73
Plant14	0.25	-33.88	16.84
Plant09	0.94	-73.21	23.06
Plant18	0.96	-32.3	36.01
Plant10	4.61	-31.2	153.71

Select a plant



Select an event and click retrieve details for more information

to	FRM	FRM manual	C	ΔF	ΔP
12/2/23 12:26	-2.56		59.972	-0.025	0.63
12/2/23 20:00	-13.07		59.953	-0.011	1.4
12/3/23 07:59	-9.67		59.953	-0.02	1.92
12/3/23 10:53	-3.39		59.958	-0.026	0.86
12/4/23 23:07	5.1		59.946	-0.015	-0.76
12/5/23 22:50	-2.28		59.956	-0.036	0.83
12/6/23 17:39	21.3		60.046	0.007	1.39
12/6/23 23:00	36.01		60.047	0.001	0.49
12/7/23 10:32	-2.53		59.958	-0.029	0.74
12/7/23 15:00	-2.04		60.044	0.035	-0.72
12/7/23 16:54	0.86		59.958	-0.045	-0.39
12/7/23 23:15	-19.26		60.039	0.004	-0.7

Retrieve Detail

Discard FRM for this Plant

Discard FRM for all Plants

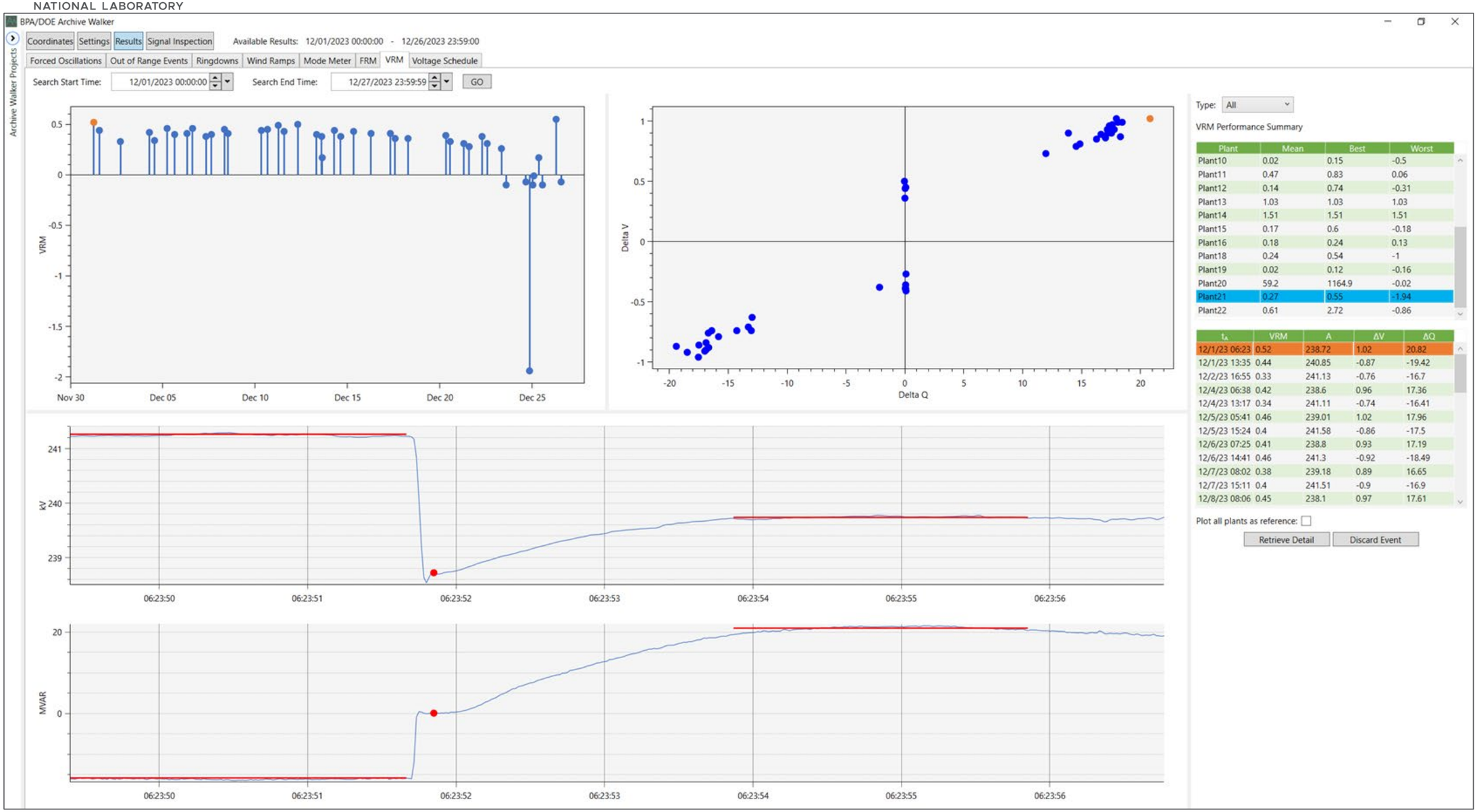
Adjust t_0 by seconds Go

Set Manual FRM to Go

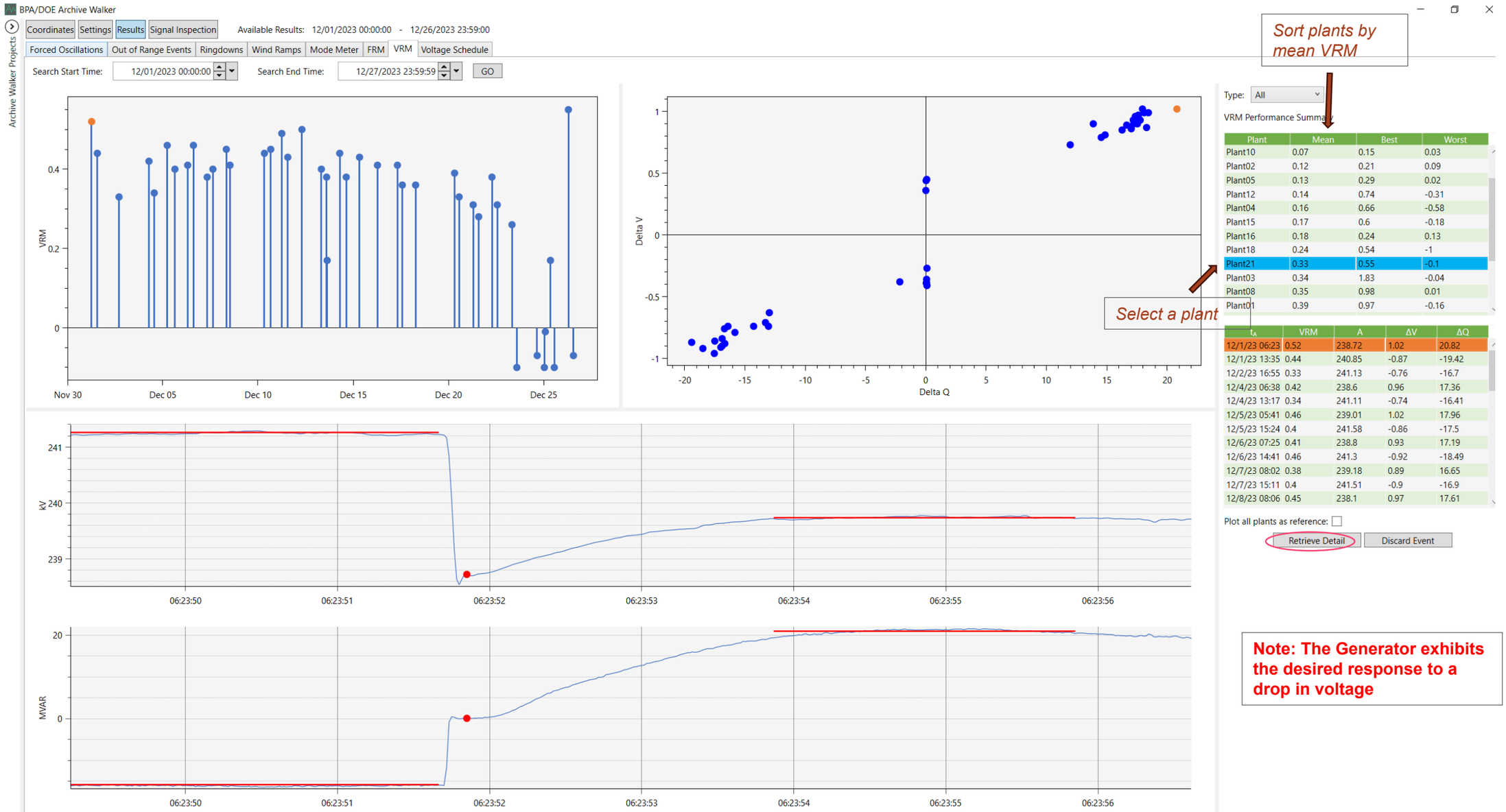
Plot all plants as reference:

Note: The Generator does not exhibit the desired response to an overfrequency event

Voltage Response Measure (VRM)



VRM



Note: The Generator exhibits the desired response to a drop in voltage

VRM

BPA/DOE Archive Walker

Coordinates | Settings | Results | Signal Inspection Available Results: 12/01/2023 00:00:00 - 12/26/2023 23:59:00

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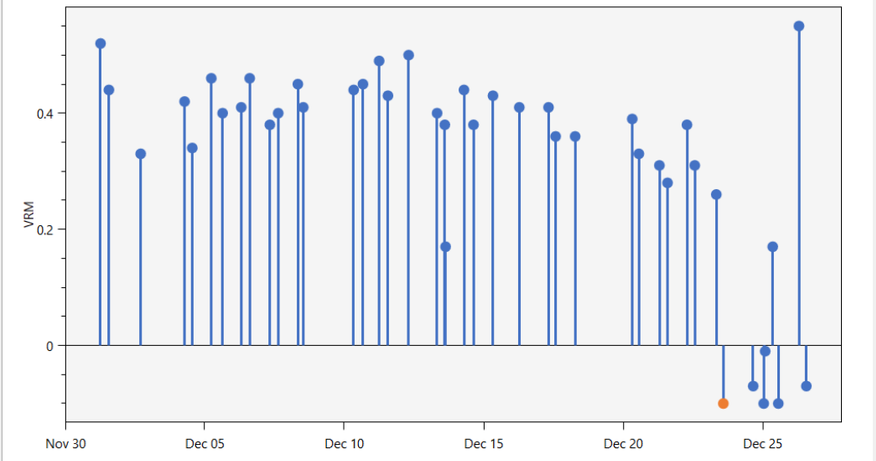
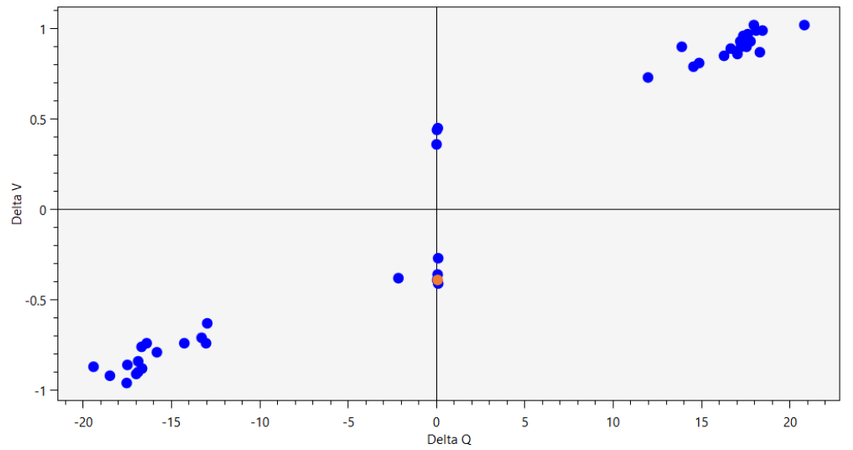




Type: All

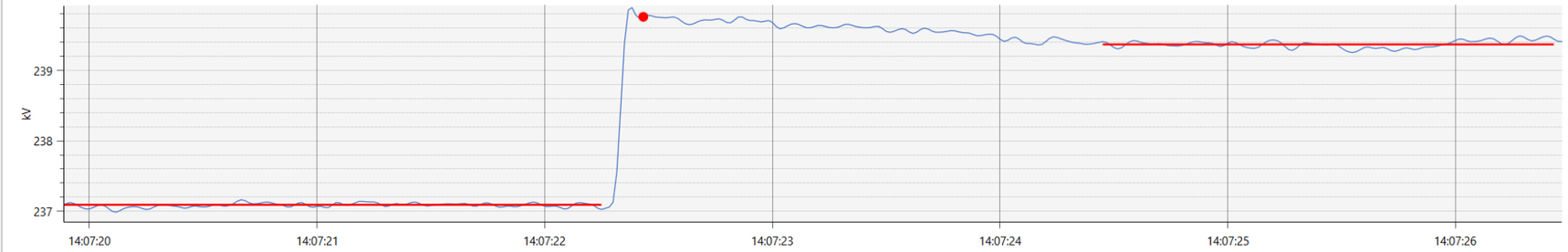
VRM Performance Summary

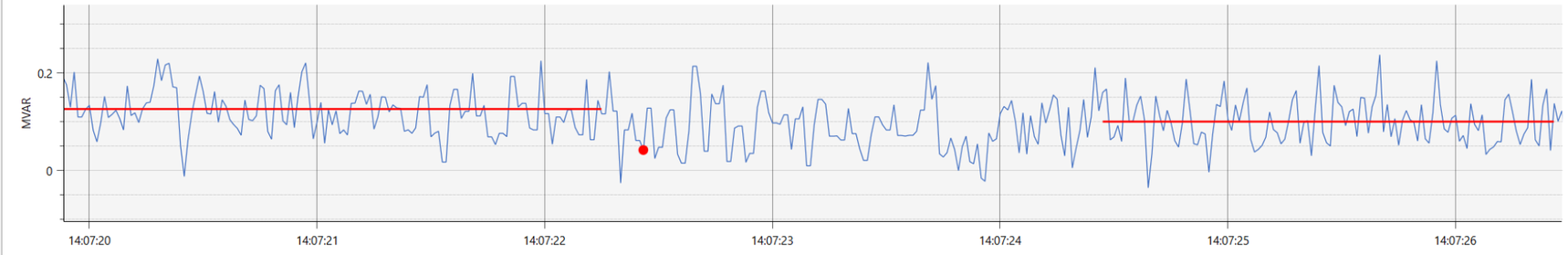
Plant	Mean	Best	Worst
Plant10	0.07	0.15	0.03
Plant02	0.12	0.21	0.09
Plant05	0.13	0.29	0.02
Plant12	0.14	0.74	-0.31
Plant04	0.16	0.66	-0.58
Plant15	0.17	0.6	-0.18
Plant16	0.18	0.24	0.13
Plant18	0.24	0.54	-1
Plant21	0.33	0.55	-0.1
Plant03	0.34	1.83	-0.04
Plant08	0.35	0.98	0.01
Plant01	0.39	0.97	-0.16

t_A	VRM	A	ΔV	ΔQ
12/1/23 06:23	0.52	238.72	1.02	20.82
12/1/23 13:35	0.44	240.85	-0.87	-19.42
12/2/23 16:55	0.33	241.13	-0.76	-16.7
12/4/23 06:38	0.42	238.6	0.96	17.36
12/4/23 13:17	0.34	241.11	-0.74	-16.41
12/5/23 05:41	0.46	239.01	1.02	17.96
12/5/23 15:24	0.4	241.58	-0.86	-17.5
12/6/23 07:25	0.41	238.8	0.93	17.19
12/6/23 14:41	0.46	241.3	-0.92	-18.49
12/7/23 08:02	0.38	239.18	0.89	16.65
12/7/23 15:11	0.4	241.51	-0.9	-16.9
12/8/23 08:06	0.45	238.1	0.97	17.61

Plot all plants as reference:

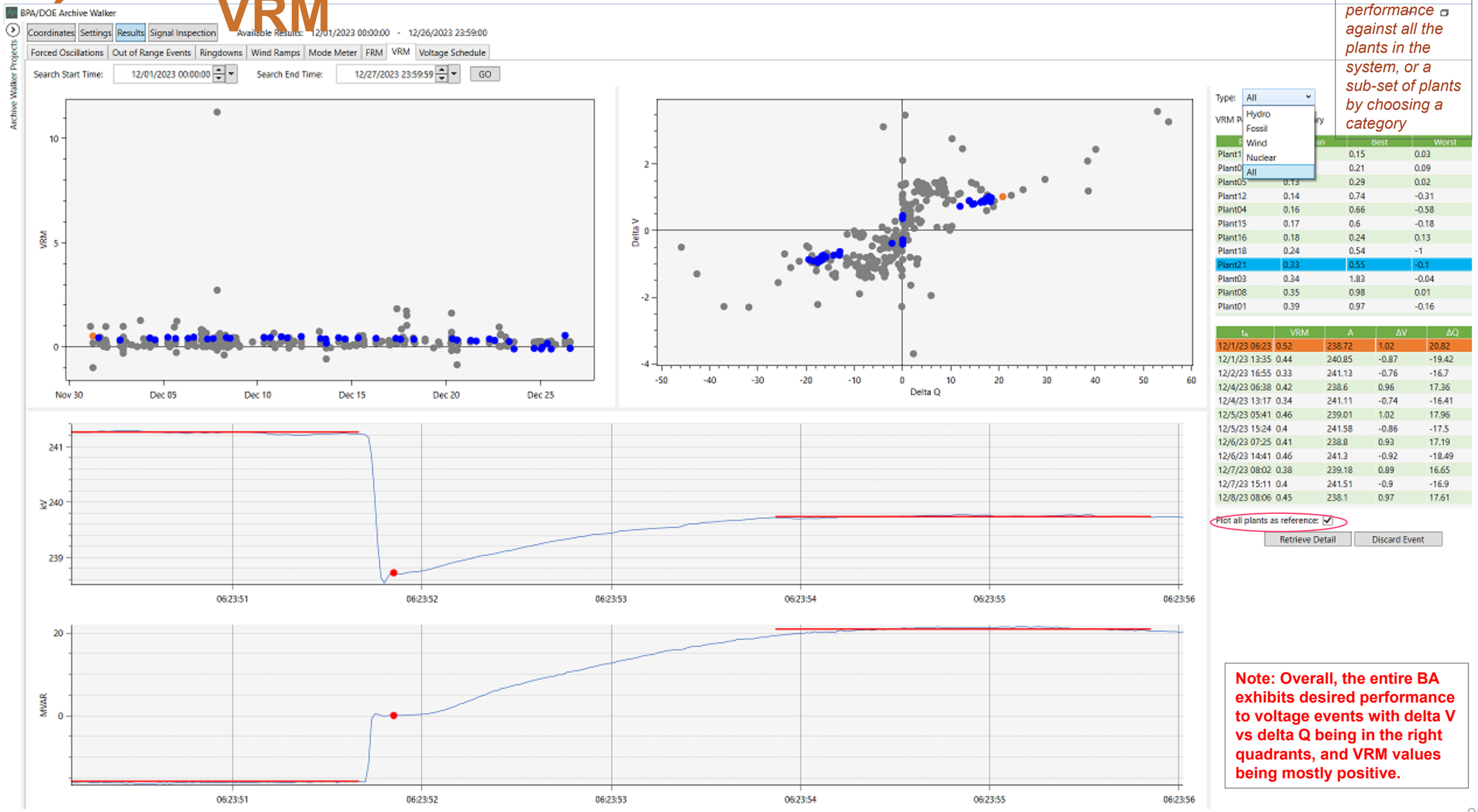
Retrieve Detail | Discard Event





Discard event if unsuitable for evaluation. E.g. plant was off during the event

VRM



Compare plant performance against all the plants in the system, or a sub-set of plants by choosing a category

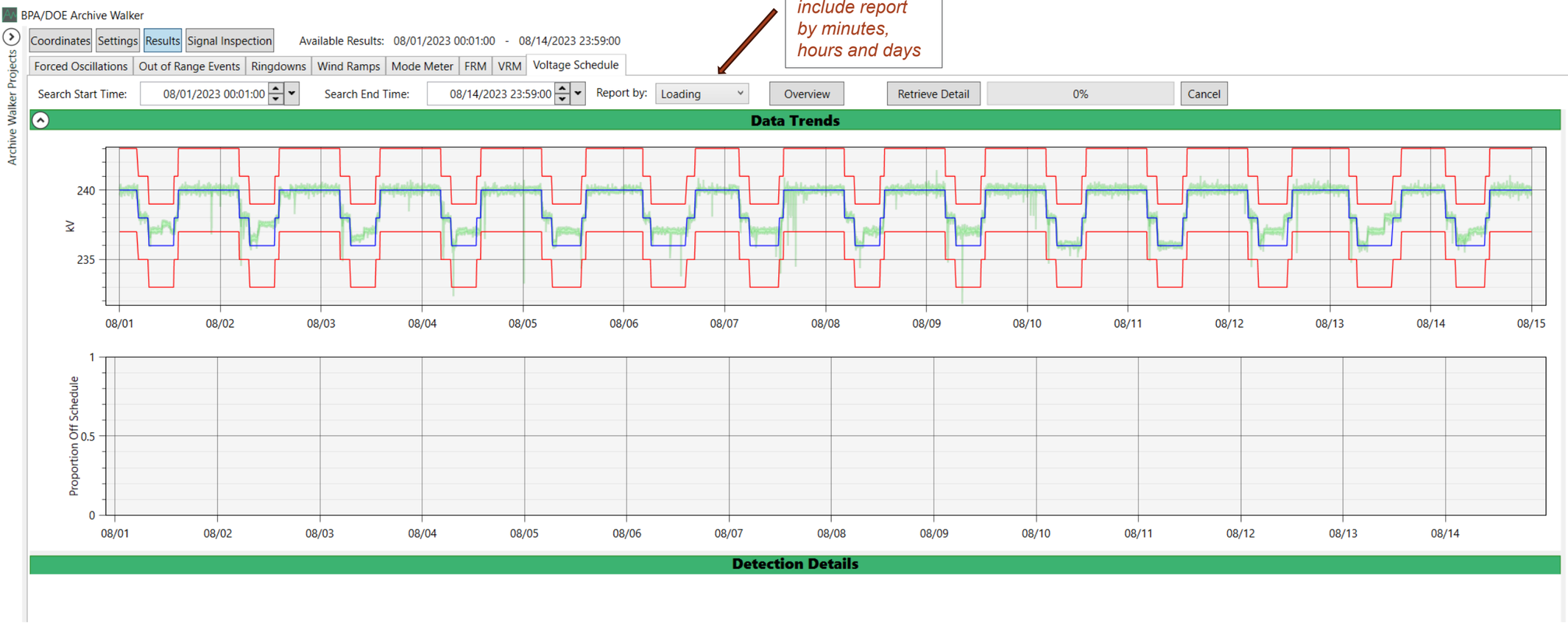
Note: Overall, the entire BA exhibits desired performance to voltage events with delta V vs delta Q being in the right quadrants, and VRM values being mostly positive.

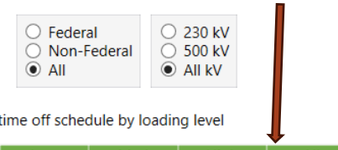
Voltage Schedule

Voltage Schedule

Reporting here by loading. Other options include report by minutes, hours and days

Sort plants by proportion off-schedule from desired voltage schedule under all loading levels



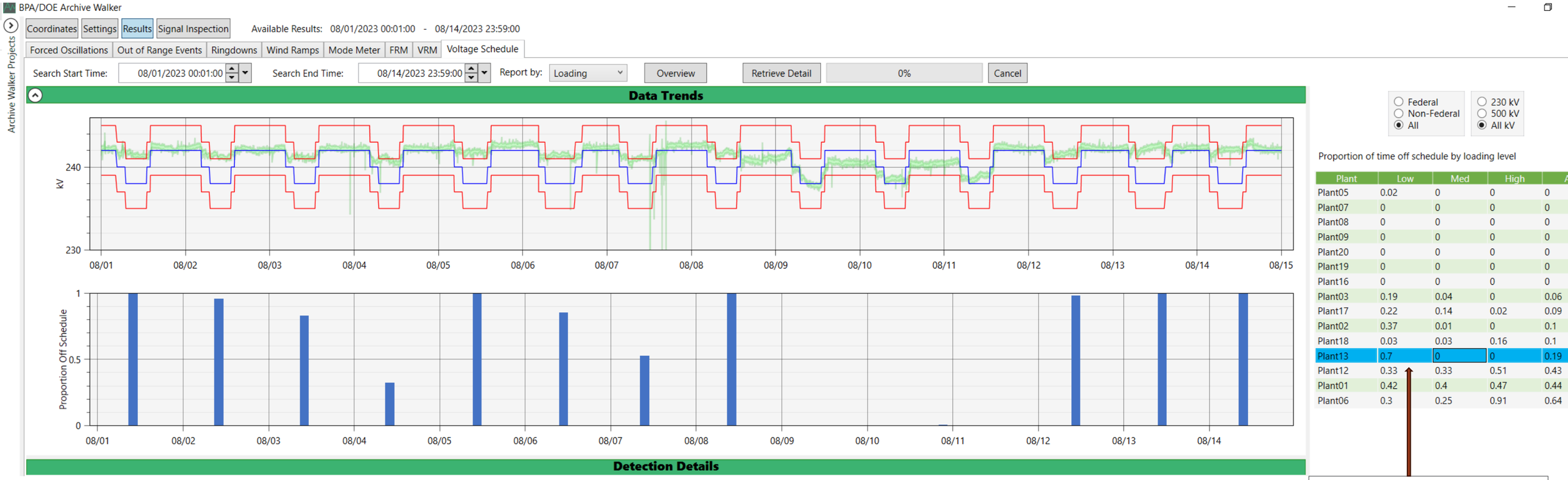


Proportion of time off schedule by loading level

Plant	Low	Med	High	All
Plant05	0.02	0	0	0
Plant07	0	0	0	0
Plant08	0	0	0	0
Plant09	0	0	0	0
Plant20	0	0	0	0
Plant19	0	0	0	0
Plant16	0	0	0	0
Plant03	0.19	0.04	0	0.06
Plant17	0.22	0.14	0.02	0.09
Plant02	0.37	0.01	0	0.1
Plant18	0.03	0.03	0.16	0.1
Plant13	0.7	0	0	0.19
Plant12	0.33	0.33	0.51	0.43
Plant01	0.42	0.4	0.47	0.44
Plant06	0.3	0.25	0.91	0.64

Note: The Generator follows the voltage schedule during the observation period

Voltage Schedule



Proportion of time off schedule by loading level

Plant	Low	Med	High	A
Plant05	0.02	0	0	0
Plant07	0	0	0	0
Plant08	0	0	0	0
Plant09	0	0	0	0
Plant20	0	0	0	0
Plant19	0	0	0	0
Plant16	0	0	0	0
Plant03	0.19	0.04	0	0.06
Plant17	0.22	0.14	0.02	0.09
Plant02	0.37	0.01	0	0.1
Plant18	0.03	0.03	0.16	0.1
Plant13	0.7	0	0	0.19
Plant12	0.33	0.33	0.51	0.43
Plant01	0.42	0.4	0.47	0.44
Plant06	0.3	0.25	0.91	0.64

Note: This Generator deviates from the voltage schedule during certain times, and the proportion off schedule for different loading levels is displayed. This plant has voltage schedule violations only during low loading in the observed period.

Voltage Schedule

Federal
Non-Federal
All

230 kV
500 kV
All kV

Proportion of time off schedule by loading level

Plant	Low	Med	High	Al
Plant05	0.02	0	0	0
Plant07	0	0	0	0
Plant08	0	0	0	0
Plant09	0	0	0	0
Plant20	0	0	0	0
Plant19	0	0	0	0
Plant16	0	0	0	0
Plant03	0.19	0.04	0	0.06
Plant17	0.22	0.14	0.02	0.09
Plant02	0.37	0.01	0	0.1
Plant18	0.03	0.03	0.16	0.1
Plant13	0.7	0	0	0.19
Plant12	0.33	0.33	0.51	0.43
Plant01	0.42	0.4	0.47	0.44
Plant06	0.3	0.25	0.91	0.64

Note: The Generator deviates from the voltage schedule after a certain time. This provides the initial information for a user to follow up with other teams and collaborators to look for the potential cause, and solutions if required.

Pacific Northwest
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Extras