

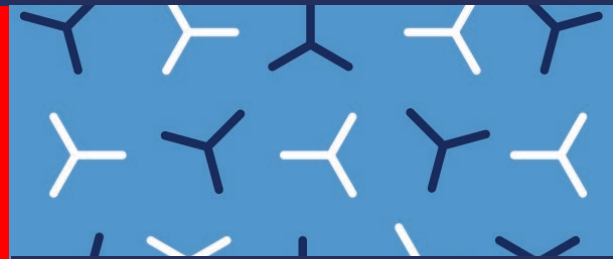


INCUBATENERGY LABS 2022 DEMO DAY

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October 26
Minneapolis
Minnesota



EPRI

Testing Vizi Metering's Wireless Non-Contact Metering System in EPRI's Knoxville Lab



Supported/Hosted by: EPRI

EPRI Subject Matter Experts: Eoin McCormack and Glen Bailey

Vizi Metering Team: Prabal Dutta, Mike Lorek

Project Overview:

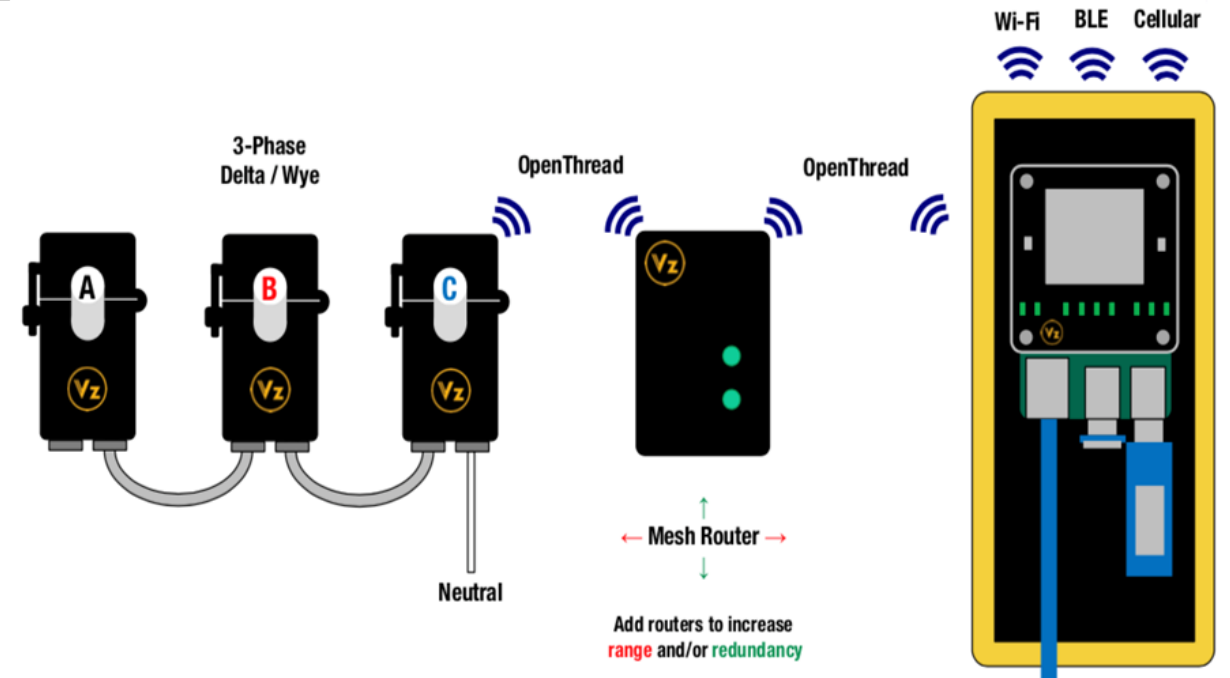
EPRI conducted tests of Vizi Metering's wireless metering system to gain a better understanding of the technology's performance, and to identify potential use cases and applications for this technology.

Project Scope

To gain a better understanding of the performance of the Vizi Metering system, EPRI conducted tests in the Knoxville Lab.

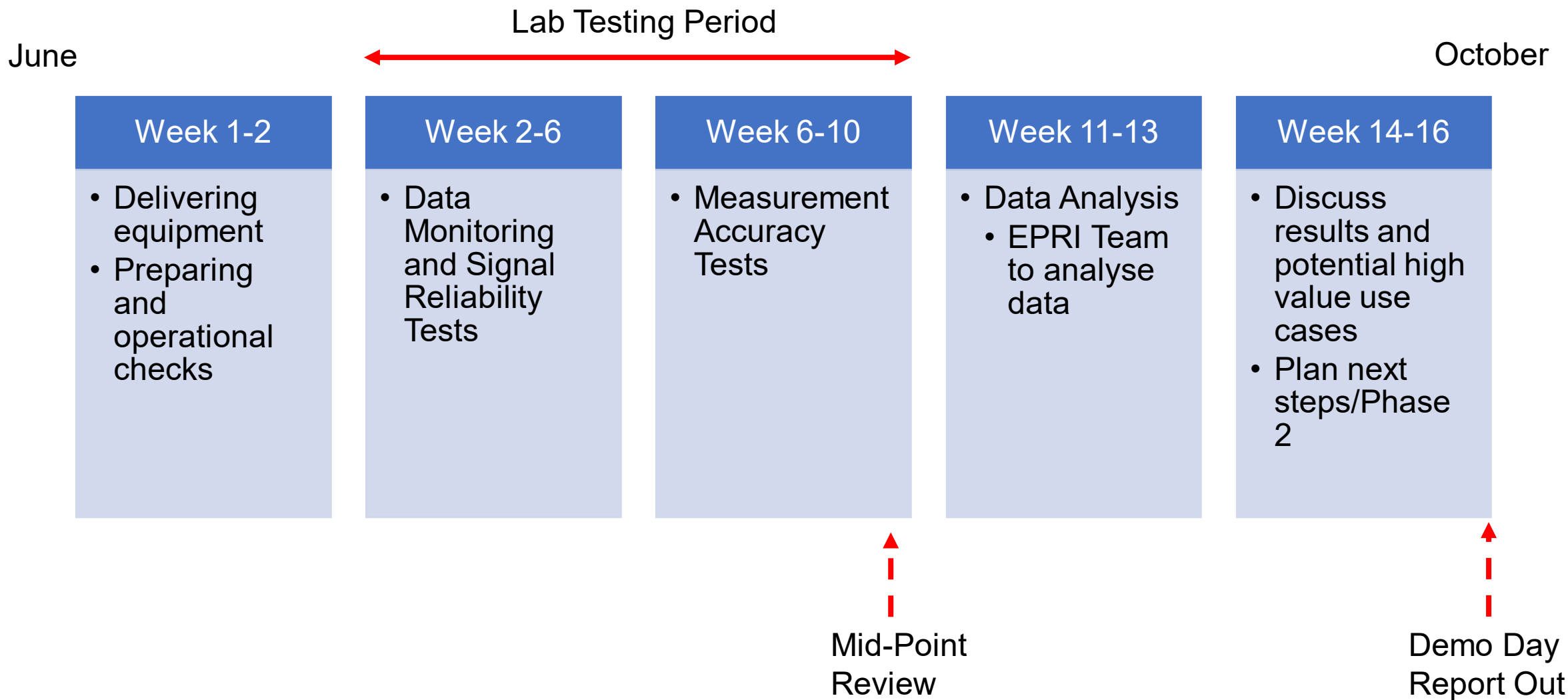
The objectives of these tests was to characterize:

- Data monitoring and signal reliability, over a continuous run test and with various obstacles and distances.
- Accuracy of Voltage, Current, Power, Power Factor, and Total Harmonic Distortion (THD) measurements over a range of power supply setpoints.

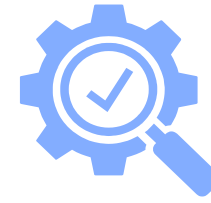
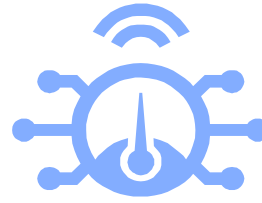


Schematic diagram of Vizi Metering's wireless metering system

Project Scope at a Glance



Overview of Testing Methodology



Testing Objective:

Data Monitoring and Signal Reliability

Measurement Accuracy

Test Description:

- 5 x Signal tests
 - Distances of 30ft to >60ft between VMs and GWs
 - Obstacles included walls, cabinets, and metal boxes
- 1 x Continuous run test
 - 33 days, 3ph HVAC system
 - Cellular and Ethernet connection
 - > 300 ft between VMs and GWs

3 testing days, with 14 tests to assess measurement accuracy of:

Voltage (*120 to 230 Volts ac*)

Current (*0.6 to 10 Amps*)

Power factor (*0.6 to 1*)

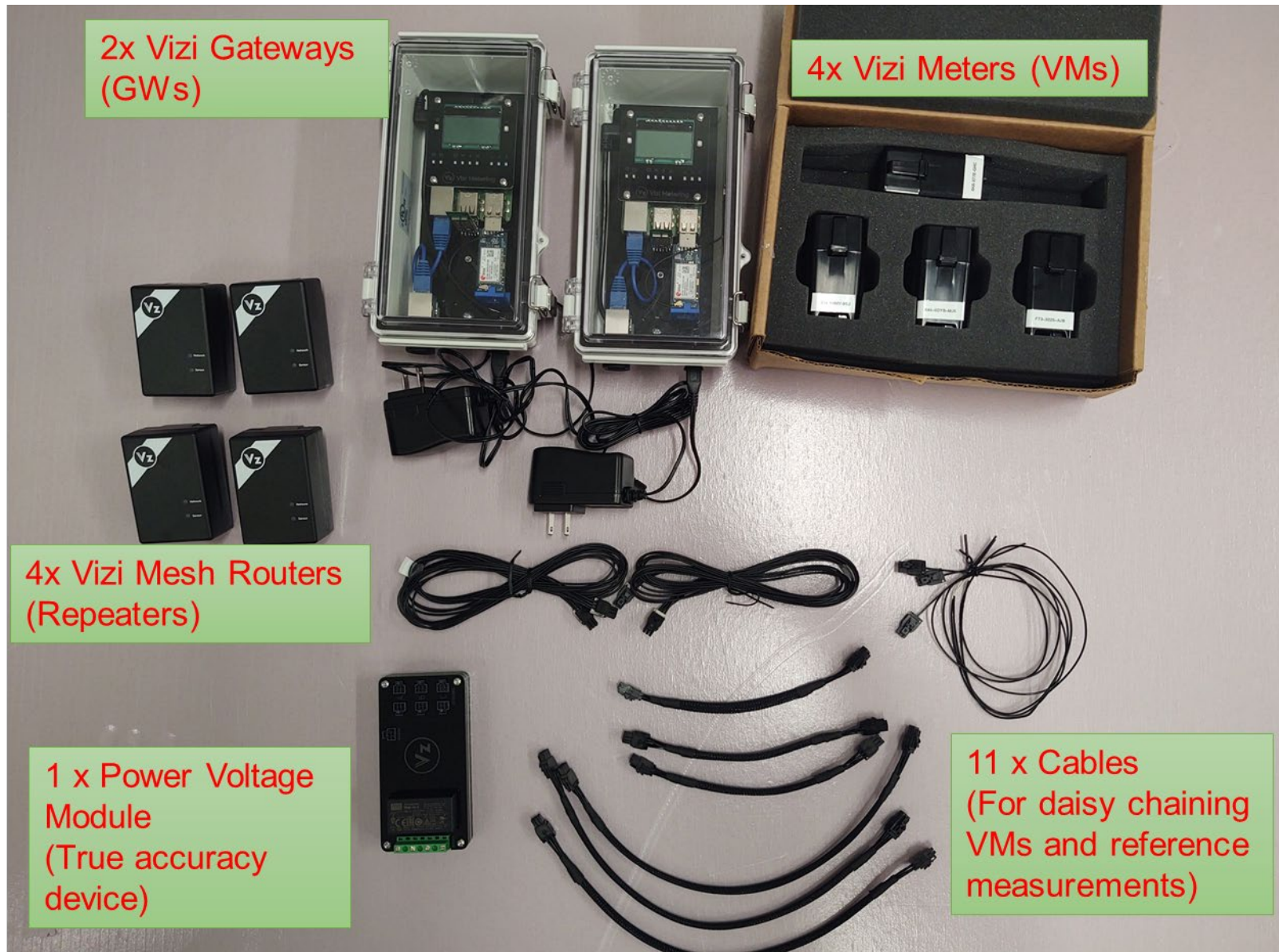
Current THD_{RMS} (*1-58%*)

Voltage THD_{RMS} (*0, 12.2%*)

Real Power

Reference Meters: Elkor MRA-75 & Yokogawa WT-3000

Vizi Metering Equipment Received and Tested

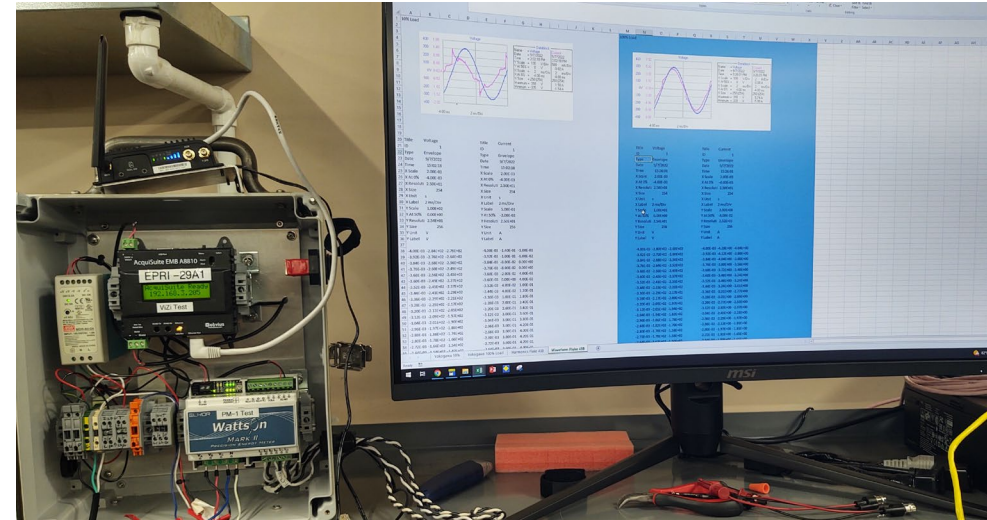
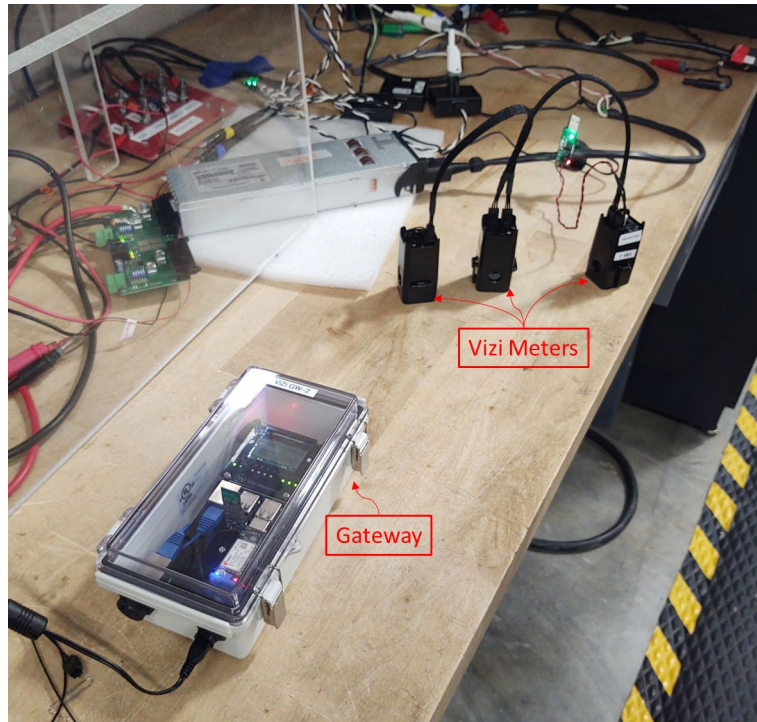


Note:

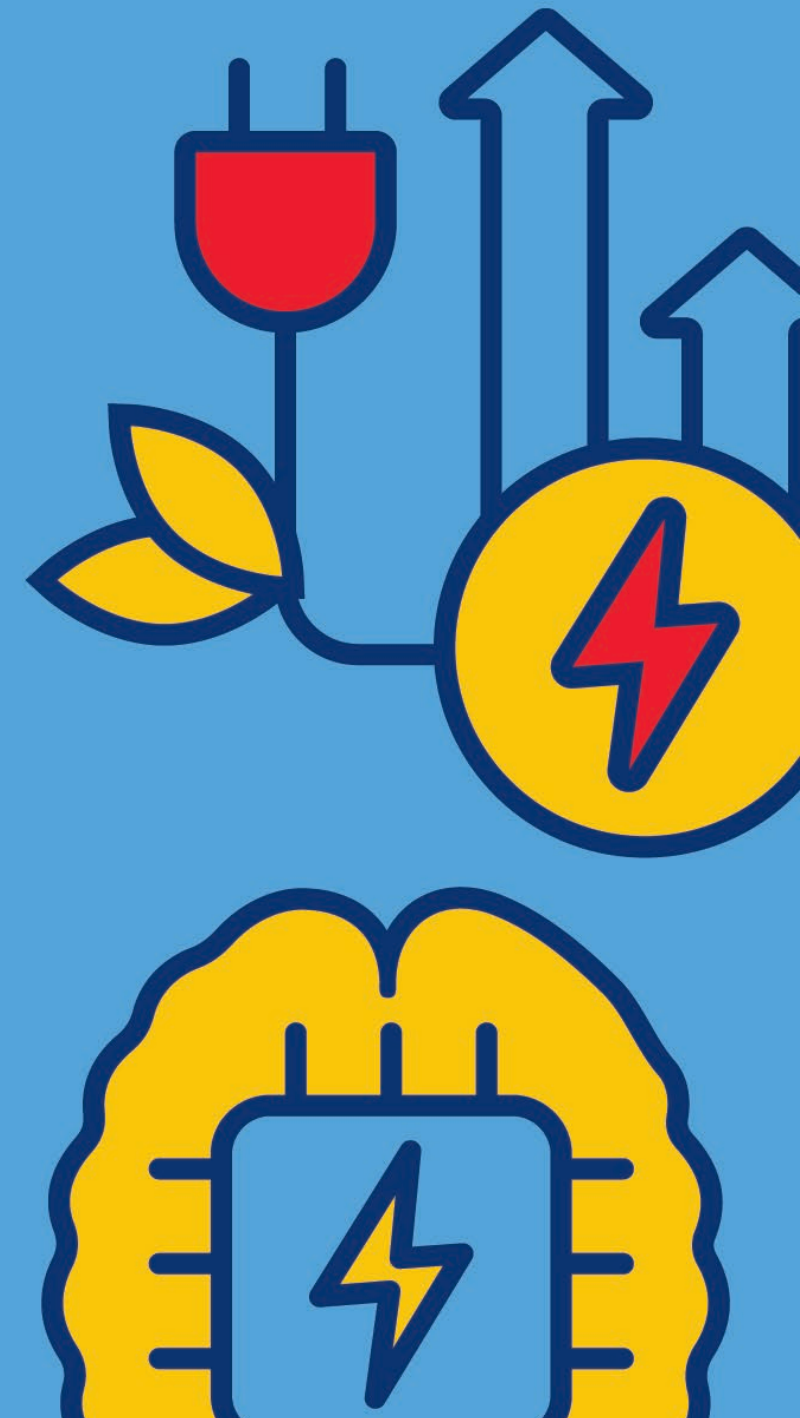
Vizi encountered manufacturing and shipping related setbacks which limited the quality and number of meters tested.

To help improve performance Vizi carried out hardware and firmware updates on the 4xVMs seen here throughout the testing period.

Vizi Meters undergoing testing in lab



Testing and Results



Data Monitoring and Signal Reliability Tests

Initial bench tests were conducted to verify operational ability and to become familiar with the Vizi meters and the data monitoring and reporting system.

Following this, dedicated Signal Tests were conducted, testing various configurations of the Vizi Metering system with obstacles and distances placed between the meters and the gateways.

The 4 Vizi meters (VMs) were then installed in a live electrical panel to monitor a 3-ph HVAC system for the continuous run test.

The goal of all of these tests was to assess how reliably the VMs monitored and stored data in the cloud. This was determined as follows:

$$\text{Data Reliability [\%]} = 100 * \left(1 - \frac{\text{Missing Data Points}}{\text{Total Data Points}} \right)$$

The following slides show the details of both the Signal and Continuous Run tests, and the results that were found.

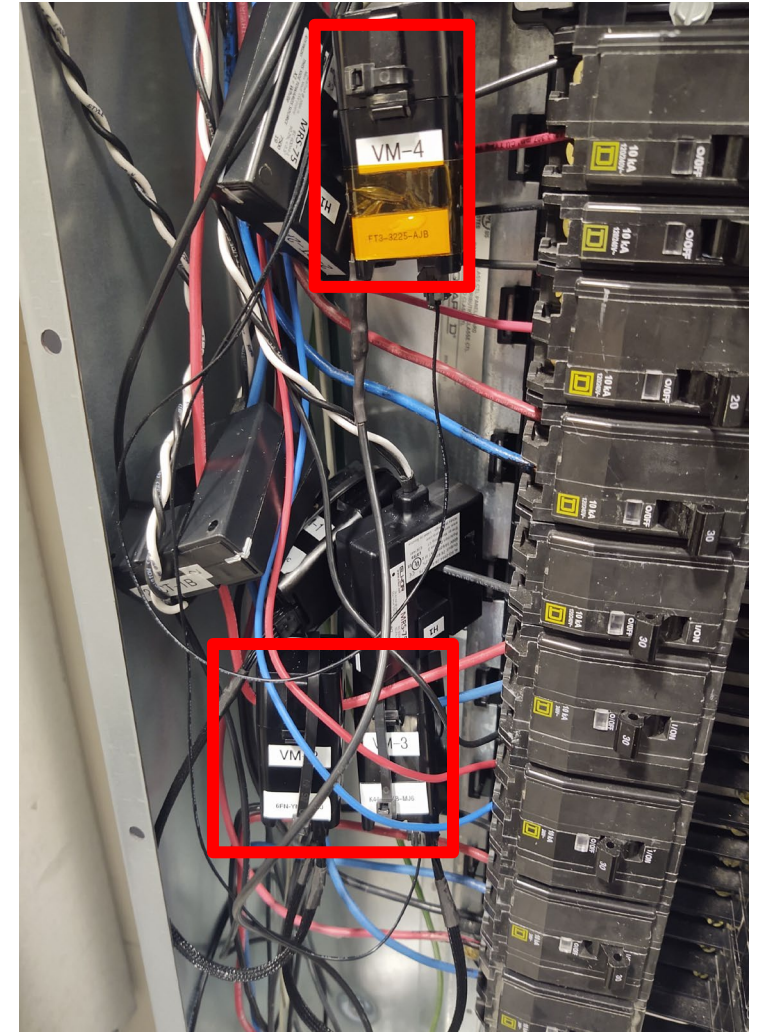


Image of the VMs installed on the HVAC system during the Continuous Run test

Data Monitoring and Reliability Tests:

Details of Signal Test



Time Period		Test Notes	Total Data Points in Test Period	Vizi Meter (% data points missing)					Average Reliability
				4HA	6FN	K44	FT3	Vizi Meter Avg	
08/08/2022 06:22	08/08/2022 08:09	Signal Test 1 Moved GW-1 ~35ft from VM's - ran until VM1-4HA dropped off then moved to next test	106	1.89%	0.94%	0.94%	1.89%	1.42%	98.58%
08/08/2022 08:58	08/08/2022 11:54	Signal Test 2 ~35ft, Added Repeater-1 near VM's	175	0.57%	0.00%	0.57%	0.00%	0.29%	99.71%
08/08/2022 12:50	08/08/2022 13:27	Signal Test 3 Distance Test 60'; with Repeaters 1 and 2.	38	5.26%	0.00%	0.00%	21.05%	6.58%	93.42%
09/08/2022 10:27	09/08/2022 12:27	Signal Test 4 Distance w/obstacles/ GW-1 in another room = 1 wall, and 1 large filing cabinet between sensors and GW-1 Repeater-1 next to sensors and repeater-2 next to GW-1	101	0.99%	0.00%	0.99%	3.96%	1.49%	98.51%
10/08/2022 05:45	10/08/2022 12:59	Signal Test 5 Distance/Obstacles Continued, added metal boxes around Sensors, but not tight seal.	435	0.00%	0.00%	0.23%	0.46%	0.17%	99.83%

Note: The VMs were configured for aggregated 1-min data collection

Data Monitoring and Reliability Tests:

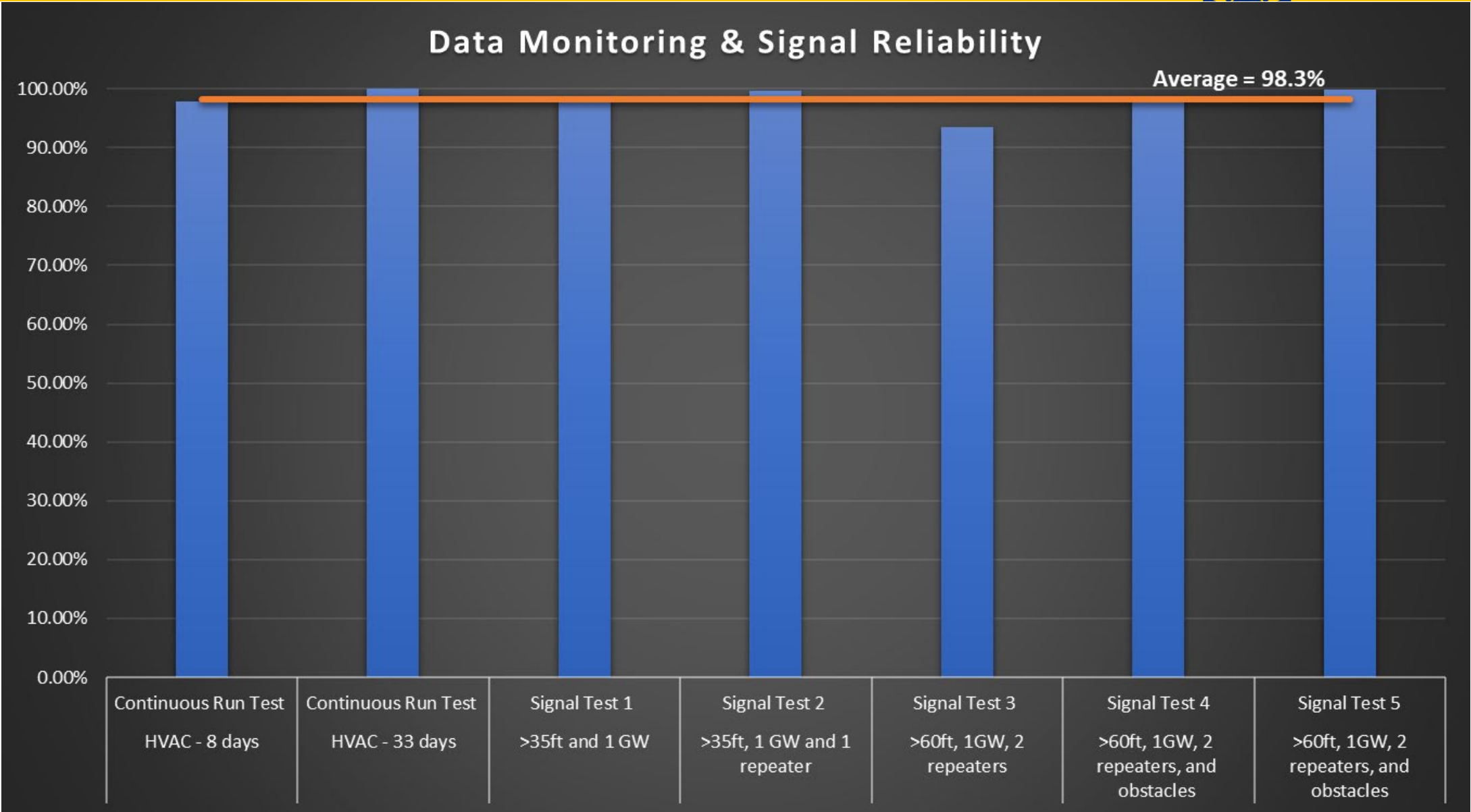
Details of Continuous Run Test



Time Period		Test Notes	Total Data Points in Test Period	Vizi Meter (% data points missing)					Average Reliability
				4HA	6FN	K44	FT3	Vizi Meter Avg	
10/08/2022 16:10	18/08/2022 11:17	Continuous run test on HVAC system 4HA-VM-1=PhA, 6FN-VM-2=B, K44-VM-3=C, FT3-VM-4=A Cellular Connectivity initially with GW-1, Repeater-1. On 11/8 and 12/8 GW-2 switched on and connected to ethernet LAN lab network. GW-1 Off. GW-2 is receiving Repeater-1 and the data which is uploading to the cloud via the LAN at a distance of 300' and several walls and large obstacles.	10988	2.35%	2.17%	2.28%	1.52%	2.08%	97.92%
		Data from Vizi cloud aggregated every 1 min							
10/08/2022 16:10	12/09/2022 04:43	Continuous run test on HVAC system FT3-VM-4=A FT3 remained, while other meters were removed and returned to Vizi for tweaking	46198				0.04%	0.04%	99.96%

Note: All 4 VMs were installed for the initial continuous run test, following an initial review of the data, 3 of the meters were removed and returned to Vizi so that hardware and firmware updates could be made before the measurement accuracy tests began.

Data Monitoring and Reliability Tests: *Summary Results*



Measurement Accuracy Tests

A total of 14 tests accuracy tests were carried out over 3 testing days. Voltage, current, power, and power factor were assessed during all of the tests, while THD was assessed over 11 of these tests.

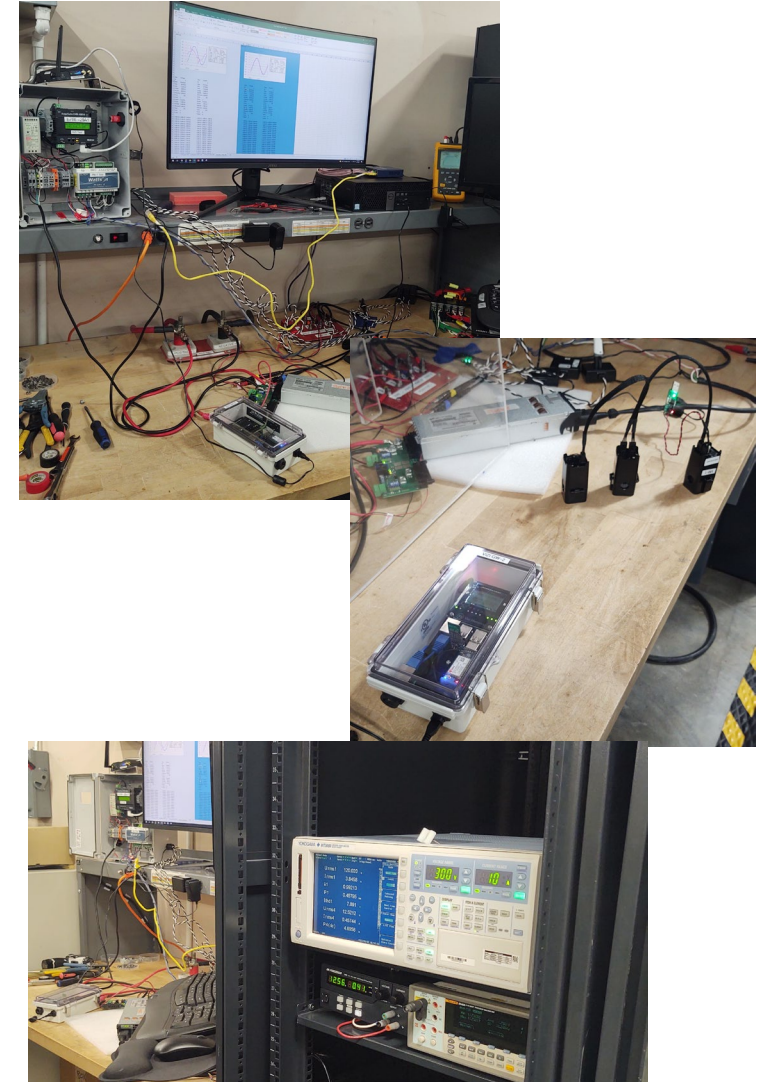
The VMs tested were installed onto an MX-45 80+ Power Supply for the majority of tests, with a Chroma AC Load Bank used in 3 of the tests. These devices allowed for the set points of the power supply to be adjusted for each test, details of the testing set points can be found on the following slide.

To determine the measurement accuracy class (or conversely the % of measurement error) of the VMs two revenue standard reference meters were installed in parallel, the Elkor MRA-75 and the WT-3000 Yokogawa. The Yokogawa meter measures with high levels of accuracy, it was used to confirm the accuracy of the Elkor meter and to provide THD reference measurements.

The accuracy class of the VMs was determined by comparing the average VM measurements against the reference meters during each test period. The equation used to determine the accuracy class is as follows:

$$\text{Measurement error [\%]} = 100 * \frac{(VM - Ref)}{Ref}$$

Where VM is the average Vizi Meter reading during the test period and Ref is the average reference meter reading during the same period. The results of the testing are summarized in the following slides, with the results of each test in the Appendix.



Images of the VMs undergoing the measurement tests in the lab.

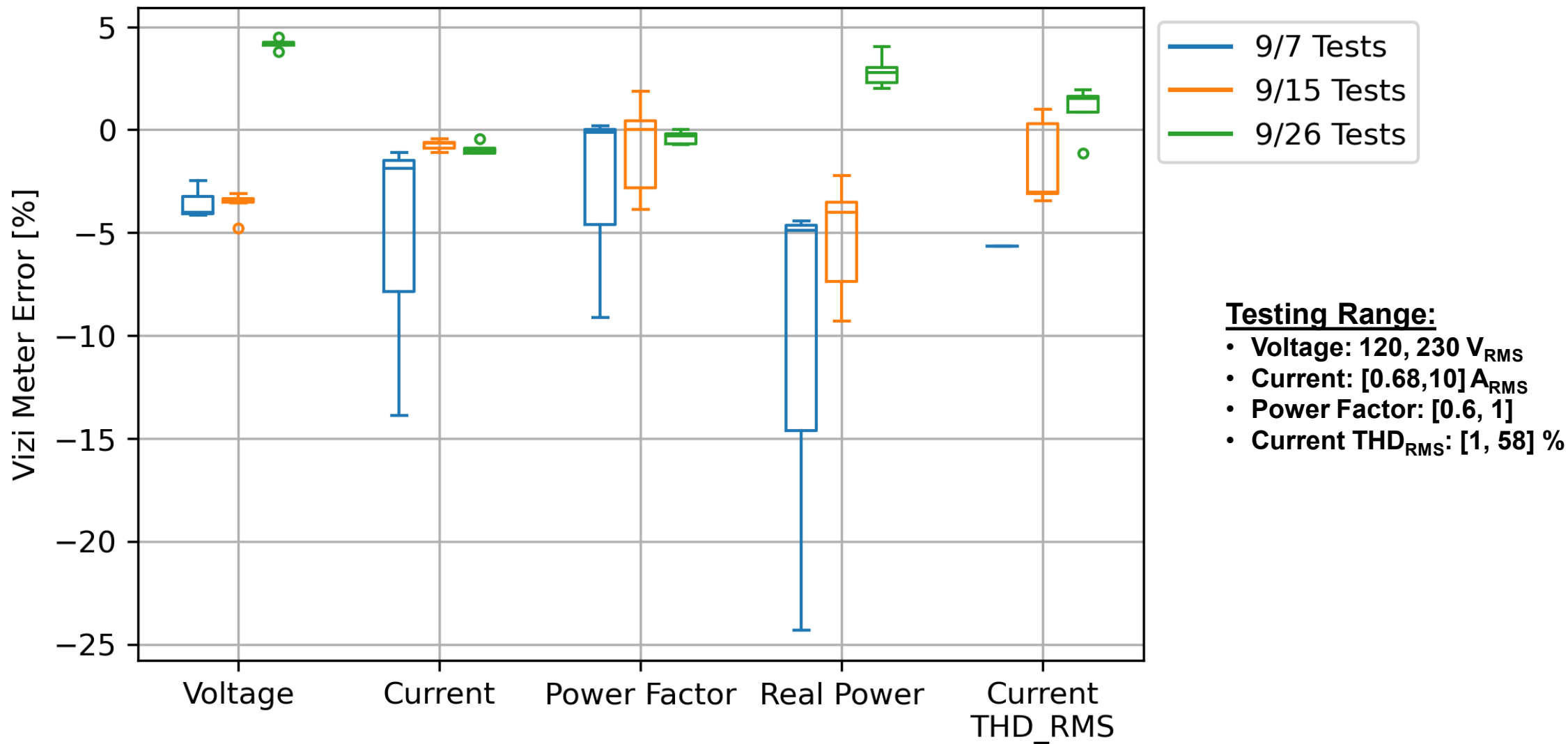
Measurement Accuracy Tests:

Details of testing setpoints

Testing Setpoints (80+ Power Supply MX-45)					
		Voltage (V-rms ac)	Current (A-rms)	Power Factor	Notes
09/07 Tests	Test 1	230	0.68	0.65	3xVMs daisy chained together, with 1 reference lead to neutral, and connected through V-line device
	Test 2	230	3.9	0.99	10% Load Test, Low Pf, 230Vac L-N
	Test 3	120	3.8	0.99	100% Load Test, High Pf, 230Vac L-N
09/15 Tests	Test 1	120	0.99	0.9	20% Load Test, High Pf, 120Vac
	Test 2	120	0.99	0.9	Firmware updated by Vizi Engineers following 09/07 Tests
	Test 3	120	5.45	0.99	VM Devices on 14-Awg Wire
	Test 4	120	10	0.605	Changed to a 6-Awg wire
	Test 5	120	10	0.8	Changed back to 14-Awg wire and higher current
	Test 6	120	10	1	Switched to Chroma AC Load Bank (63804) to Sweep Pf.
09/26 Tests	Test 1	120	4.99	0.99	Chroma AC Load Bank
	Test 2	120	4.99	0.9	Chroma AC Load Bank
	Test 3	120	4.99	0.9	Firmware updated by Vizi Engineers following 09/15
	Test 4	230	5	0.8	Power bump stopped test recording of Yokogawa
	Test 5	230	5	0.8	Re-Run of test 2 above
					Voltage increased to 230Vac (L-N)
					Added Voltage Harmonic Distortion of 12.2%

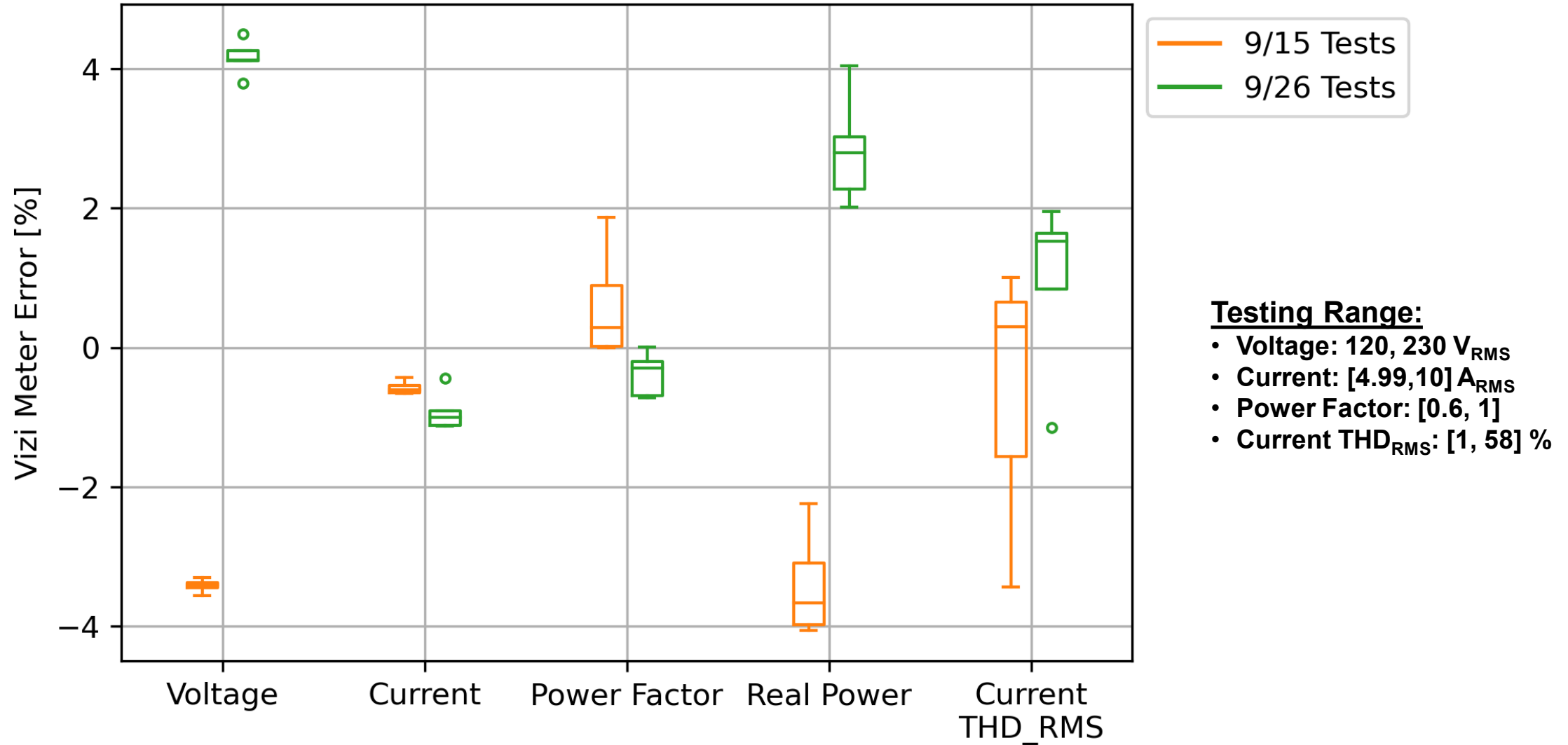
Note: The VMs received firmware updates following each set of accuracy tests

Measurement Accuracy Tests: *Summary Results, All Tests*



NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}

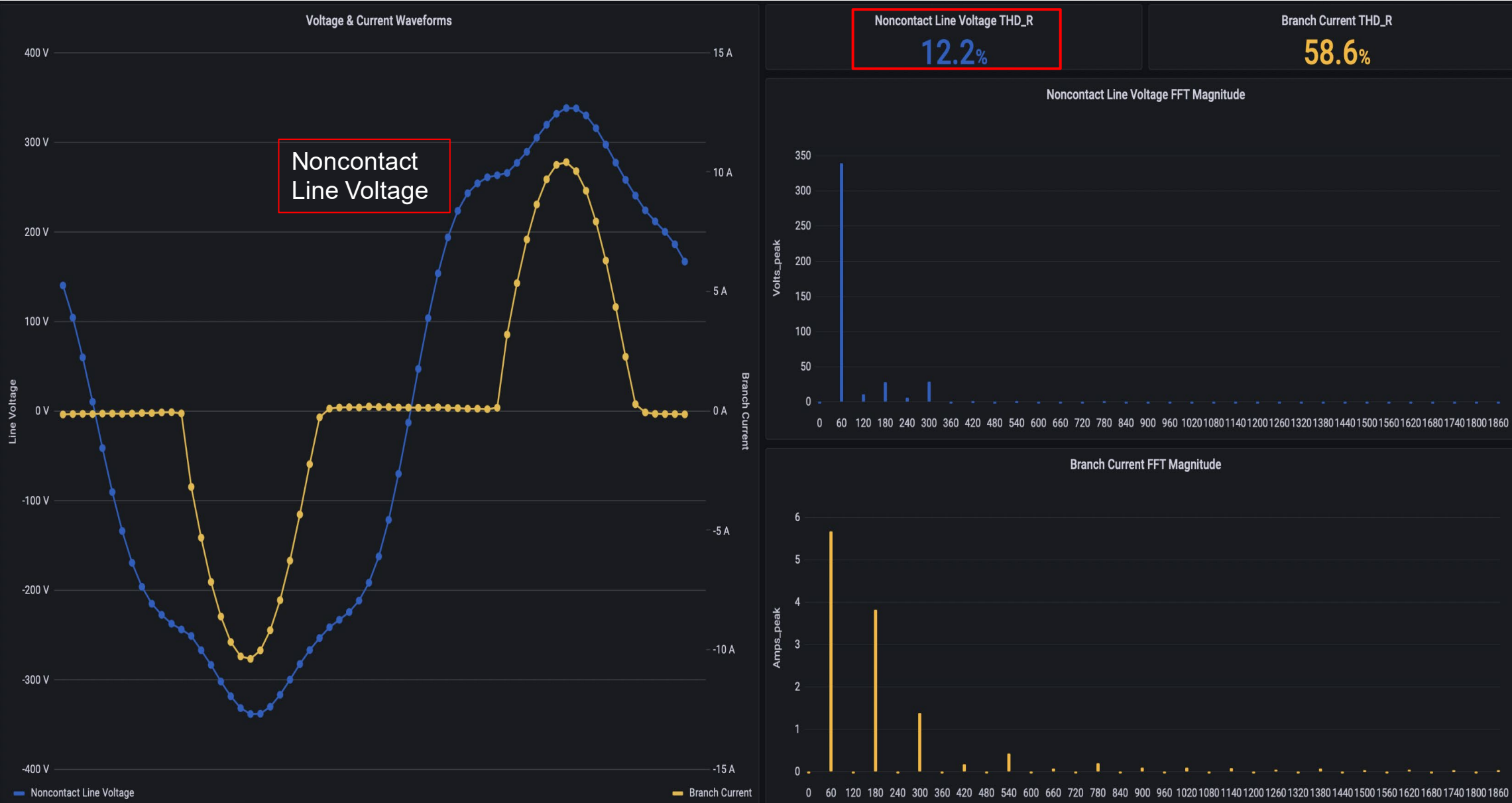
Measurement Accuracy Tests: *Summary Results, Tests $\geq 4.99 A_{RMS}$*



NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Measurement Accuracy Tests:

Vizi Dashboard showing measurement of added 12.2% voltage distortion



Results and Learnings – Data Monitoring and Signal Reliability Tests

The lab testing has shown that the Vizi Metering system can reliably store monitored data in the cloud

- Overall average data reliability of 98.3%
 - Both Ethernet and Cellular connections performed reliably
 - Distances of up to 300 feet and metal obstacles and several walls did not impede data reliability significantly
- Data reliability was found to improve with time, with 99.9% of data points monitored and stored in the cloud during the 33-day long continuous run test

It was found that the correct use of the Vizi signal repeaters was important to maintaining data reliability.

- For example, when installed in an electrical panel with the door closed a signal repeater was required within a few feet of the panel to maintain signal strength to the gateway.

Results and Learnings – Measurement Accuracy Tests

Summary Results

Noting that Vizi engineers made hardware and firmware updates to the VMs following each set of tests, and the first set of tests were performed with current below 1 A when Vizi recommends specs of between 5A – 100A. The measurement accuracy of the VMs improved in the later tests, it was found that:

- The average voltage measurements were $\pm 4\%$ of the reference meters for each set of tests
- Average power readings improved to within 3% accuracy class in final tests
- Average accuracy class of the current and power factor was within 1% in the final tests

The ability to measure Power Quality Metrics are a unique and valuable application of the Vizi Meters. The results showed that the VMs measured Current Total Harmonic Distortion within 1% of reference meters on average in the final tests. The VMs were also found to accurately measure the Voltage Harmonic Distortion during the last test.



Results and Learnings – Measurement Accuracy Tests

Accuracy by Current, Voltage, and Power Factor

When the current measurement is below the Vizi recommended 5A – 100A accuracy was impaired. In the first tests conducted on 09/07, current was set to below 1A, this was shown to significantly impair the measurement accuracy.

In the tests when current was $\geq 4.99\text{A}$, the accuracy of power measurements improved, and the average accuracy class of the current, power factor and THD measurements was within 1-2% of the reference meters. The average accuracy class of voltage measurements was around -3.4% to +3.9%, which resulted in power measurements with an average error of +2.1 and -3.4%.

While the majority of tests were carried out at 120V, no significant difference in accuracy was found when compared with the tests carried out at 230V.

The Power Factor of the power being measured was not found to significantly impact accuracy, in the 09/15 and 09/26 tests current, PF, and THD readings had comparable accuracies when PF was below and above 0.9.

During the 9/15 testing, tests with the same current and power factor were completed on both 14-awg and 6-awg wires. The testing showed that the error in voltage measurement was 1.65% higher with the 6-awg wire.

The appendix of this report contains tables with results from each test as well as detailed plots comparing the measurement error of each metric.

Results and Learnings – Outcomes and Next Steps

The average accuracy class of the voltage measurements was found to be around 4%. While not within the 1-2% accuracy class, the achieved accuracy class is still impressive for a wireless meter, and the reliability of data monitoring is clear. There is significant potential for this device thanks to its reliably and granular data monitoring, and the ability to accurately measure power quality metrics opens a broader array of use cases.

Understanding how these devices perform in the field is the logical next step. There are several potentially high value use cases that utilities could have for this device, including:

- M&V for utility EE programs
- Verifying demand reduction for DR programs
- Energy and demand management in commercial and industrial facilities

EPRI and Vizi are ready and interested to further test these devices in the field. However, EPRI recommends that if manufacturing challenges are resolved and Vizi perform further firmware updates as is planned, the next generation of VMs could undergo a short lab test which simulates the specific use case of interest to utilities. This can ensure the devices are ready for any large scale and long-term field testing of specific use cases in the field.

Appendix

Detailed Test Results



Measurement Accuracy Tests

09/07 Test results



	09/07 Tests - Average Accuracy Class				
	Voltage	Current	Power	Power Factor	Current THD_RMS*
Test 1 (230Vac, Low PF)	-4.136%	-13.862%	-24.316%	-9.113%	
Test 2 (230Vac, High PF)	-3.990%	-1.103%	-4.866%	0.183%	
Test 3 (120Vac, High PF)	-2.484%	-1.879%	-4.414%	-0.122%	-5.635%
Average	-3.537%	-5.615%	-11.198%	-3.017%	-5.635%
Median	-3.103%	-1.881%	-4.810%	-0.021%	-6.434%
Max	-1.908%	-0.464%	-4.036%	2.830%	-3.957%
Min	-4.905%	-16.358%	-39.431%	-24.028%	-6.514%

* Total Harmonic Distortion (THD) results were converted post-testing from THD Fundamental to THD RMS. In later tests, Vizi's updated firmware reports THD RMS directly to match the Yokogawa WT-3000 calculation method.

https://en.wikipedia.org/wiki/Total_harmonic_distortion

Measurement Accuracy Tests

09/15 Test results



	09/15 Tests - Average Accuracy Class				
	Voltage	Current	Power	Power Factor	Current THD_RMS*
Test 1 (120Vac, 0.9 PF, 0.99A, 14-Awg Wire)	-3.112%	-1.085%	-8.470%	-3.777%	-3.099%
Test 2 (120Vac, 0.9 PF, 0.99A, 6-Awg wire)	-4.761%	-0.977%	-9.278%	-3.879%	-3.036%
Test 3 (120Vac, 0.99 PF, 5.45A, 14-Awg Wire)	-3.563%	-0.583%	-4.068%	0.018%	-3.435%
Test 4 (120Vac, 0.605 PF, 10A)	-3.403%	-0.658%	-2.238%	1.864%	0.293%
Test 5 (120Vac, 0.8 PF, 10A)	-3.299%	-0.643%	-3.374%	0.562%	1.006%
Test 6 (120Vac, 1 PF, 10A)	-3.416%	-0.427%	-3.954%	0.000%	
Average	-3.592%	-0.729%	-5.230%	-0.869%	-1.654%
Median	-3.500%	-0.958%	-5.306%	0.000%	-1.322%
Max	-1.535%	0.332%	0.008%	2.269%	1.648%
Min	-5.904%	-1.736%	-11.143%	-7.359%	-5.182%

* Total Harmonic Distortion (THD) results were converted post-testing from THD Fundamental to THD RMS. In later tests, Vizi's updated firmware reports THD RMS directly to match the Yokogawa WT-3000 calculation method.

https://en.wikipedia.org/wiki/Total_harmonic_distortion

Measurement Accuracy Tests

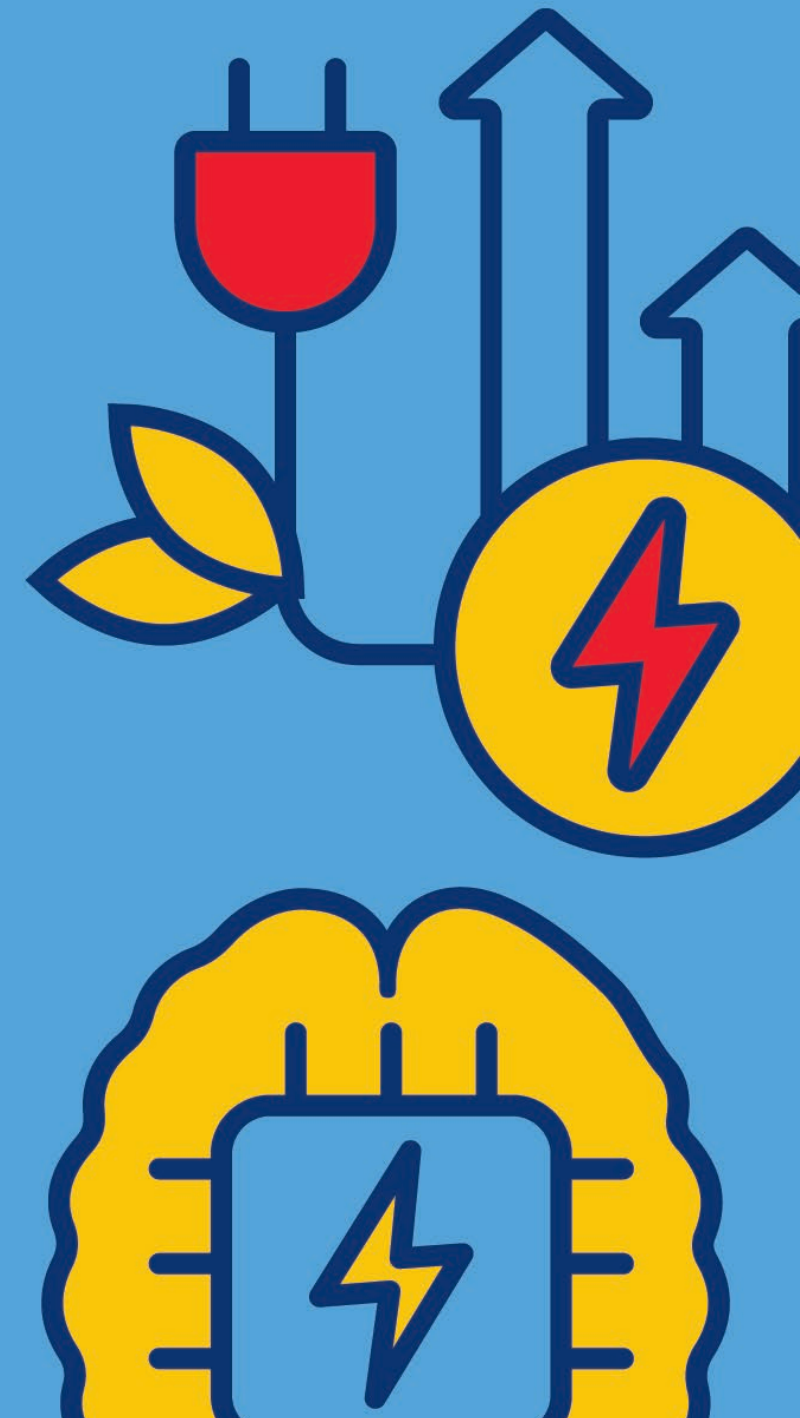
09/26 Test results

	09/26 Tests - Average Accuracy Class				
	Voltage	Current	Power	Power Factor	Current THD_RMS
Test 1 (120Vac, 4.99A; Pf= .999)	4.503%	-0.445%	4.038%	0.011%	-1.154%
Test 2 (120Vac; 4.99A; Pf = .900)	4.257%	-1.001%	3.020%	-0.202%	
Test 3 (120vac Re-Run of test 2)	4.120%	-0.907%	2.791%	-0.292%	1.948%
Test 4 (230Vac (L-N); 5A; Pf= .80)	4.127%	-1.126%	2.277%	-0.694%	1.539%
Test 5 (230Vac (L-N); 5A; Pf = 0.8)	3.796%	-1.120%	2.012%	-0.728%	1.509%
Average	4.160%	-0.920%	2.828%	-0.381%	0.960%
Median	4.213%	-0.867%	2.832%	-0.192%	1.370%
Max	5.908%	-0.092%	4.988%	0.126%	5.584%
Min	2.717%	-1.796%	0.714%	-1.450%	-8.781%

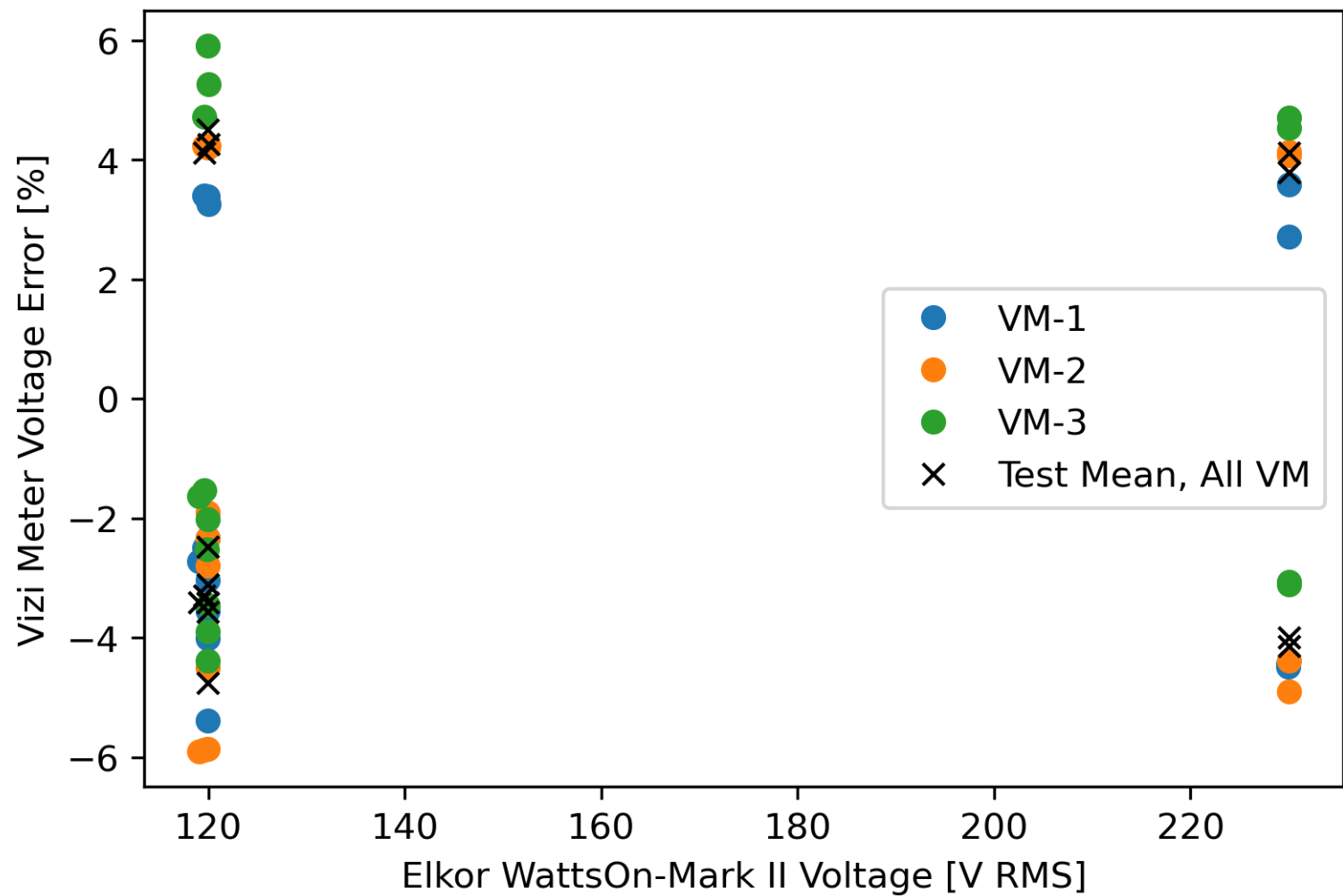
Note: Test data recorded using updated Vizi meter firmware that reports THD RMS values directly using only 50 harmonics to match the Yokogawa WT-3000 calculation method and bandwidth.

Accuracy Results

All tests

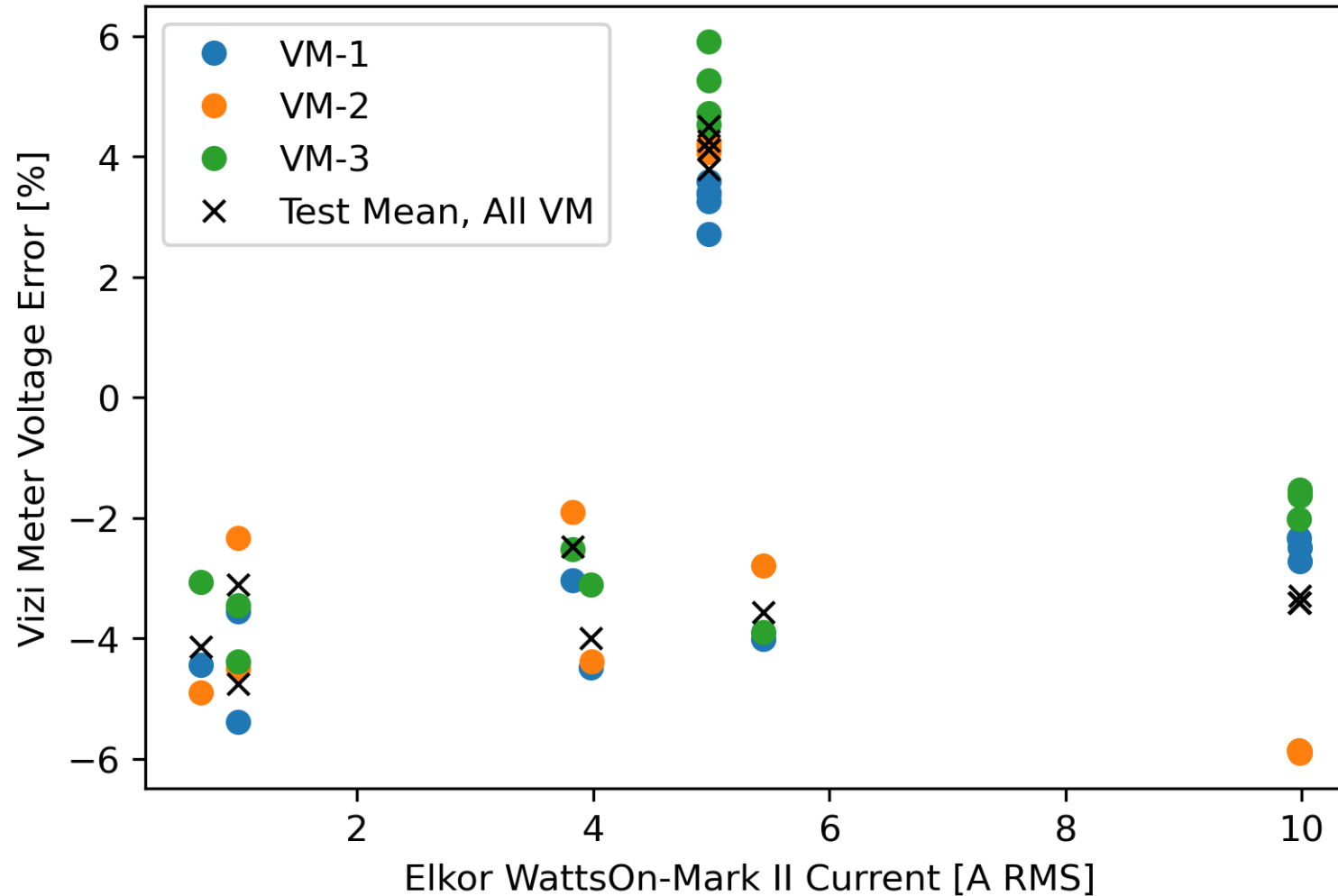


Vizi Meter Voltage Error vs. Voltage (All Currents)



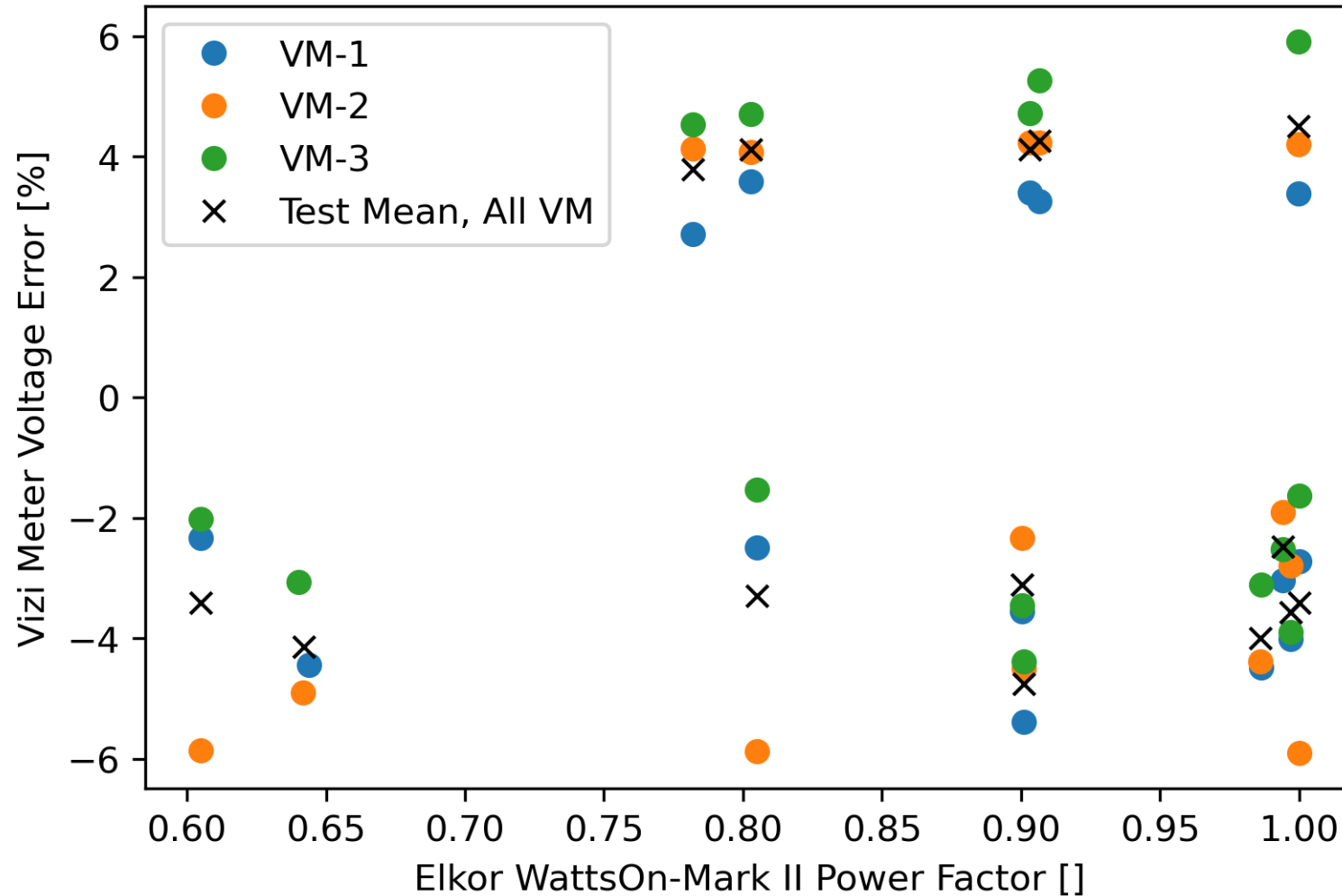
NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}

Vizi Meter Voltage Error vs. Current (All Currents)



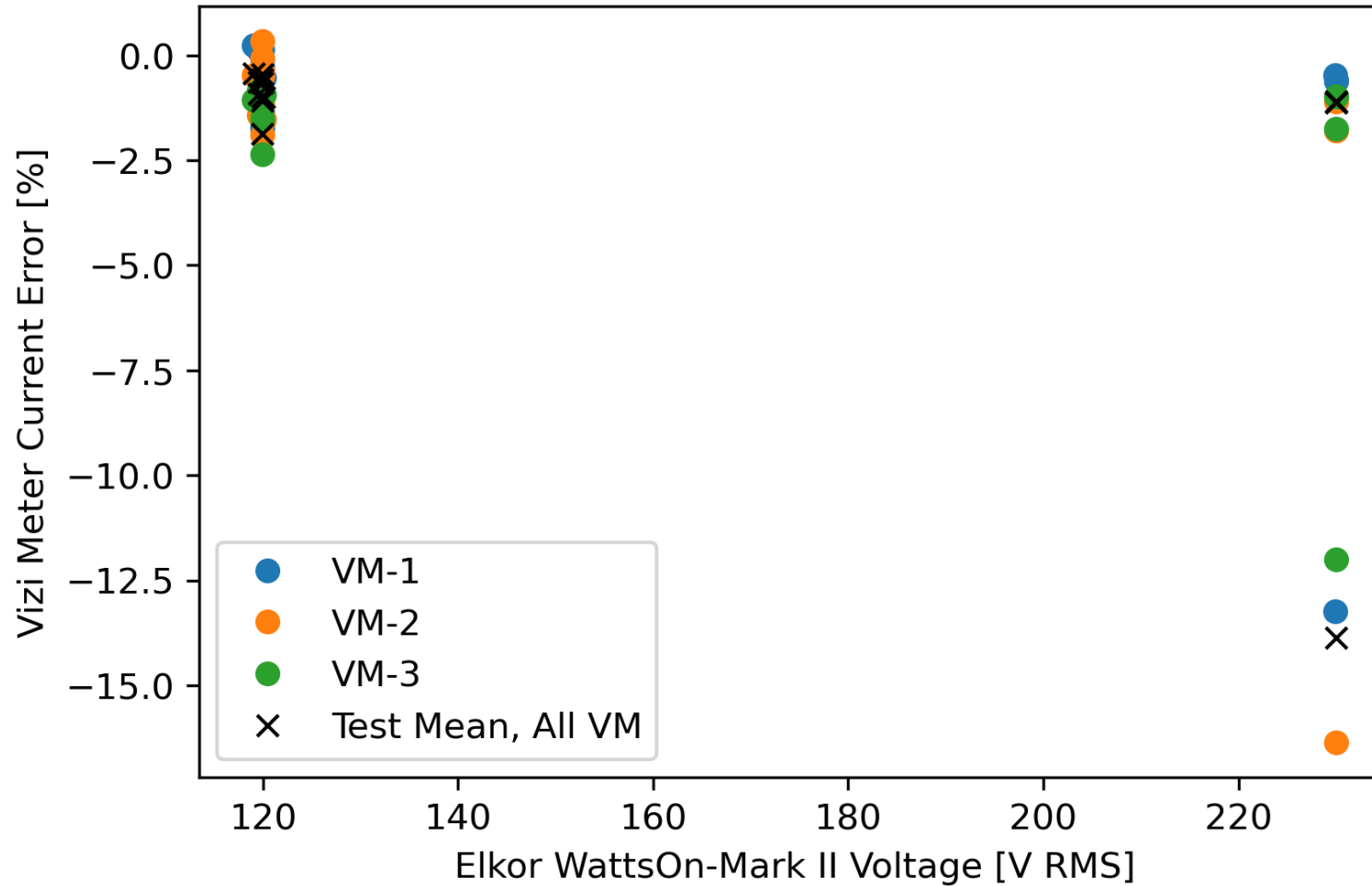
NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}

Vizi Meter Voltage Error vs. Power Factor (All Currents)



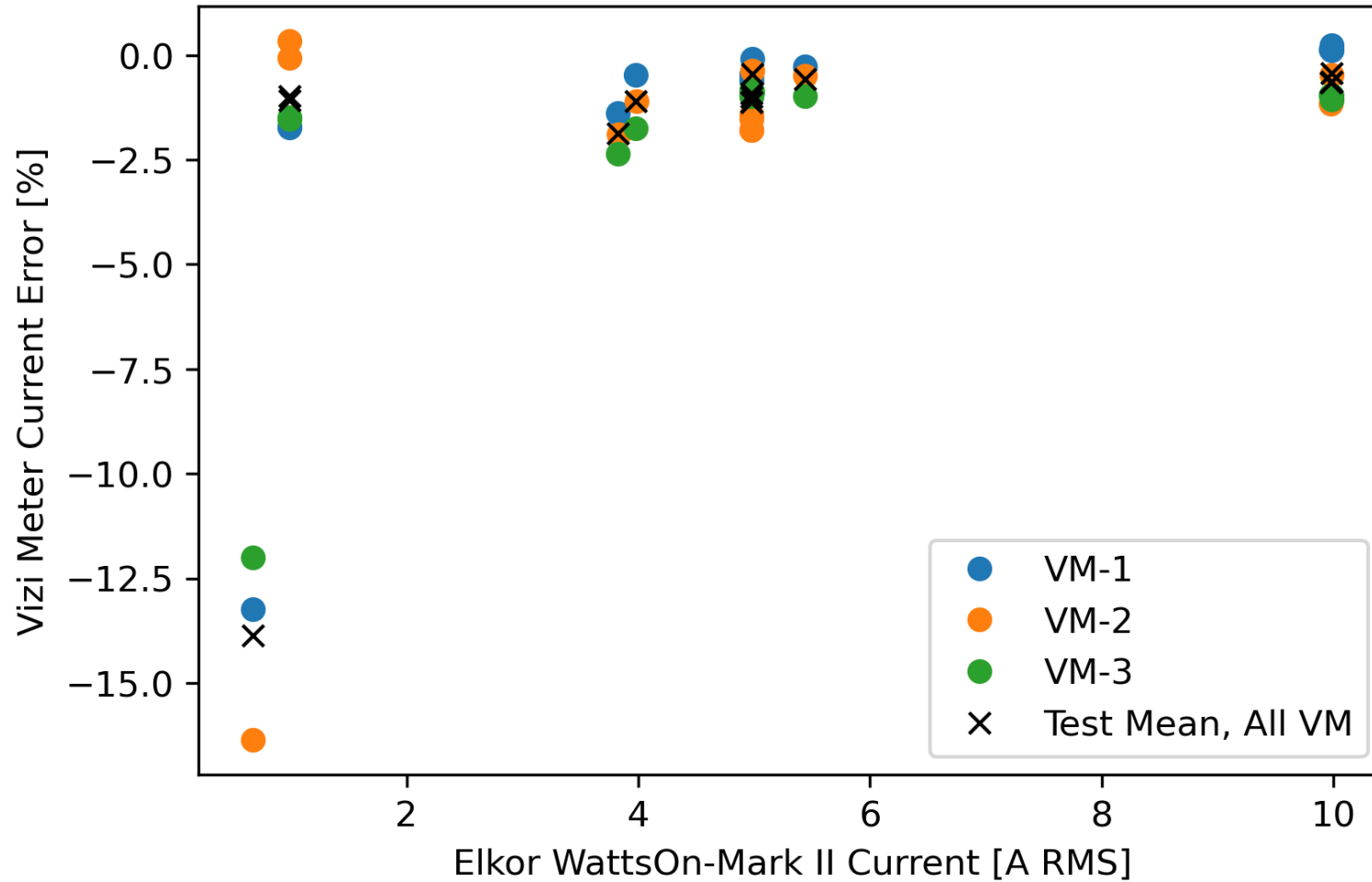
NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}

Vizi Meter Current Error vs. Voltage (All Currents)



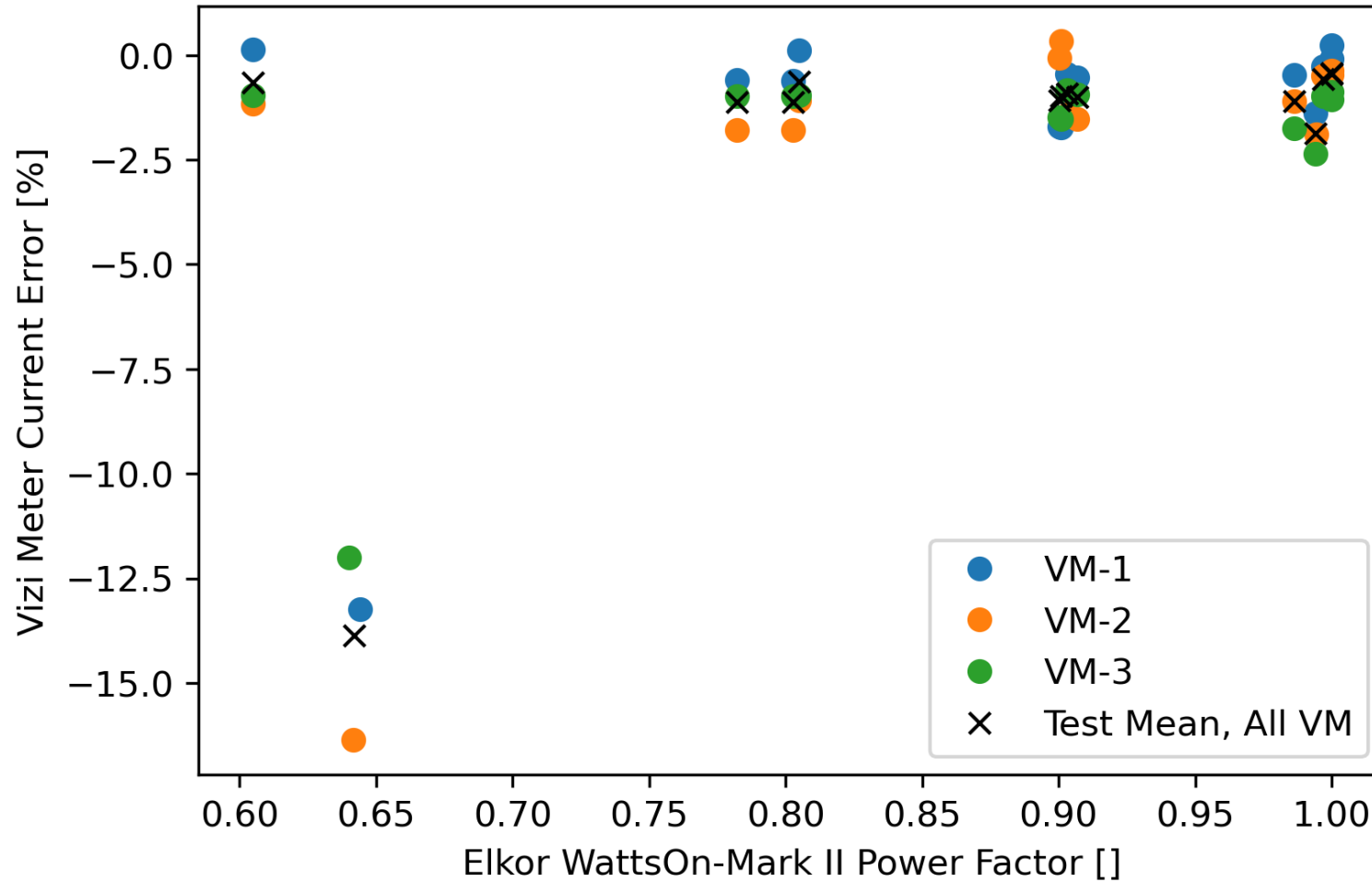
NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}

Vizi Meter Current Error vs. Current (All Currents)



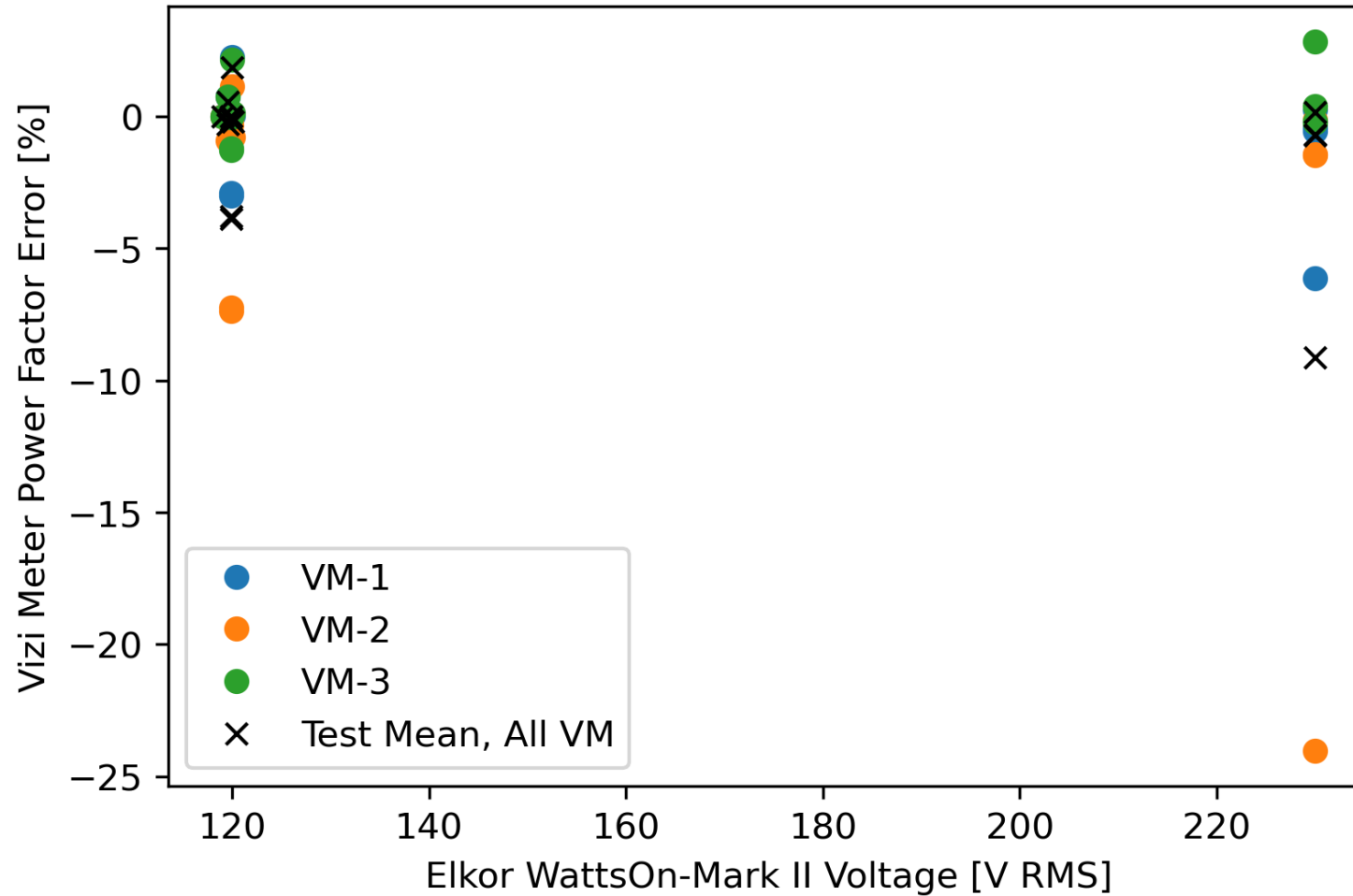
NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}

Vizi Meter Current Error vs. Power Factor (All Currents)



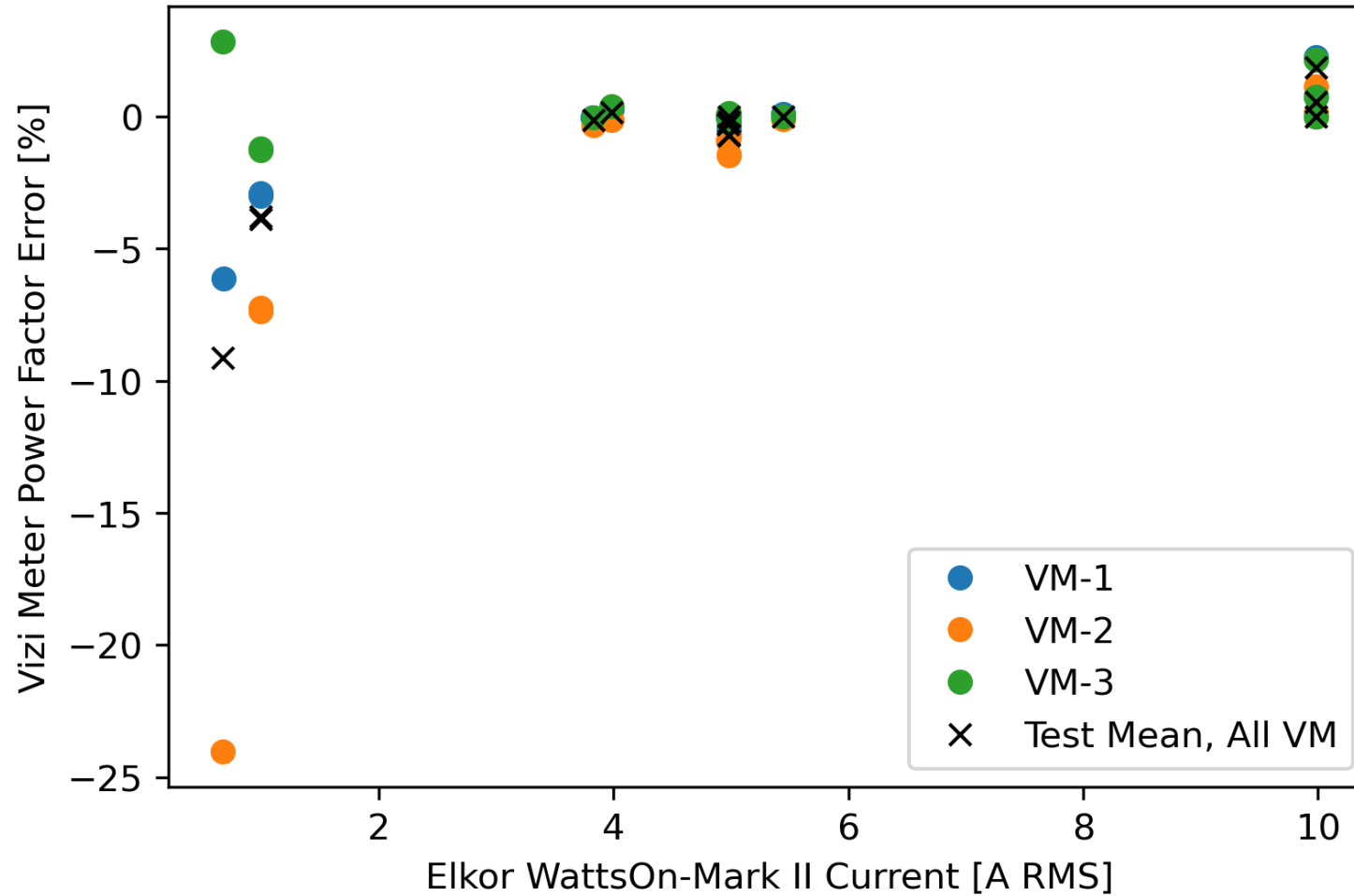
NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}

Vizi Meter Power Factor Error vs. Voltage (All Currents)



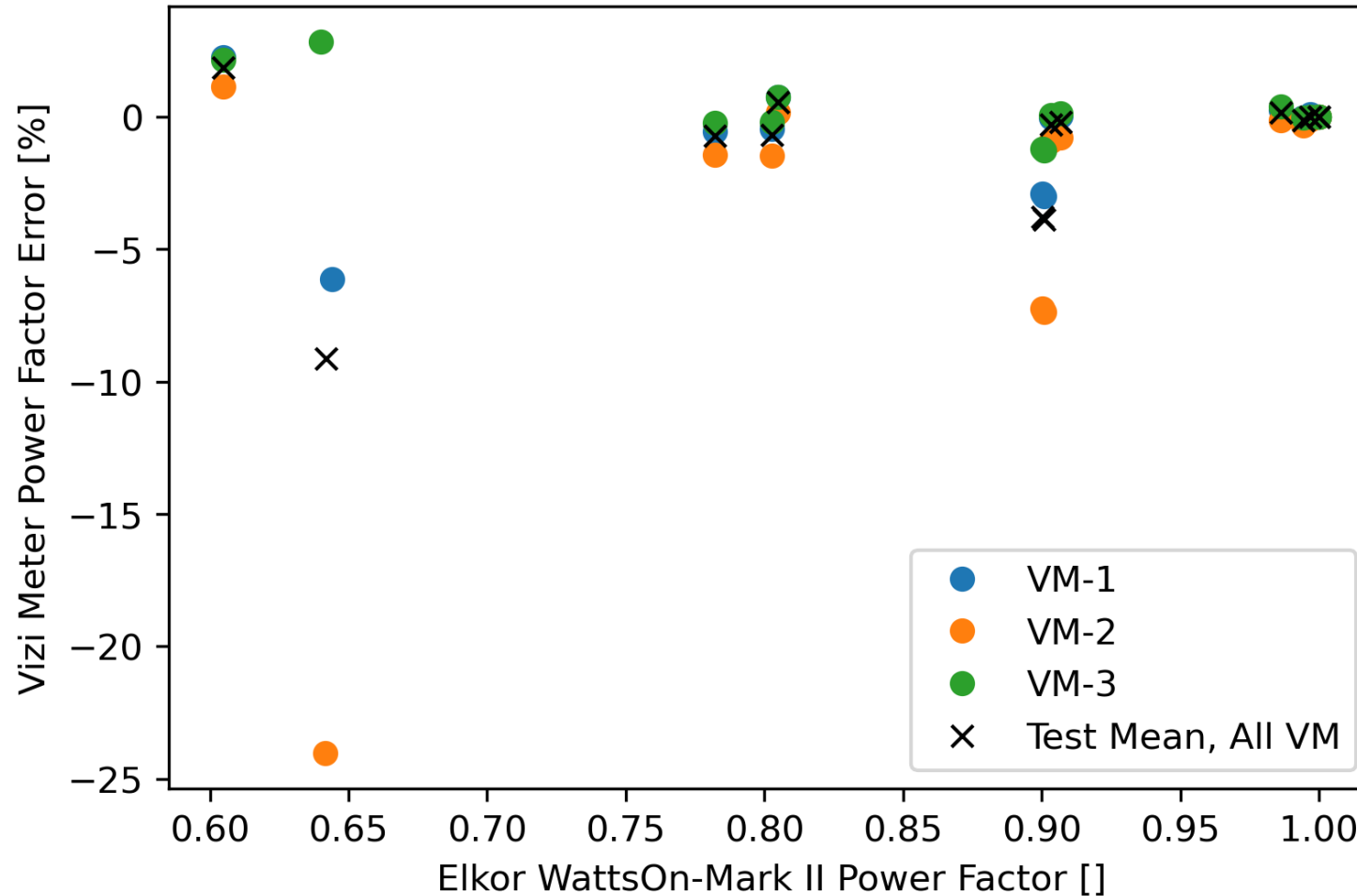
NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}

Vizi Meter Power Factor Error vs. Current (All Currents)



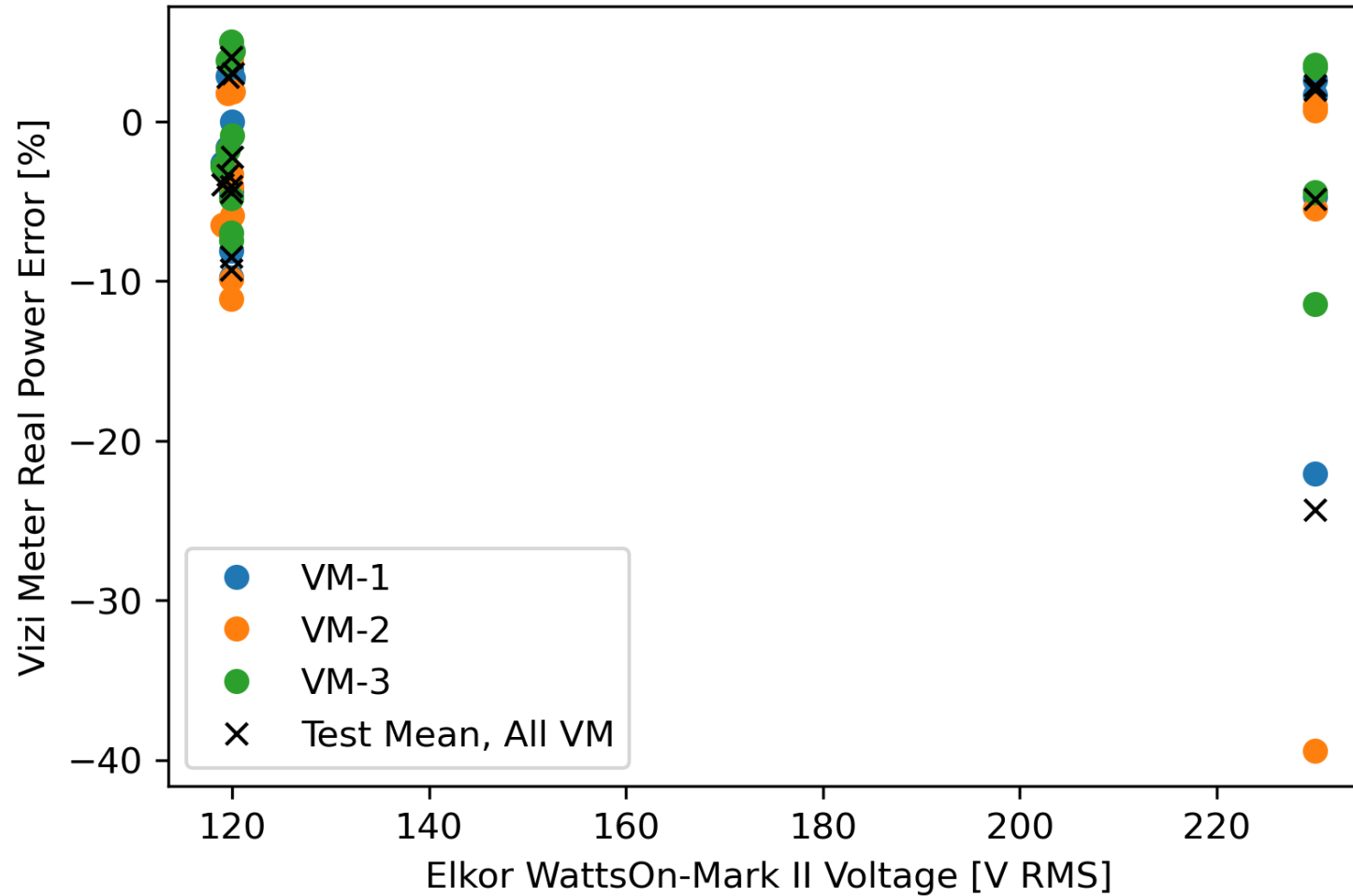
NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}

Vizi Meter Power Factor Error vs. Power Factor (All Currents)

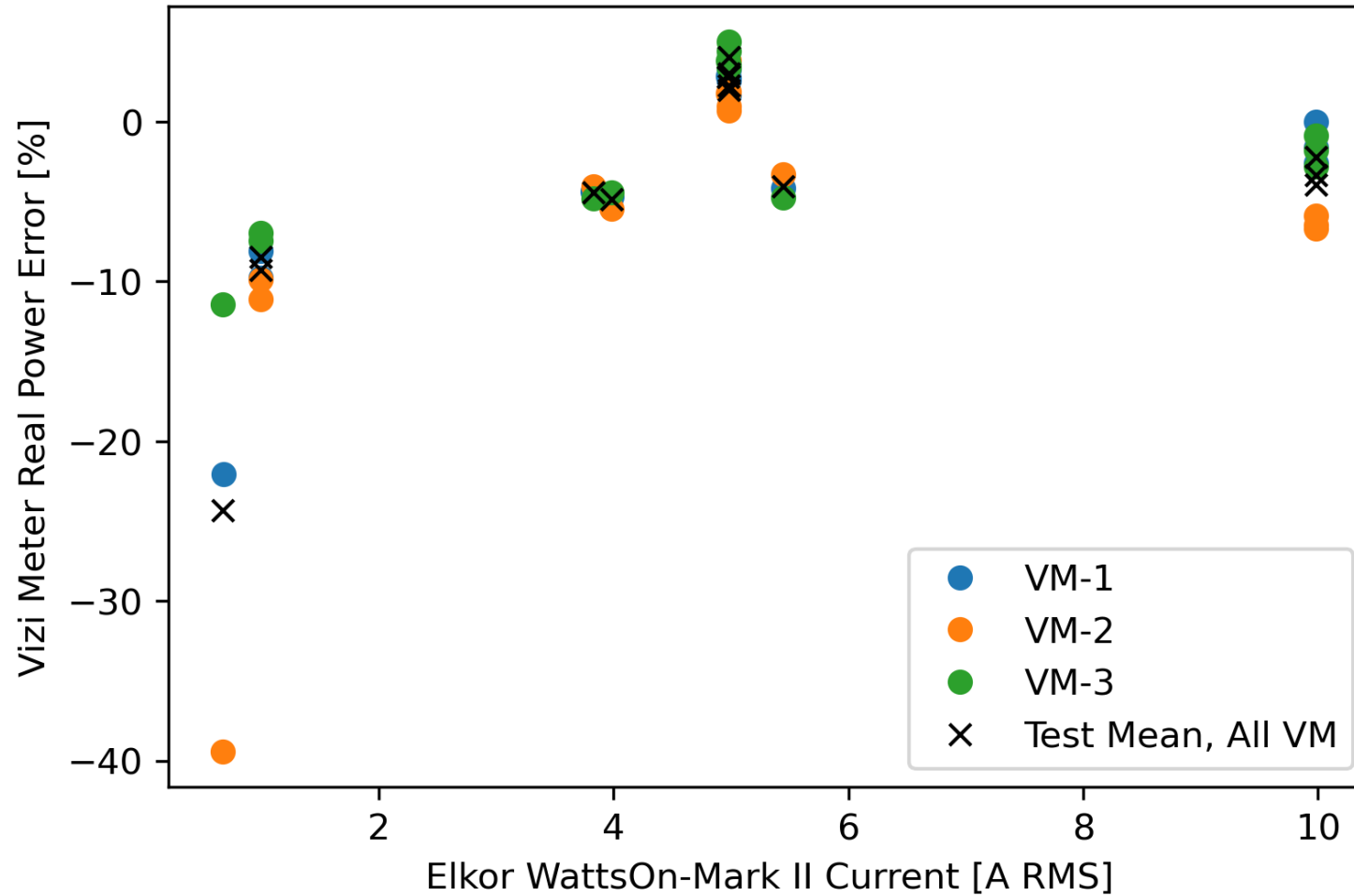


NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}

Vizi Meter Real Power Error vs. Voltage (All Currents)

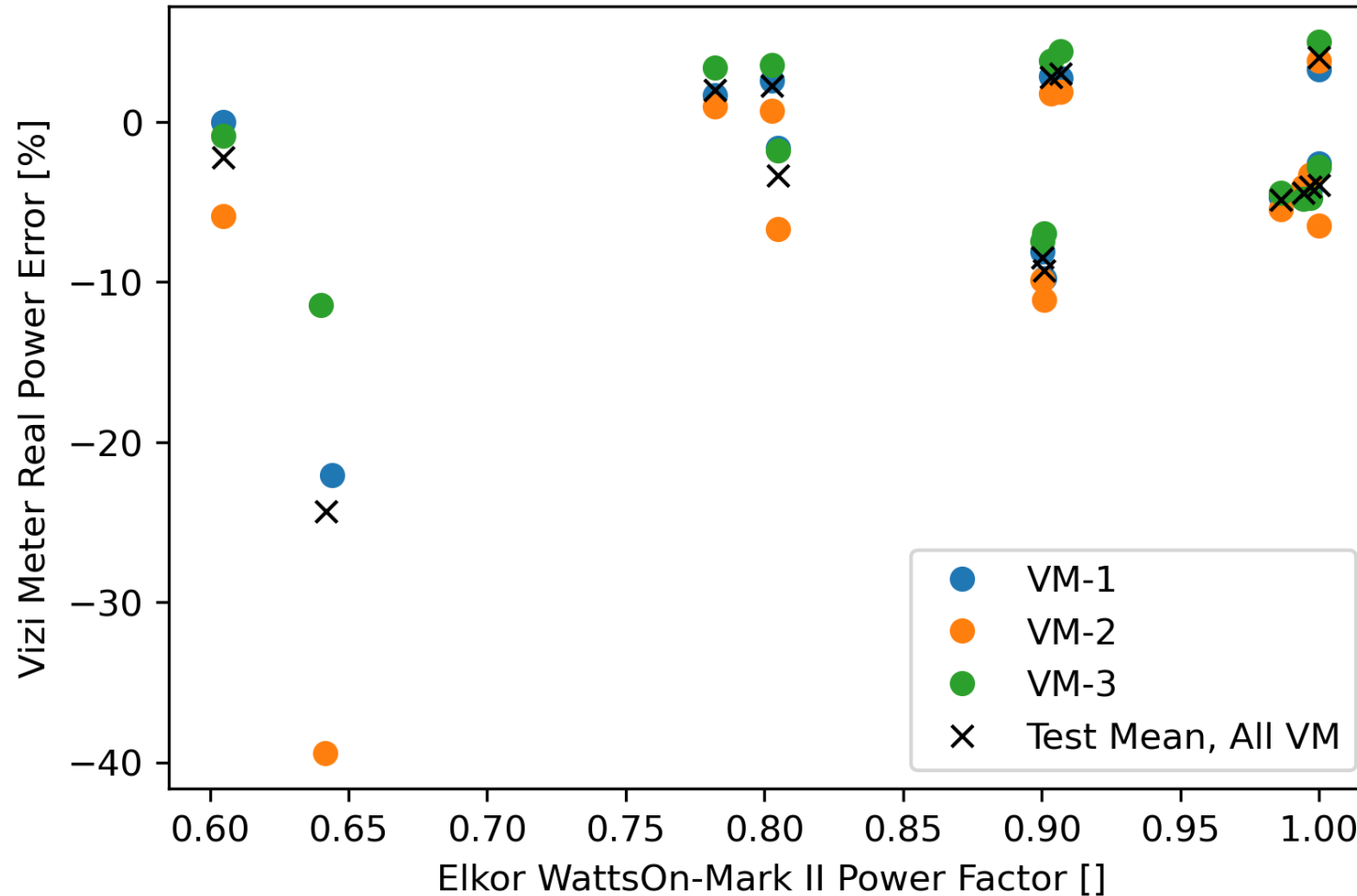


Vizi Meter Real Power Error vs. Current (All Currents)

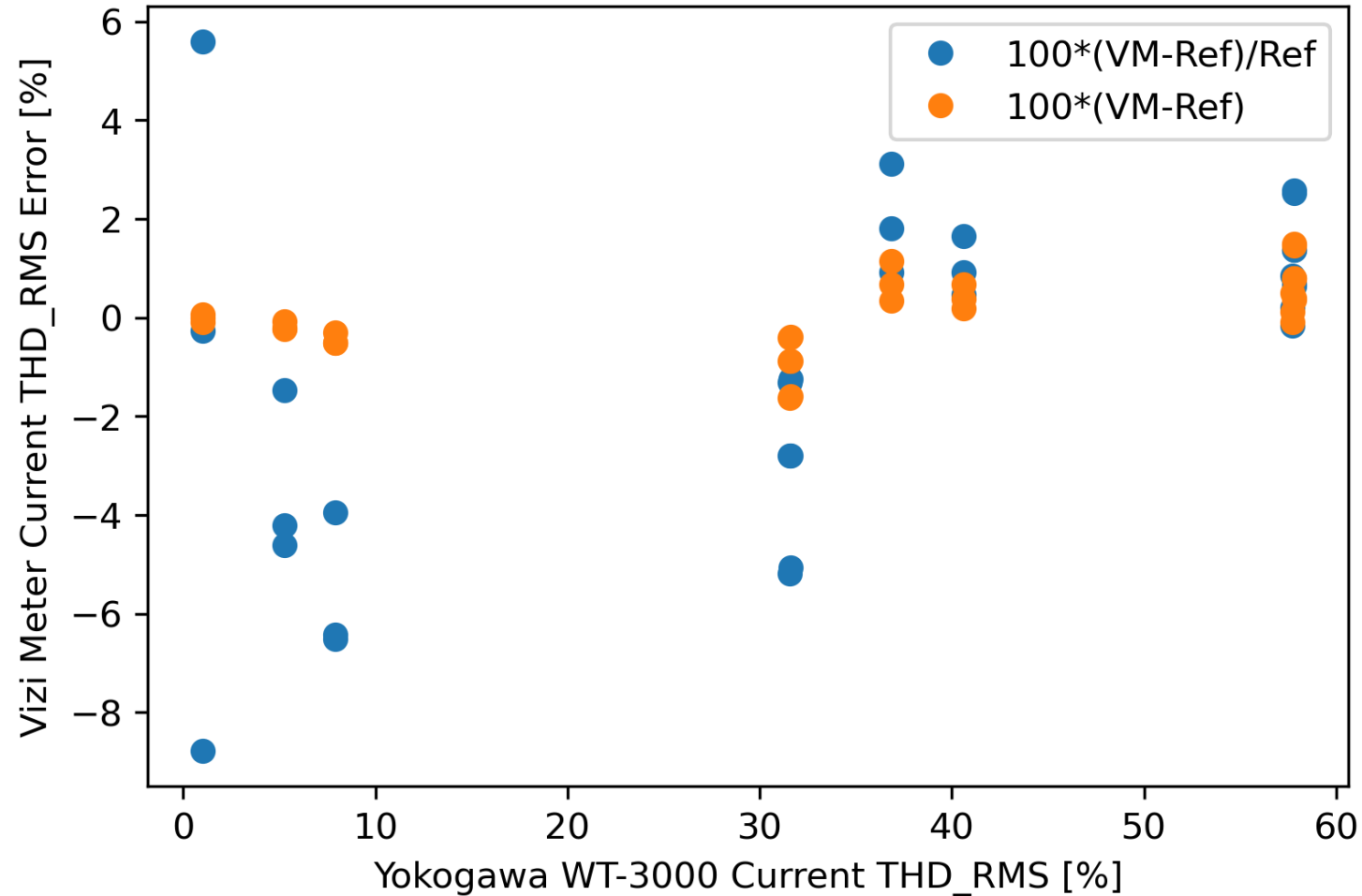


NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}

Vizi Meter Real Power Error vs. Power Factor (All Currents)



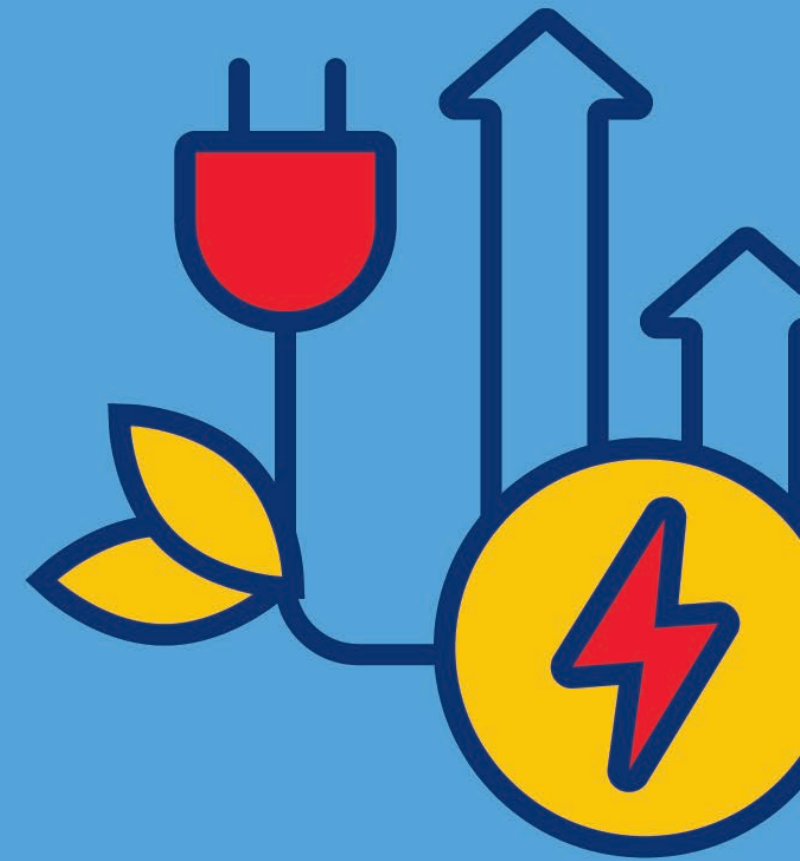
NOTE: Includes test data below Vizi recommended meter current range of 5-100 A_{RMS}



NOTE: It was unclear how to calculate percent error between two THD_{RMS} values, which are percentages (out of 100) themselves. The blue dots above were calculated with the standard percent error method used throughout the rest of the analysis, and the orange dots were calculated with an absolute difference method.

Accuracy Results

All tests $\geq 4.99 A_{RMS}$

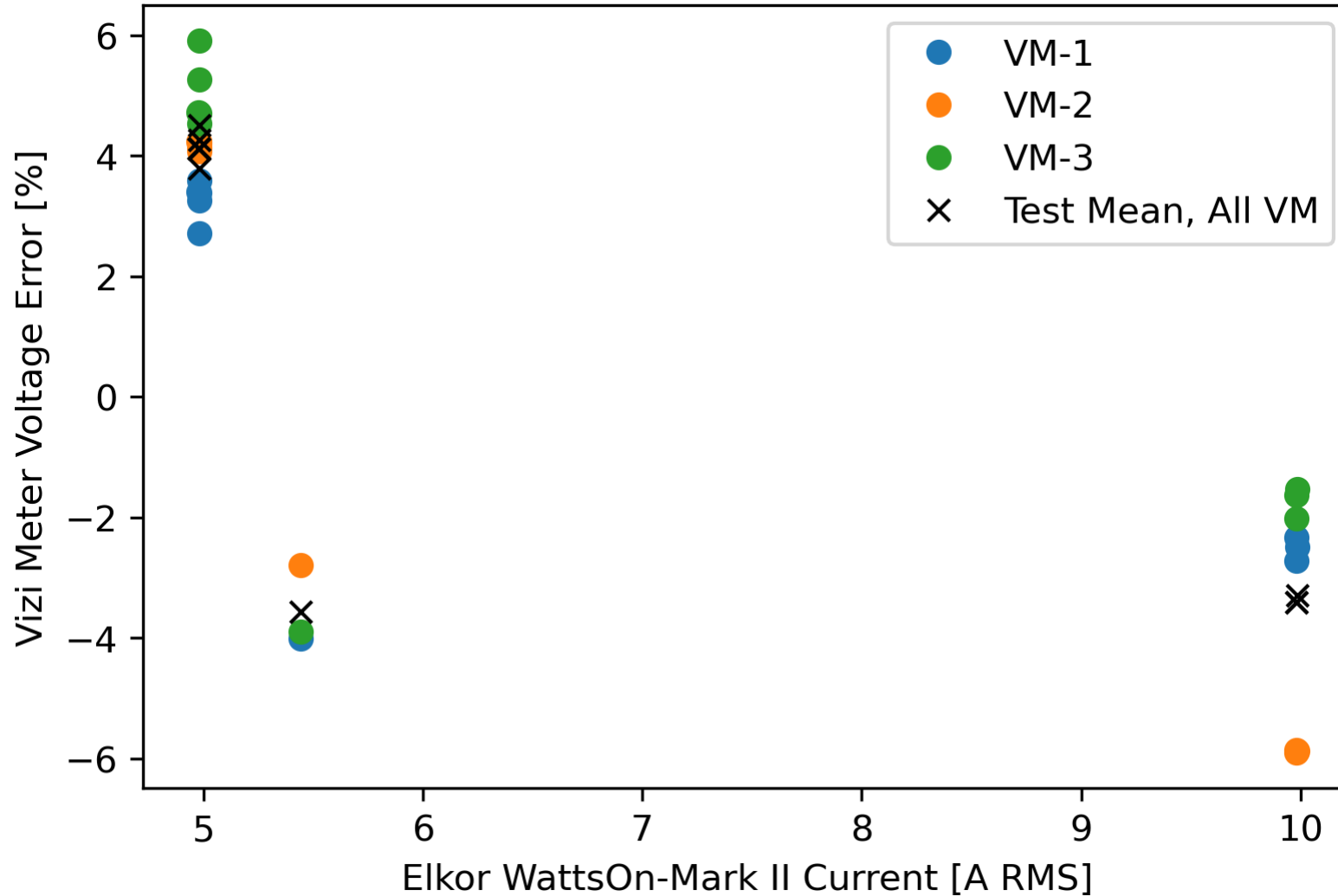


NOTE: Vizi recommended meter current range is 5-100 A_{RMS}



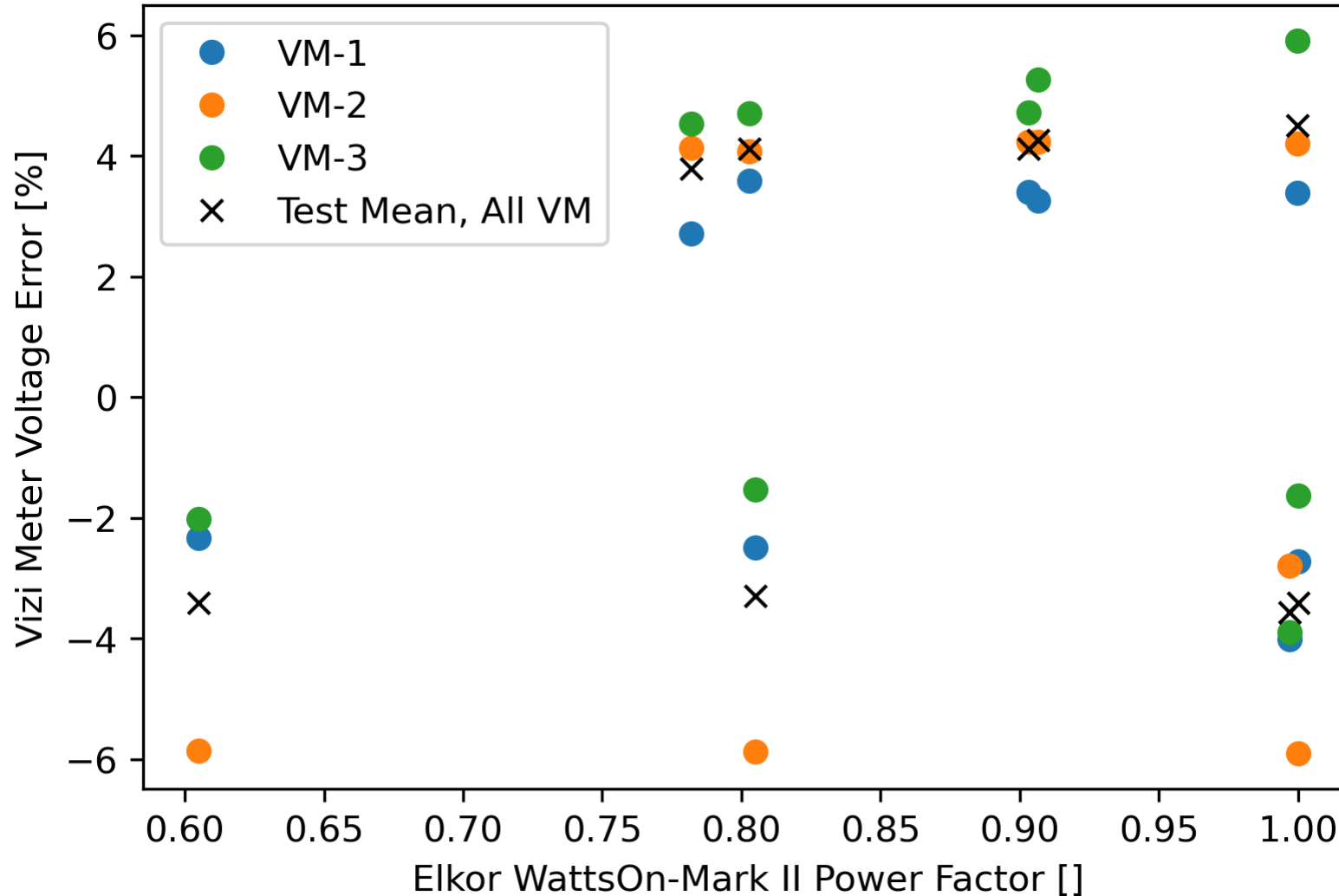
41

Vizi Meter Voltage Error vs. Current (Current $\geq 4.99A_{RMS}$)



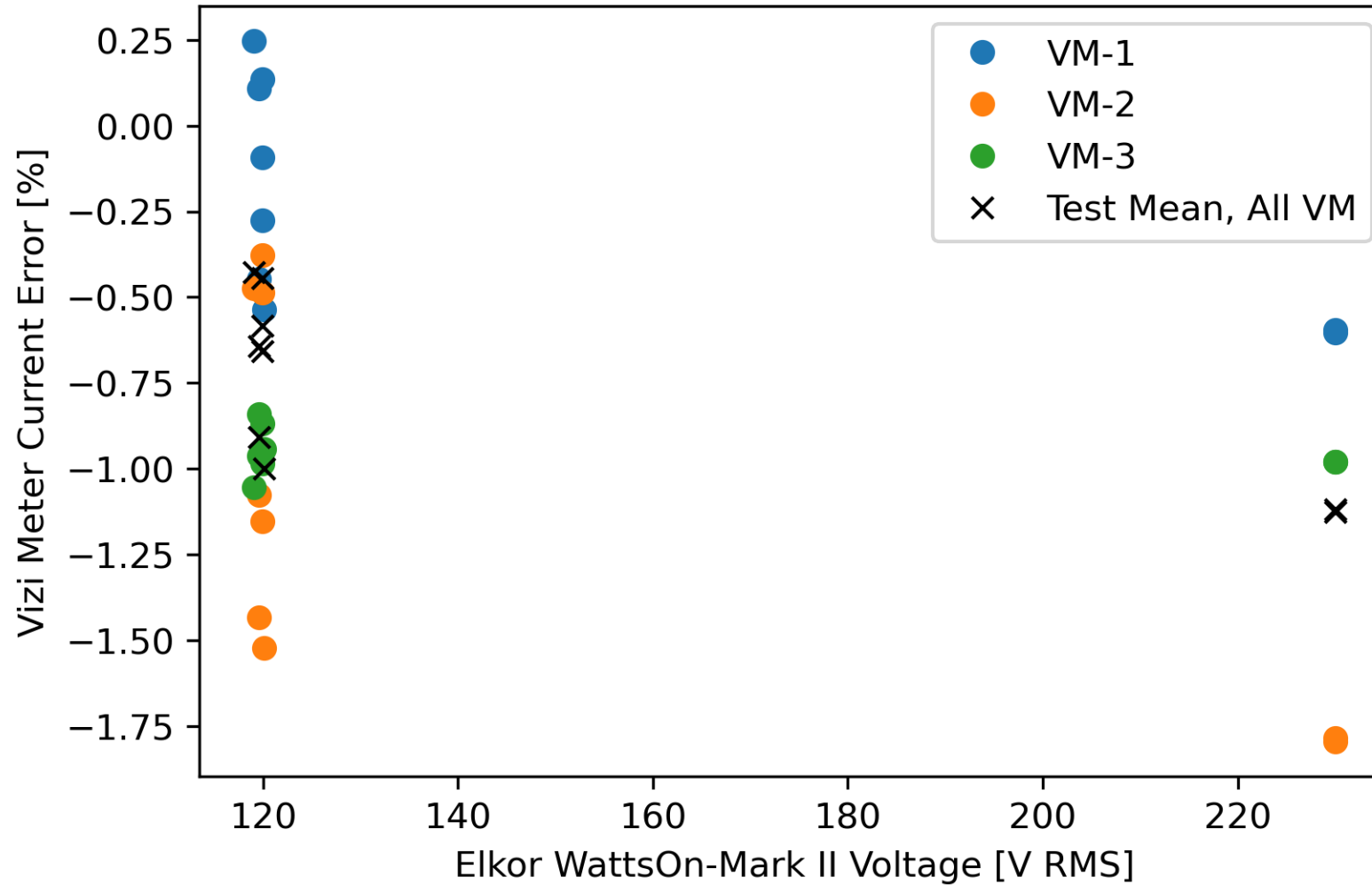
NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Vizi Meter Voltage Error vs. Power Factor (Current $\geq 4.99A_{RMS}$)



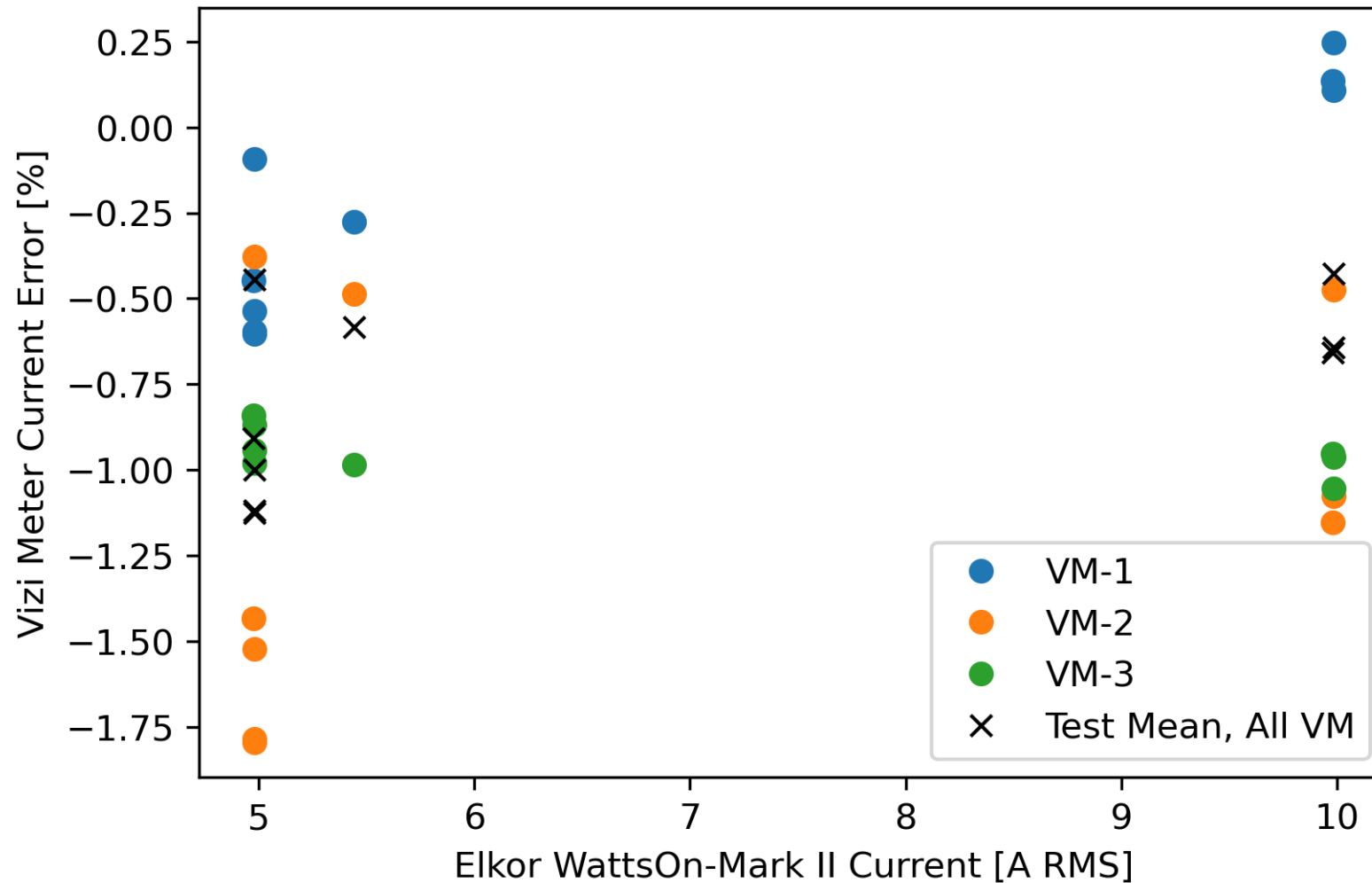
NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Vizi Meter Current Error vs. Voltage (Current $\geq 4.99A_{RMS}$)



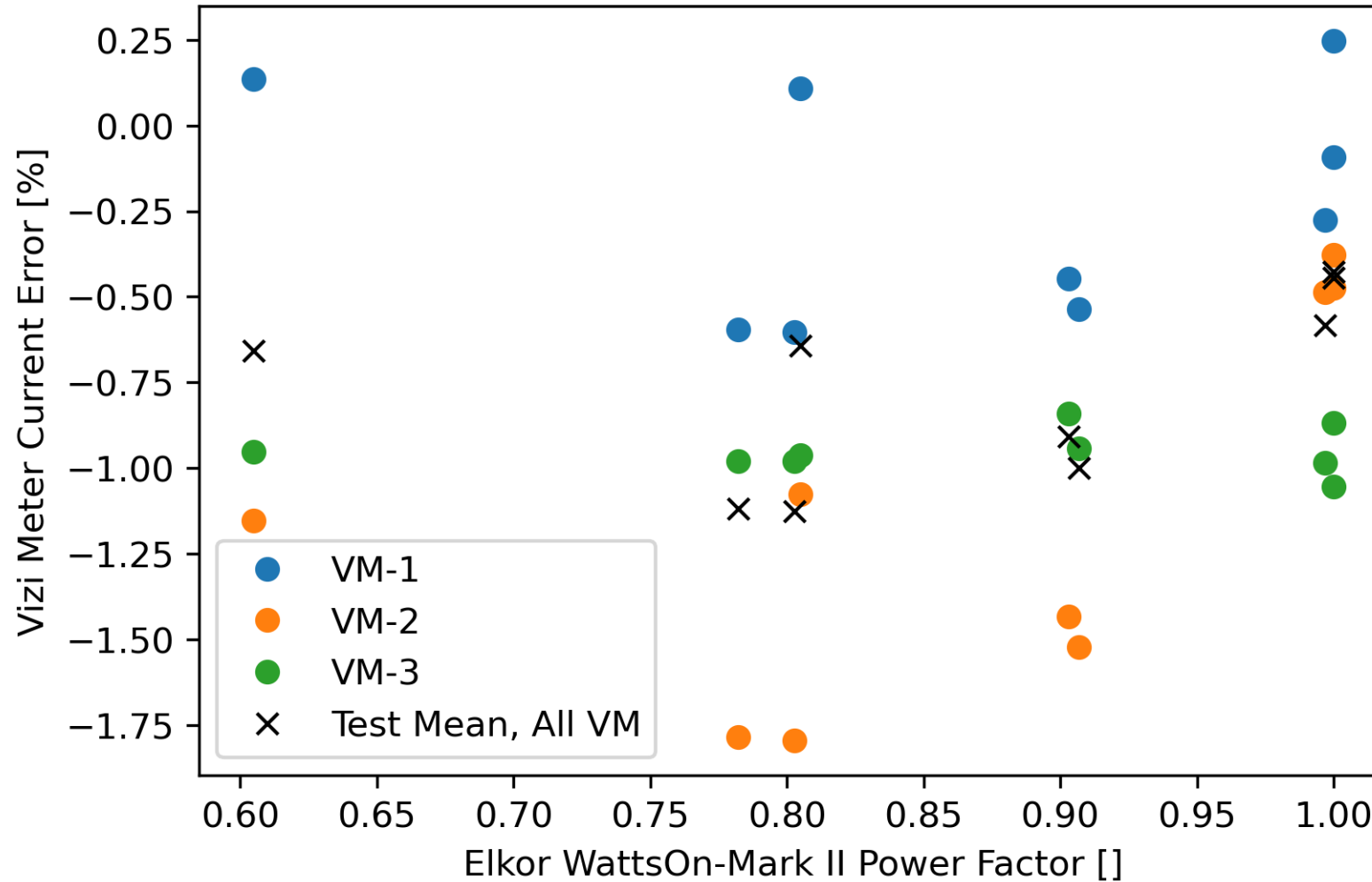
NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Vizi Meter Current Error vs. Current ($\text{Current} \geq 4.99\text{A}_{\text{RMS}}$)



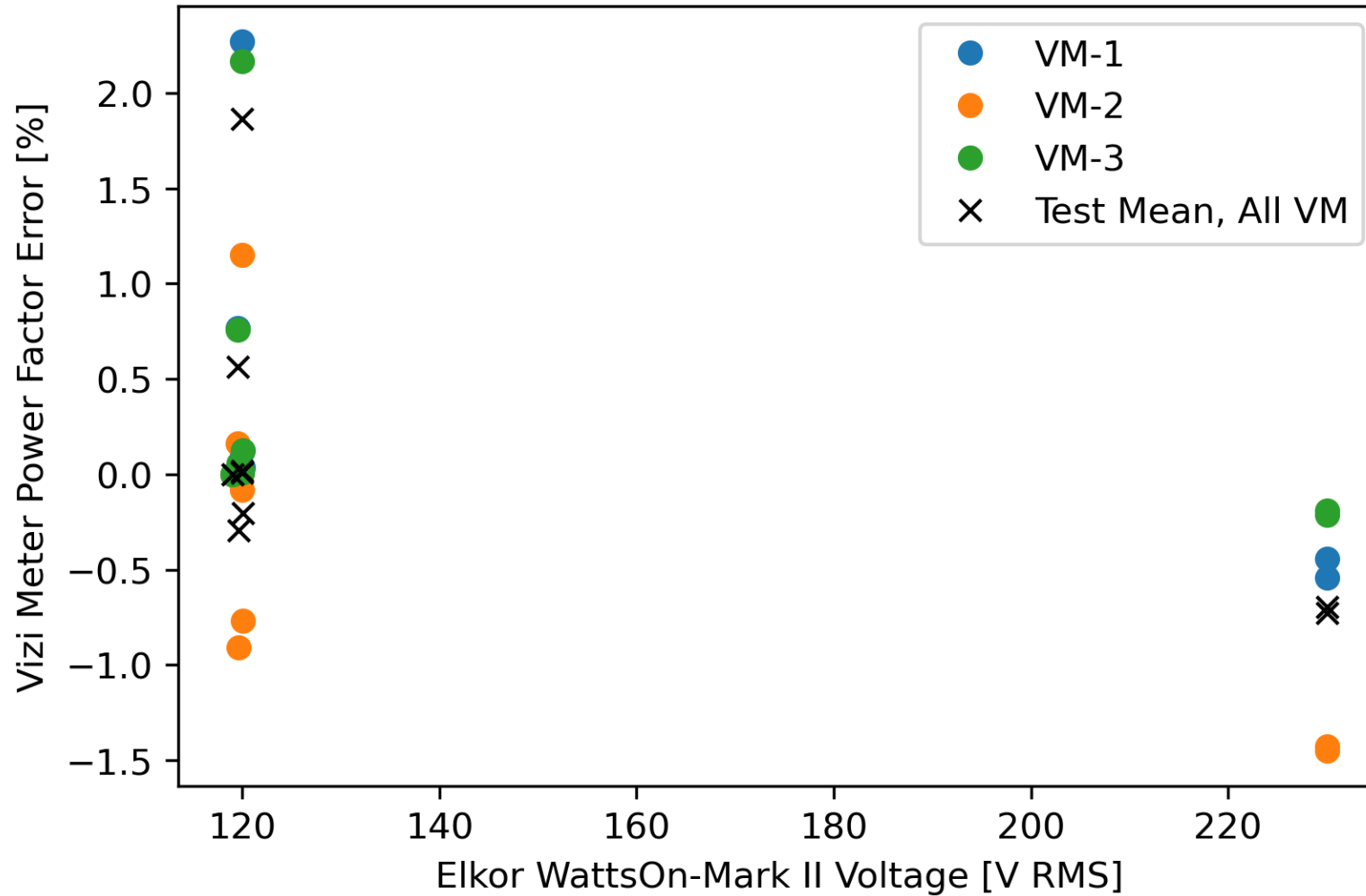
NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Vizi Meter Current Error vs. Power Factor (Current $\geq 4.99A_{RMS}$)



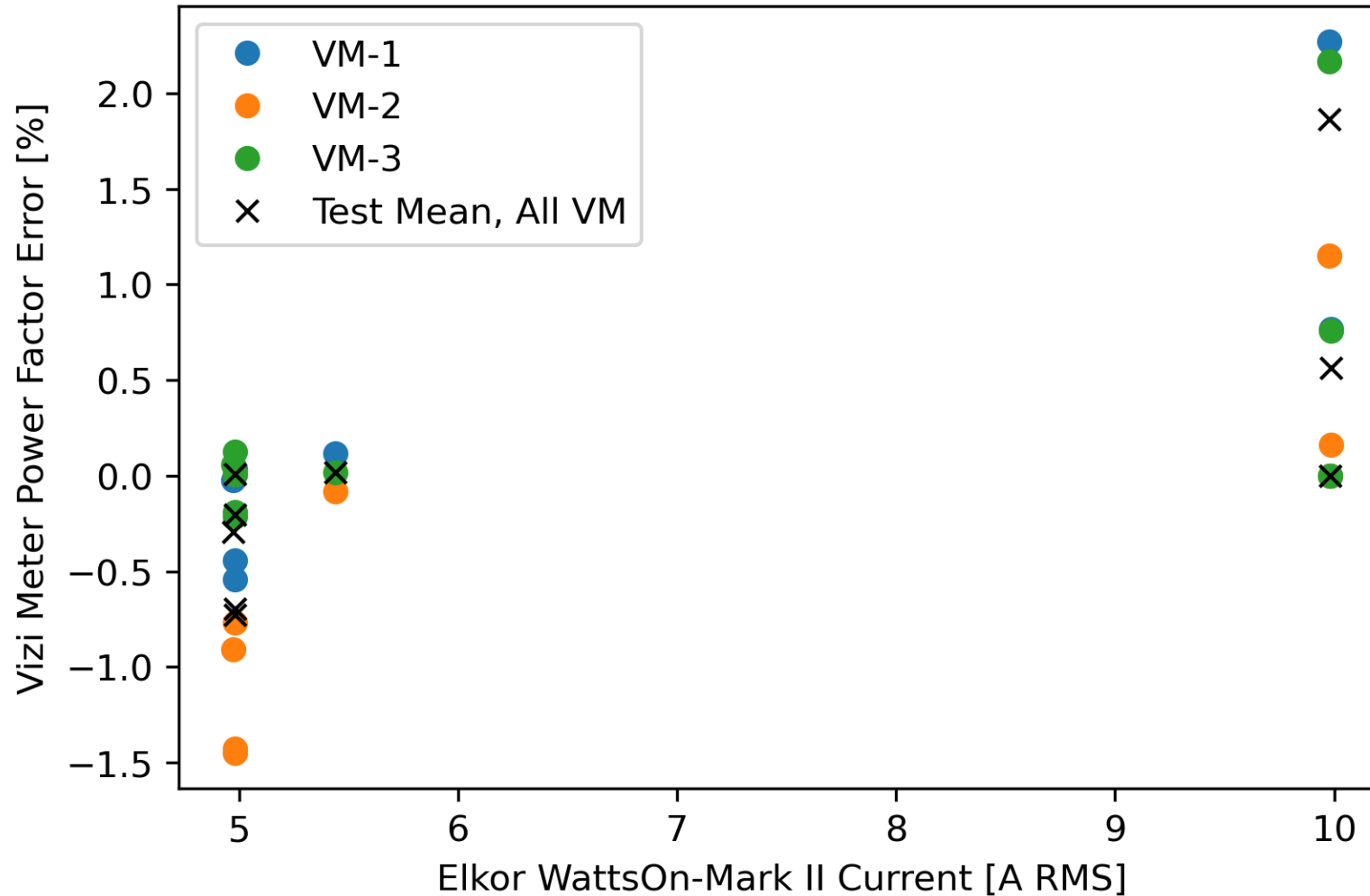
NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Vizi Meter Power Factor Error vs. Voltage (Current $\geq 4.99A_{RMS}$)



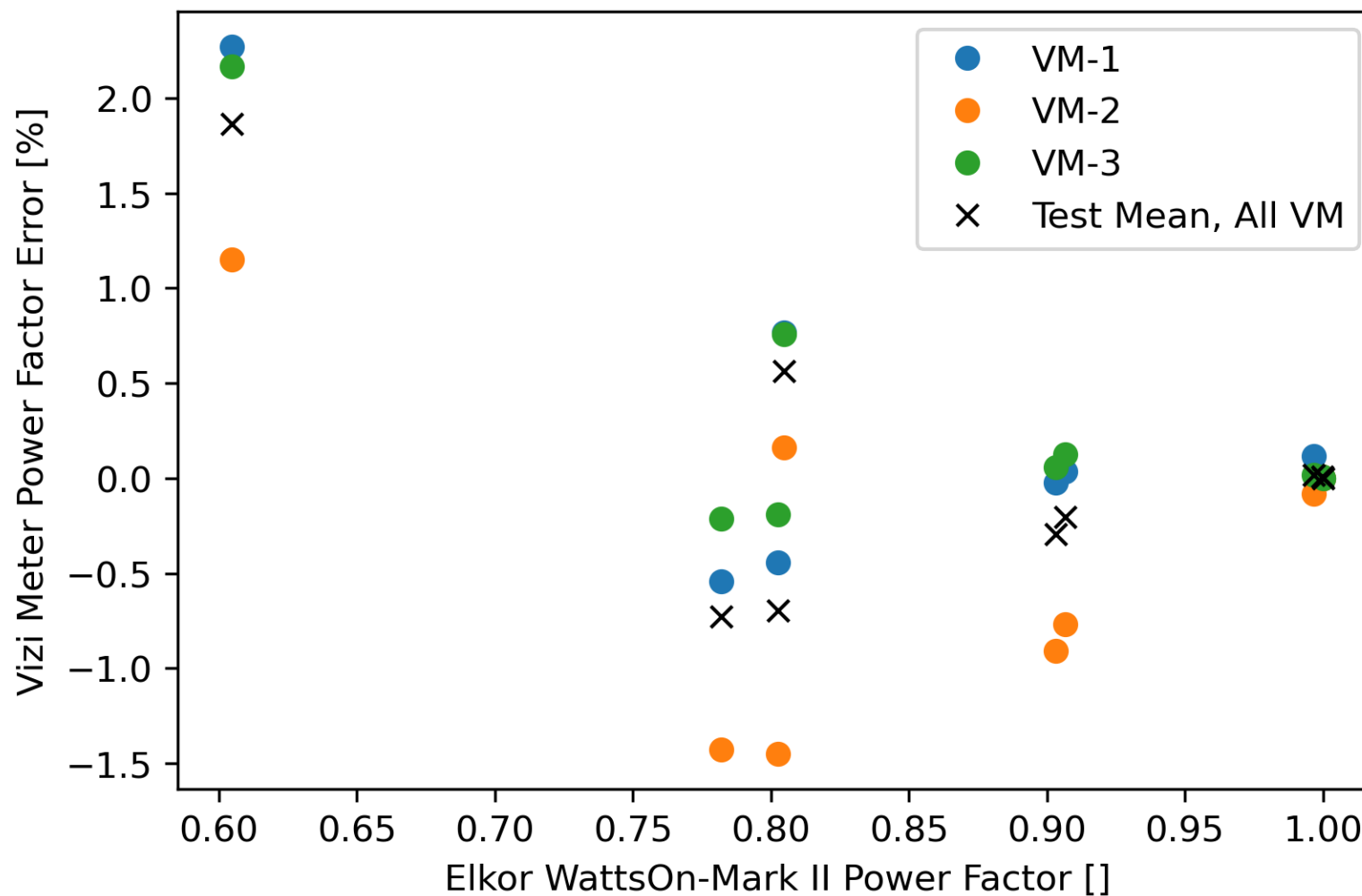
NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Vizi Meter Power Factor Error vs. Current (Current $\geq 4.99A_{RMS}$)



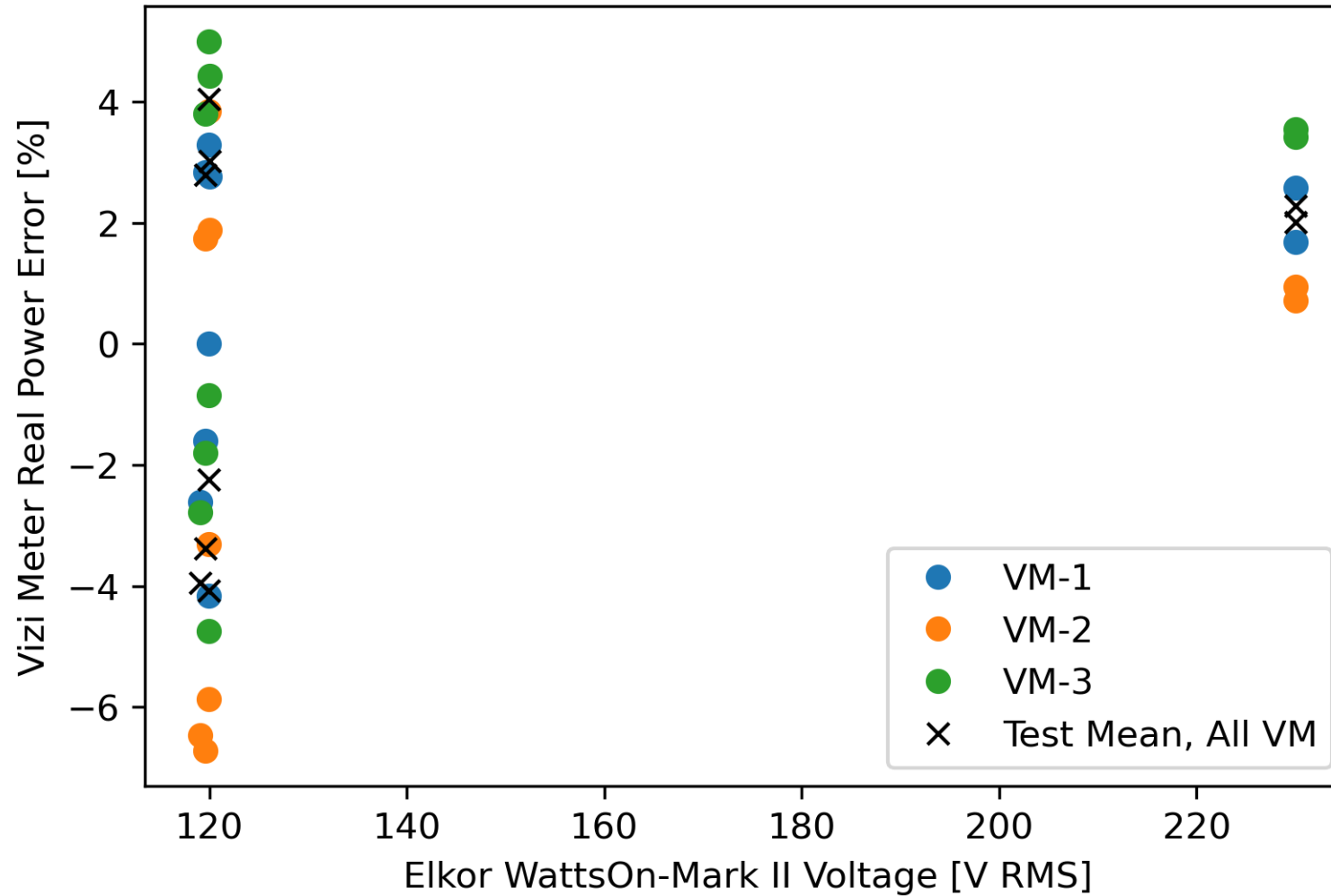
NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Vizi Meter Power Factor Error vs. Power Factor (Current $\geq 4.99 A_{RMS}$)



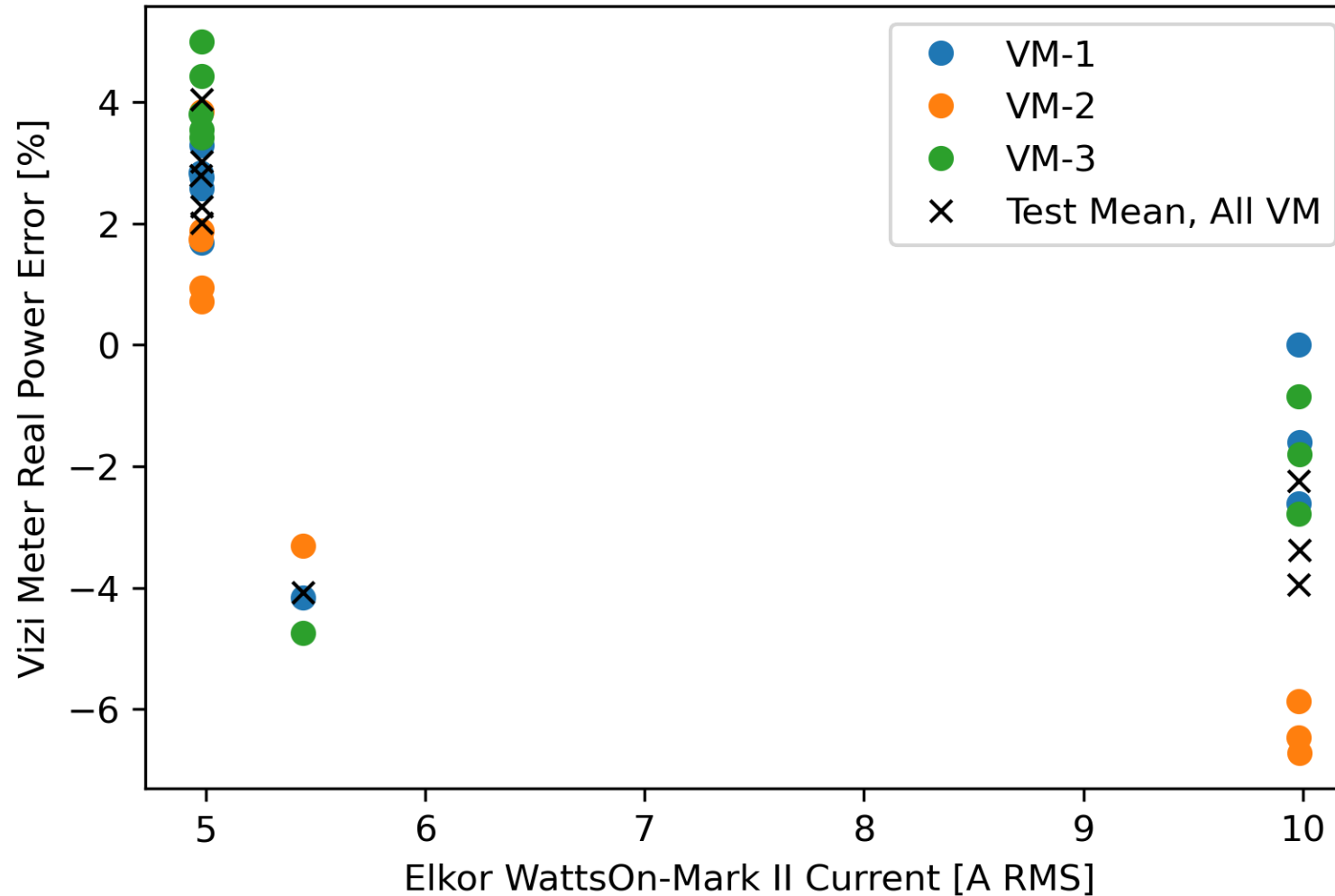
NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Vizi Meter Real Power Error vs. Voltage (Current $\geq 4.99A_{RMS}$)



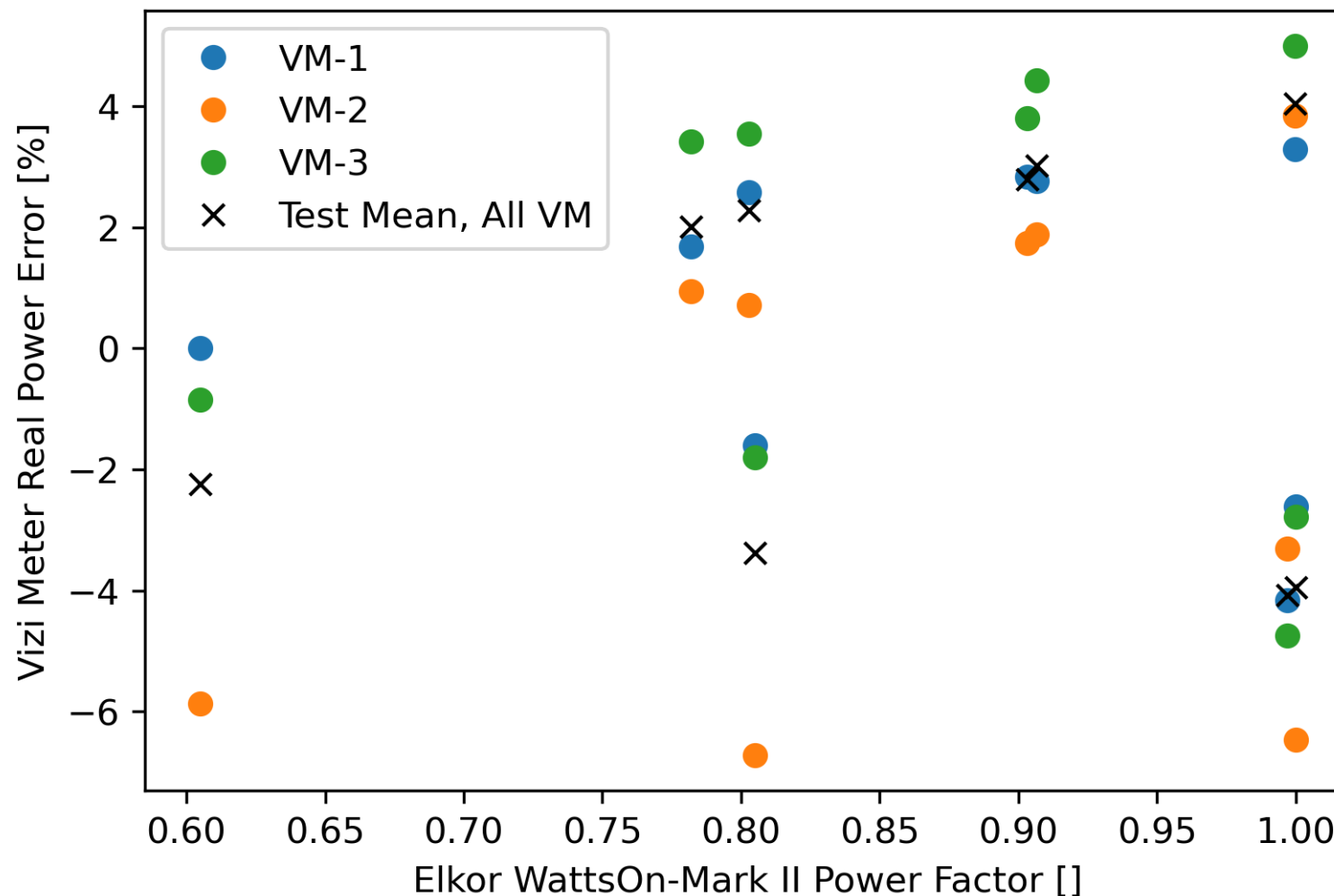
NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Vizi Meter Real Power Error vs. Current (Current $\geq 4.99\text{A}_{\text{RMS}}$)



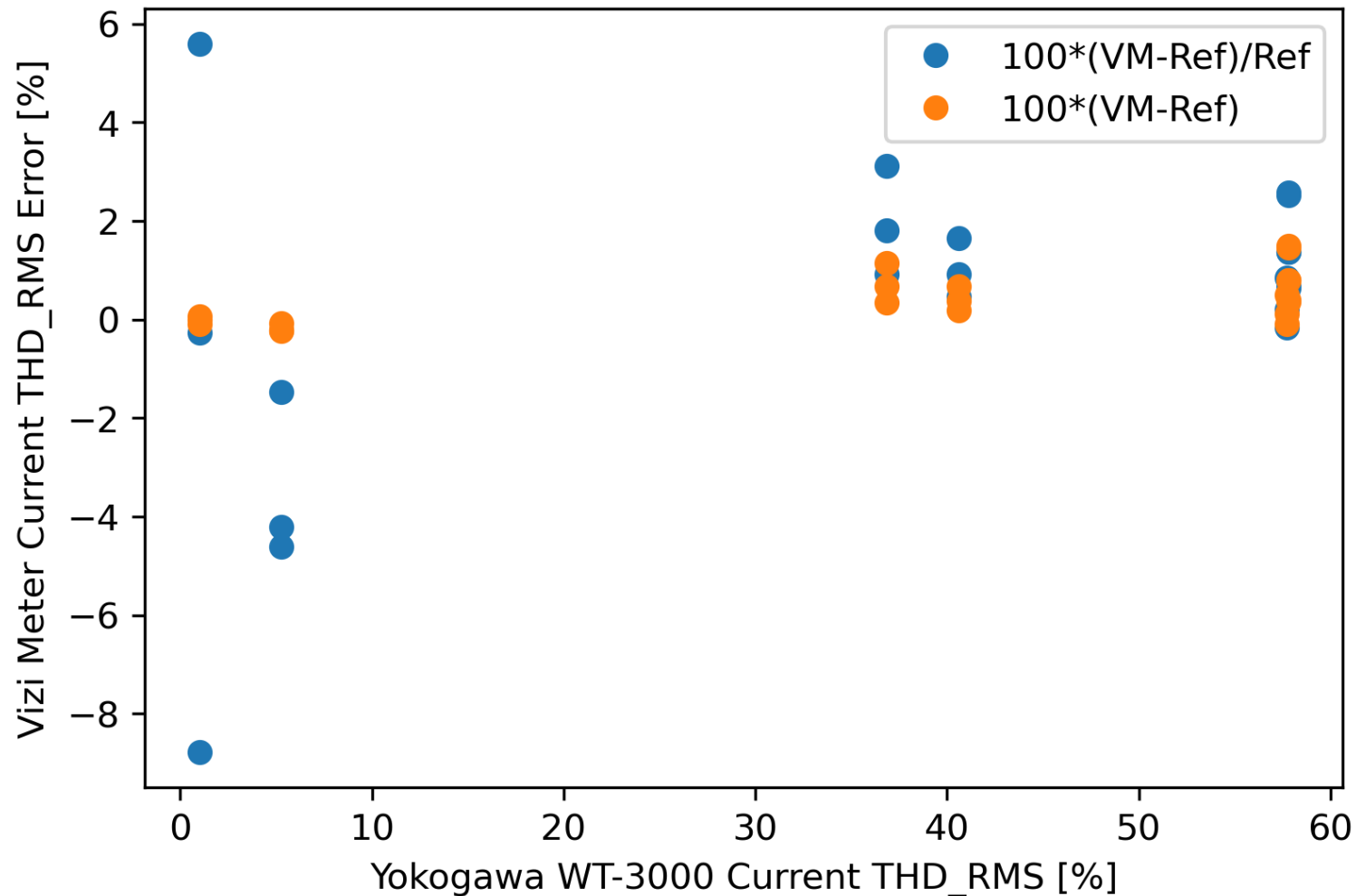
NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Vizi Meter Real Power Error vs. Power Factor (Current $\geq 4.99A_{RMS}$)



NOTE: Vizi recommended meter current range is 5-100 A_{RMS}

Vizi Meter Current THD_{RMS} vs. Current THD_{RMS} (Current $\geq 4.99\text{A}_{\text{RMS}}$)



NOTE: It was unclear how to calculate percent error between two THD_{RMS} values, which are percentages (out of 100) themselves. The blue dots above were calculated with the standard percent error method used throughout the rest of the analysis, and the orange dots were calculated with an absolute difference method.

Thank You

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