



Power Quality Health Index

Tony Murphy
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Motivation

- How can we track and implement processes for continuous improvement in PQ?
- How can we best interact with customers to show a concern and understanding of their PQ needs and for resolving PQ issues?

Process

- Develop candidate metrics
- Test metrics using a small sample of industrial customers
 - Are they understandable and meaningful?
 - What are likely outcomes?
 - How difficult are they to produce?

Why have a composite PQ Health Index?

- PQ is a significant cause-and-effect business driver
- Moves corporate power delivery metrics to a tier beyond “reliability”
- Creates an understandable business metric
- Promotes relationship growth with consumers
- Provides organizational motivation to improve the underlying causes of poor PQ
- Supports the creation of secondary metrics to identify and correct emerging issues

What are the attributes of a good composite index?

- Facilitates tracking of an absolute number – not a relative value
- Creates a metric that is tightly aligned with customer PQ “business impact”

PQHI Dimensions

- Harmonics
- Flicker
- Unbalance
- Regulation
- Disturbances

PQHI – Base Measurements

- **Harmonics** – Average of the THDs for each phase
- **Flicker** – Average of the PSTs for each phase
- **Unbalance** – Ratio of Neg Seq to Pos Seq Voltage (S2/S1)
- **Regulation** – Average of the LL voltages for each phase
- **Disturbances** – Sags or swells that result in a measurable loss-of-load

Weekly Pass/Fail Metrics Flow Into Periodic Reporting

Monthly Reporting

Count of Weekly
Pass / Fail Status



Monthly Report

Good = All Pass

Warning = 1 Fail

Alert = > 1 Fail

Annual Reporting

Count of Monthly
Alerts



Annual Report

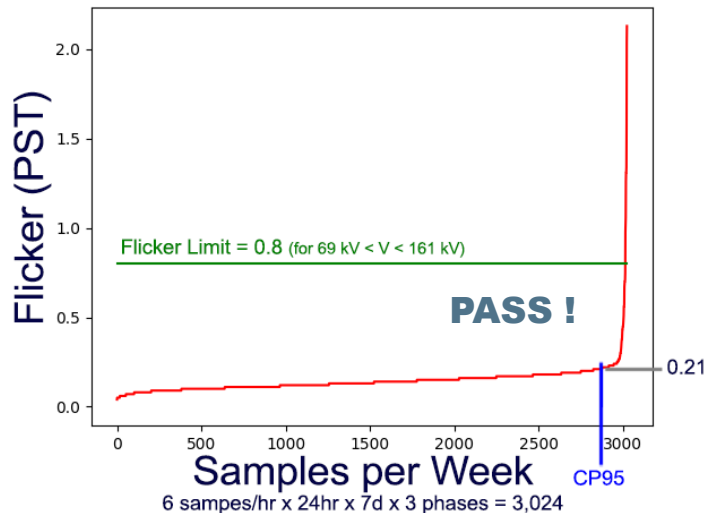
Good = All Pass

Warning = 1 Monthly Alert

Alert = > 2 Monthly Alerts

CP95 Is Used to Identify Significant PQ Issues

Limits		THD	PST	VUB
		IEEE 519	IEEE 1453	IEC 61000-3-13
	$V \leq 1.0$ KV	8.0%	1.0	2.0%
	1 KV $< V \leq 69$ KV	5.0%	0.9	1.8%
	69 KV $< V \leq 161$ KV	2.5%	0.8	1.4%
	161 KV $< V$	1.5%	0.8	0.8%



- Cumulative Probability (CP) of 95% statistically separates the normal from the abnormal.
- CP95 value of ten minute intervals over weekly period standard methodology
- CP95 is a pass-fail metric
- There are predictive insights to be gained from study of the top 5%

Test Sample: 29 Customers from 6 Sectors

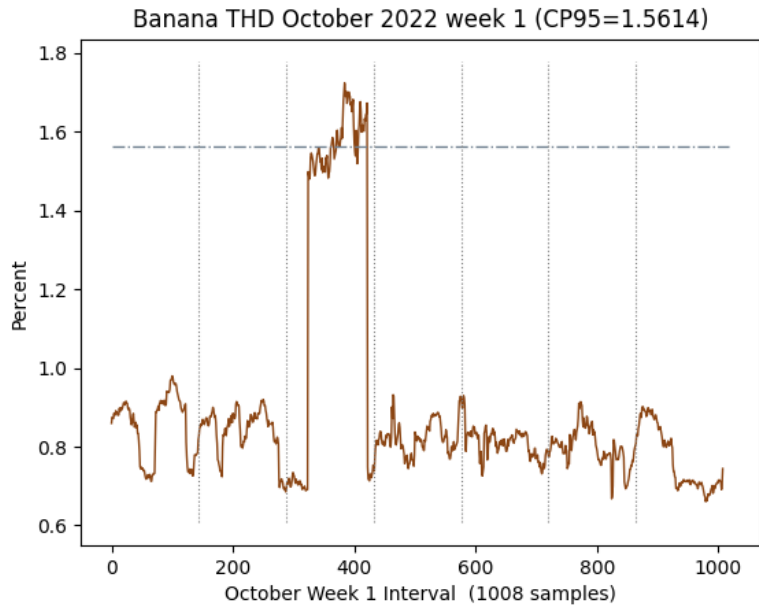
- Aluminum Rolling Mills [3]
- Chemical Plants [6]
- Inverter Based Resources [4]
- Federal Installations [4]
- Paper Mills [4]
- Steel Mills [8]

Interval and waveform data for October 2022 used.

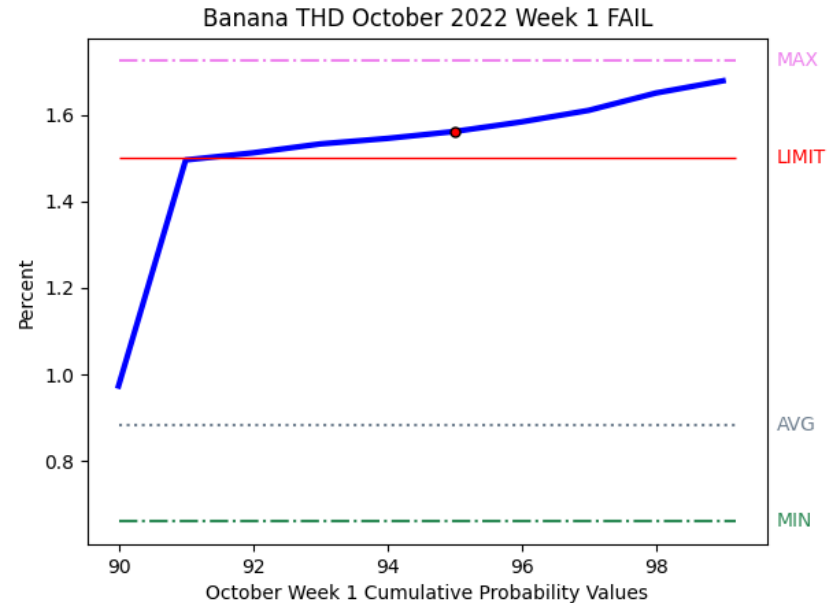
Many customers selected where known to have power delivery challenges.

THD Failing Example

CP95 Limit = 2.5% for > 69 kV
1.5% for > 161 kV



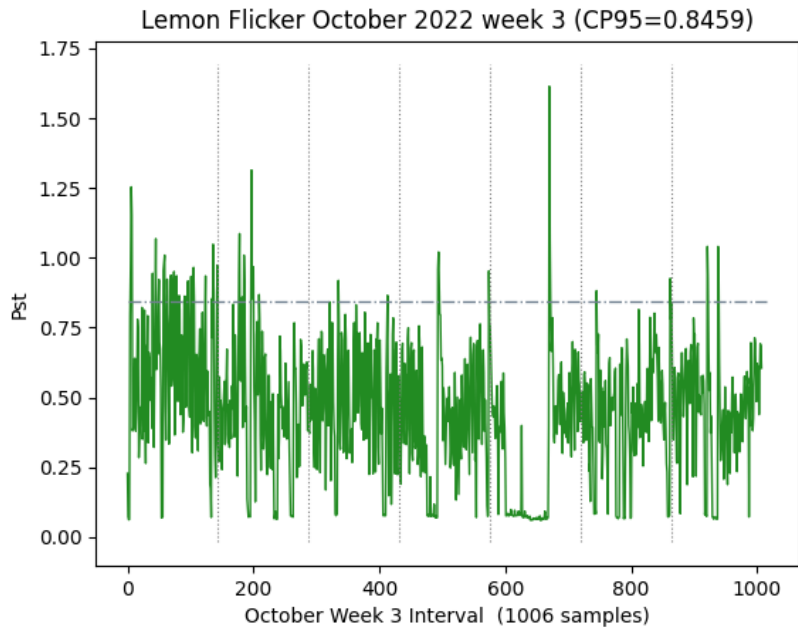
CP95



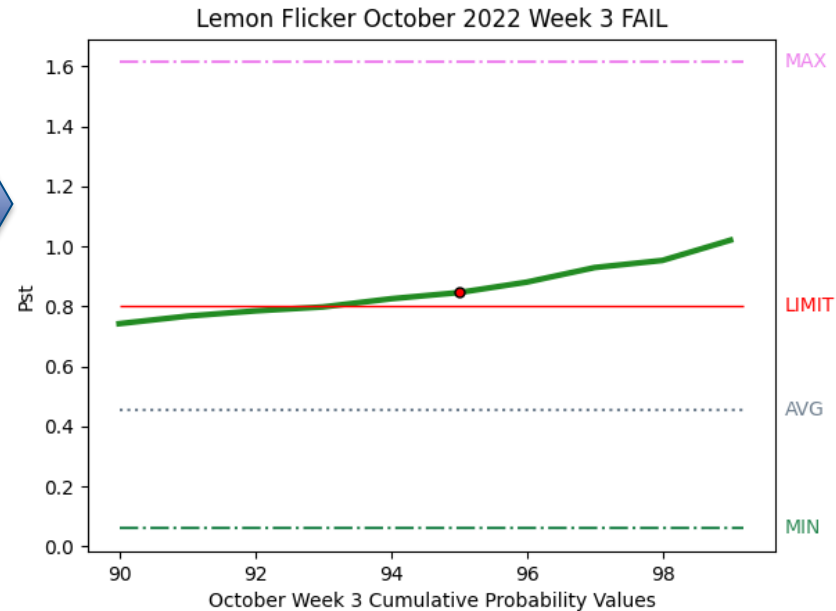
There were 37 (32%) failing THD metric weeks in October.

Flicker Failing Example

CP95 Limit = 0.8 for > 69 kV



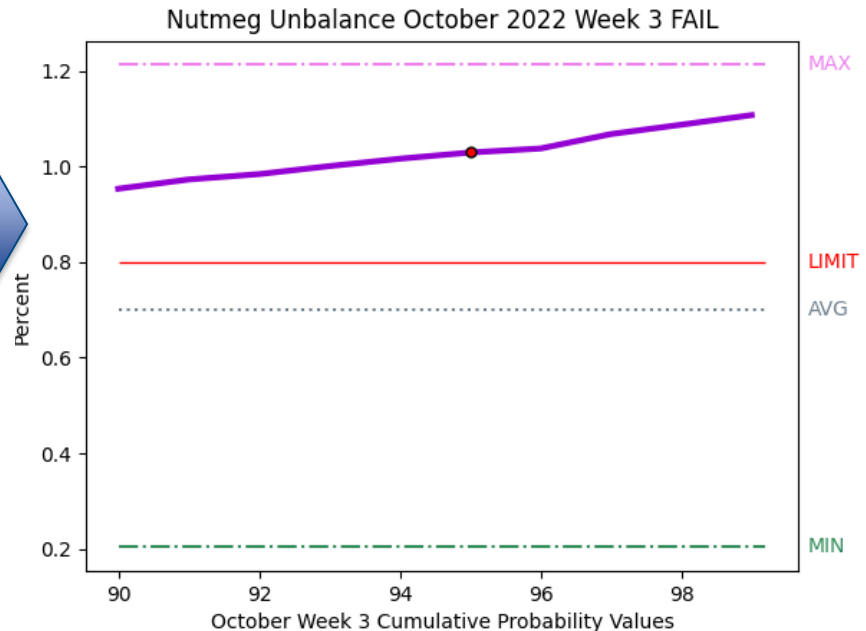
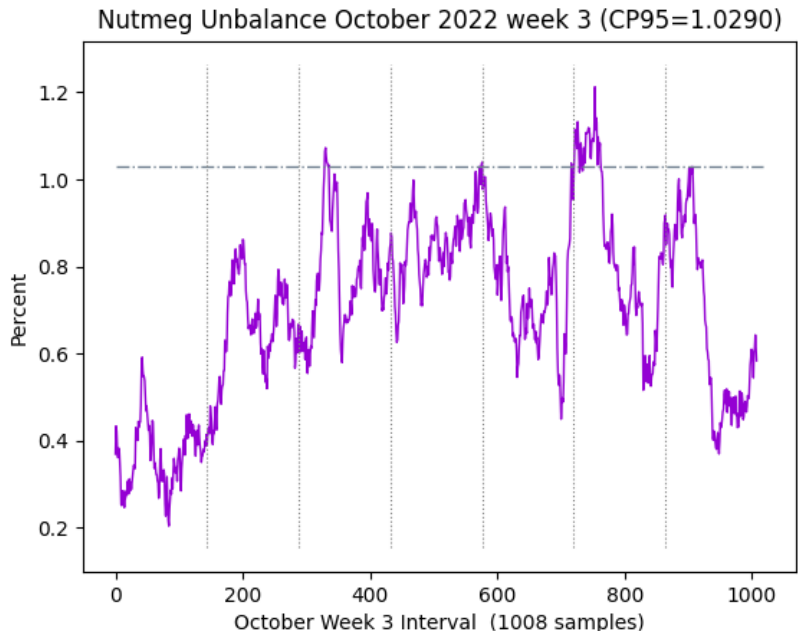
CP95



There were 17 (15%) failing flicker metric weeks in October.

Unbalance Failing Example

CP95 Limit = 1.4% for > 69 kV
0.8% for > 161 kV

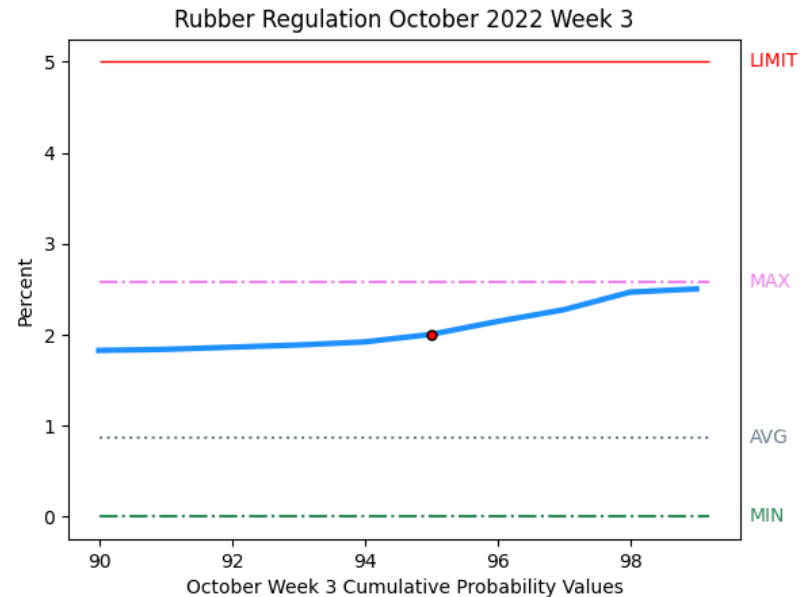
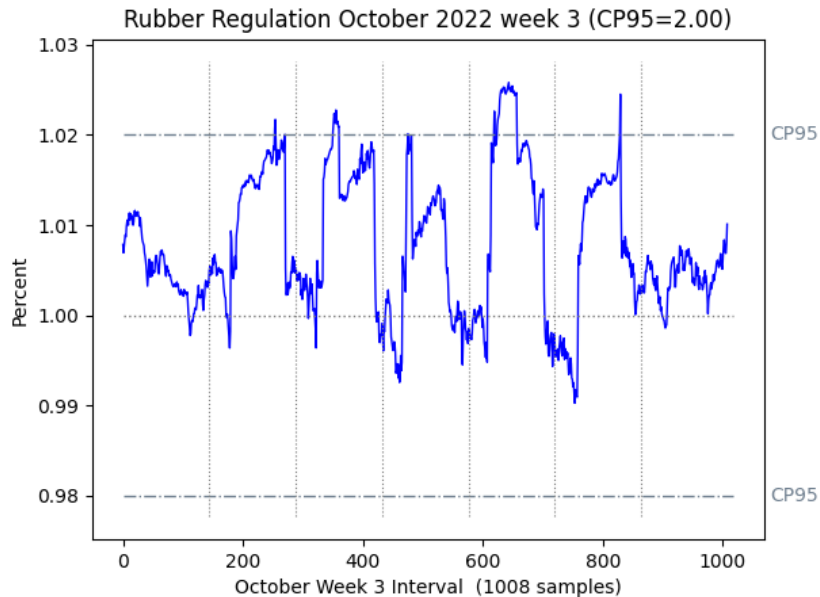


There were 8 (7%) failing unbalance metric weeks in October.

Regulation Example

CP95 Limit = +/- 3% Nominal

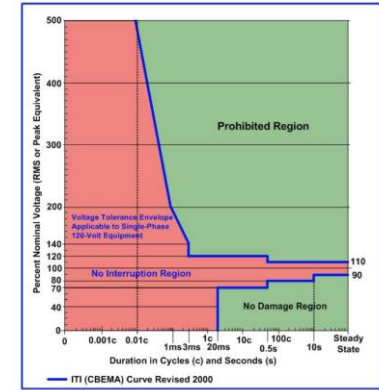
Rubber nominal = 166 kV



There were no failing regulation metric weeks in October.

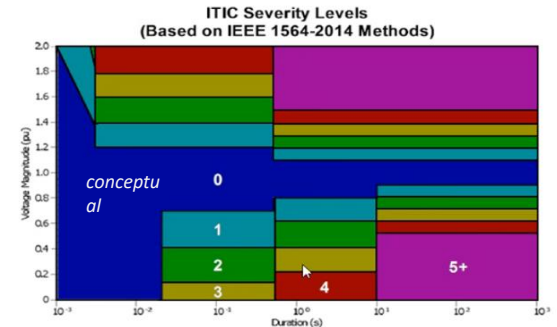
Disturbances – Severity Level Approach

- Severity level approach did not yield meaningful results
- PQ waveform event records are short – often about 0.25 seconds
- Sustained sag and swell events are rare on the transmission system
- A pre-defined “severity level” approach does not adequately measure the adverse impact of low-severity sags to sag-sensitive industry

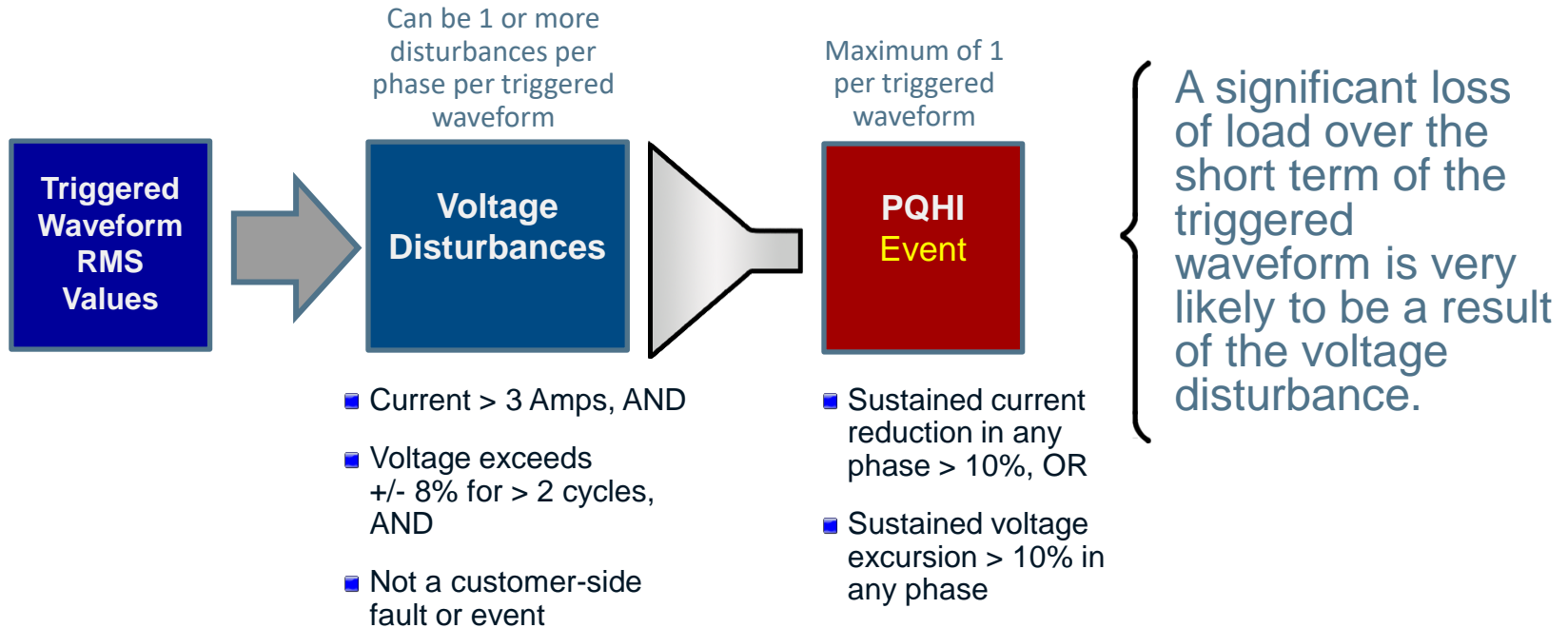


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Disturbance metric based on loss-of-load

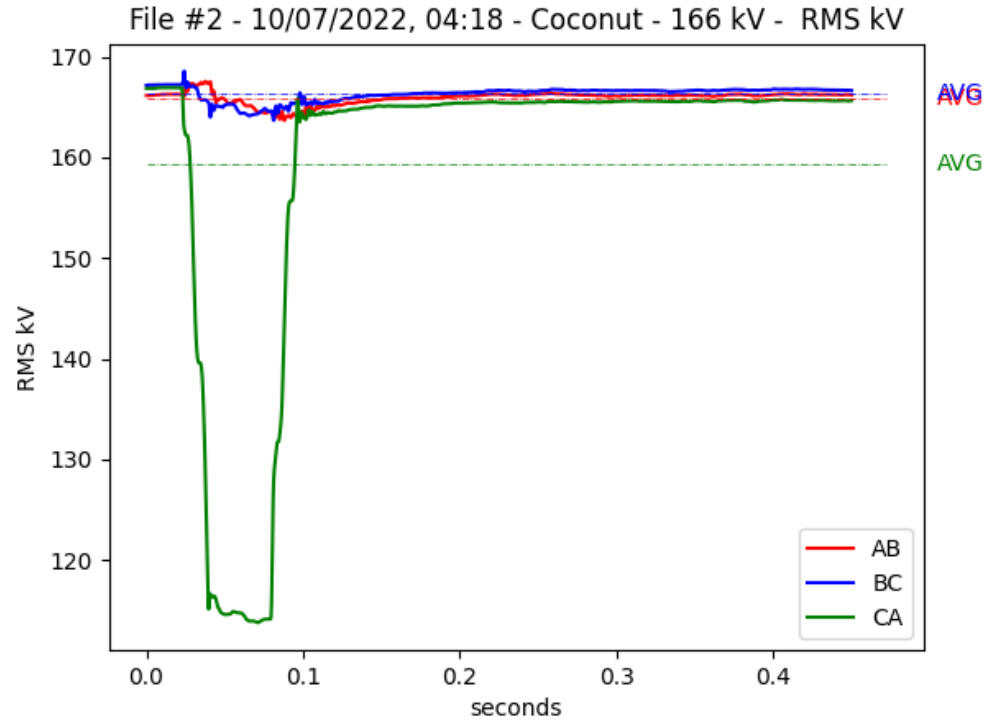
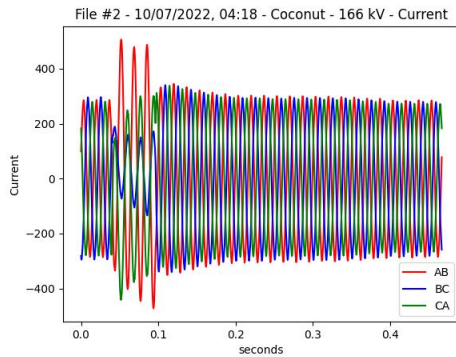
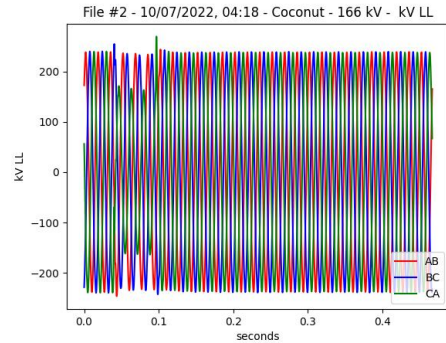


Capturing voltage disturbances provides PQ visibility below the EVENT level.

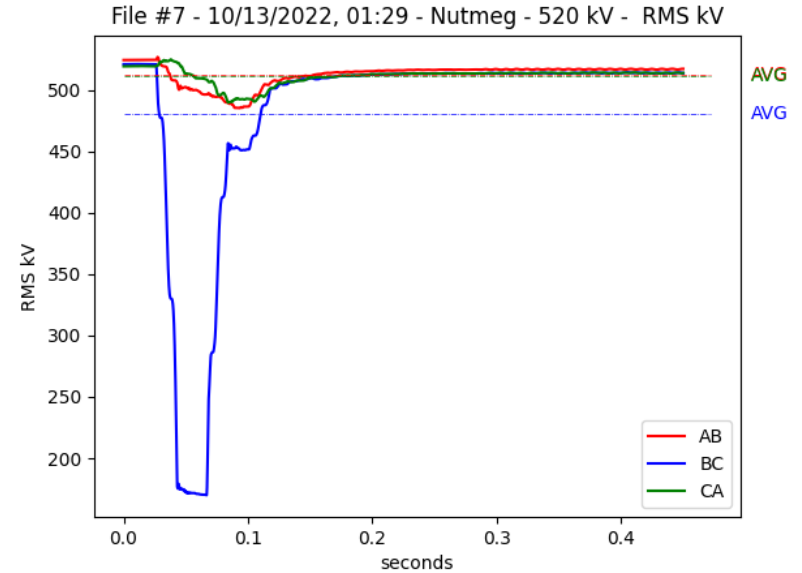
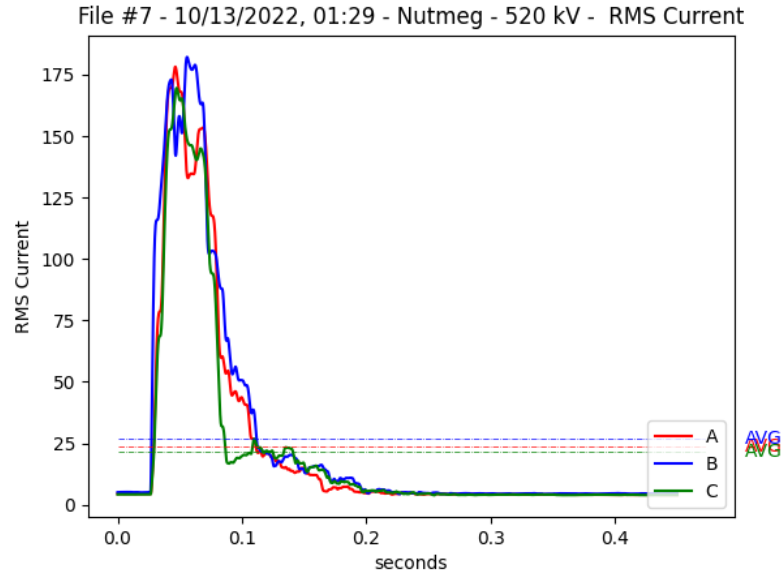
How small can a voltage disturbance be to have ANY significance?

Disturbance Example

Criterion = Loss of current > 10%
Following a sag/swell



No Failing Sags or Swells Found in October



Example of a customer-side non-qualifying event.






PQHI

Customer PQ Health Scorecard

A Monthly PQ Status Report for Large Customers

- Demonstrates a corporate focus on PQ
- Stop-light-based and non-technical
- “No numbers” to prevent inappropriate comparisons
- Meaningful depth behind each stop-light for detailed customer discussion if needed
- Can be made part of web portal for industrial customers

Customer Monthly **Scorecard**

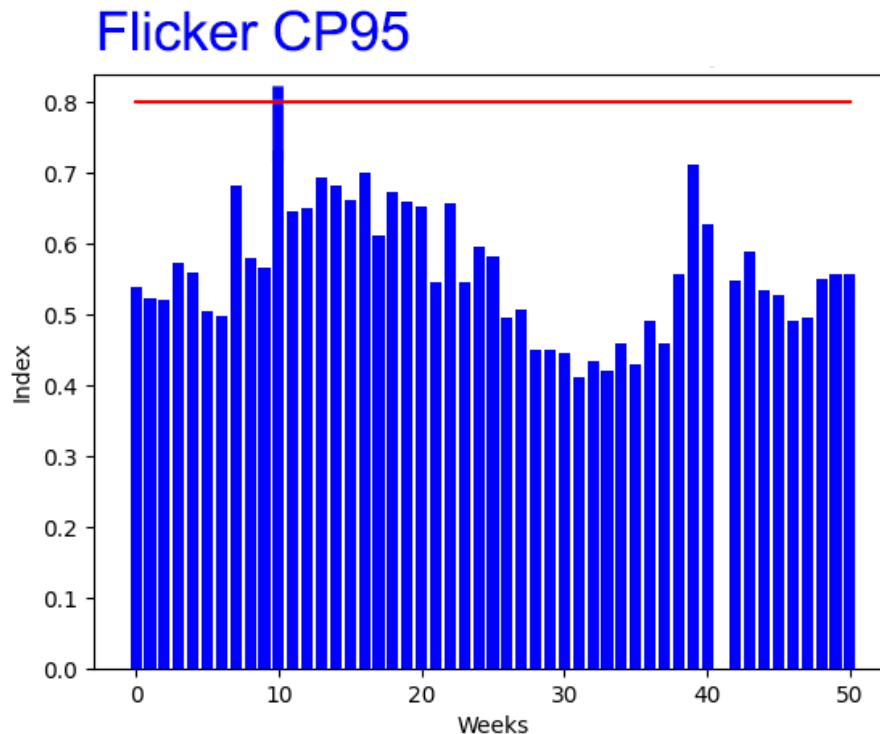
Voltage Regulation	
Voltage Balance	
Harmonic Performance	
Flicker Performance	
Disturbance Performance	

Monthly Performance Indicator

 All Good  1 Week Poor  >1 Week Poor

Annual PQ Health Report for Large Customers

- Automatically produced pdf report to support annual customer discussions – especially where there are PQ concerns
- Reveals gap between the weekly measured value and the limit



PQHI

Corporate PQ Health Index

A Simple Corporate Monthly PQ Health Index

- Based on a count of the failing weeks across all 5 PQ dimensions.
- Normalized for the number of customers and the weeks in the period.

$$\text{PQHI} = 54 = 62 / 29 / 4 * 100$$

(for the test sample)

Short term goal 40

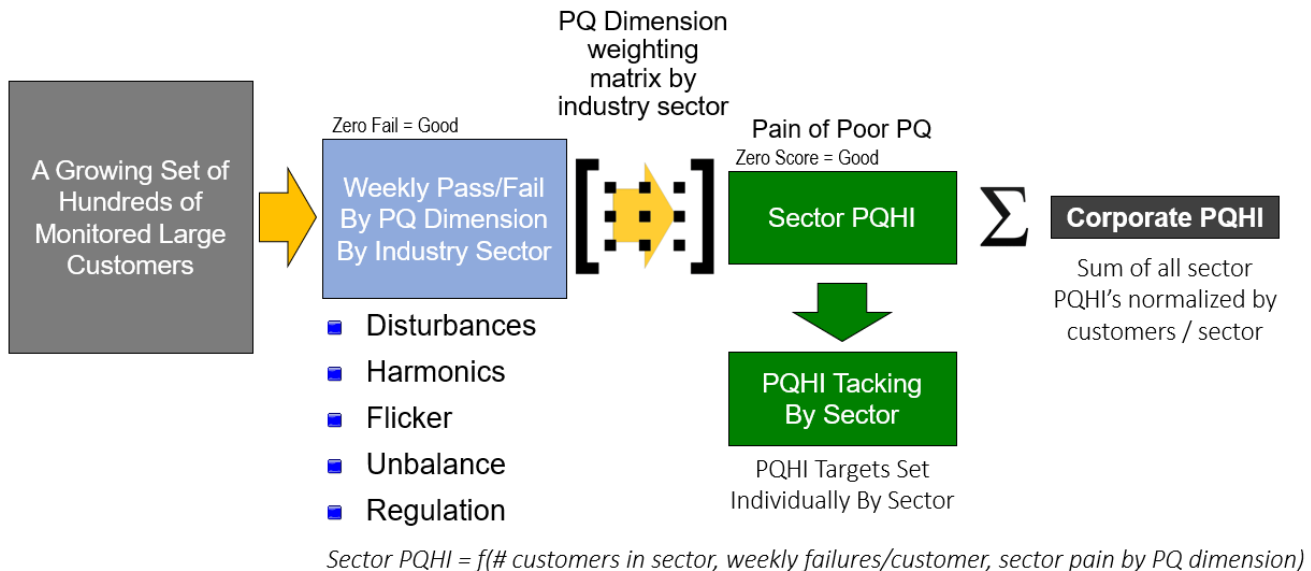
Medium term goal 10

Long term goal 1 = 4 events across all 5 PQ dimensions per 100 customers



A More Sophisticated Monthly PQ Health Index

- Based on weekly metrics
- Recognizes that industry sectors are impacted differently by the 5 dimensions of power quality
- Tacking and improvement targets set by sector.



PQHI Score – Normalize Weekly Counts

	#
Aluminum	3
Chemical	6
DER	4
Federal	4
Paper	4
Steel	8

	THD	Flr	UnBal	Reg	Dist
Aluminum	0	0	0	0	0
Chemical	6	0	2	0	0
DER	8	0	3	0	0
Federal	2	0	0	0	0
Paper	6	0	0	0	0
Steel	15	17	3	0	0



	THD	Flr	UnBal	Reg	Dist
Aluminum	0.00	0.00	0.00	0.00	0.00
Chemical	1.00	0.00	0.33	0.00	0.00
DER	2.00	0.00	0.75	0.00	0.00
Federal	0.50	0.00	0.00	0.00	0.00
Paper	1.50	0.00	0.00	0.00	0.00
Steel	1.88	2.12	0.38	0.00	0.00

Failing week count
for the month

Sector Count Normalization
(divide by customers in sector)

PQHI Score – Apply Impact Weighting

Aluminum	10	10	30	10	40
Chemical	15	15	20	20	30
DER	0	0	50	0	50
Federal	20	20	20	20	20
Paper	10	10	20	30	30
Steel	5	5	40	10	40

100 points
distributed across
the PQ Dimensions

Sector Weighting Matrix

	THD	Flr	UnBal	Reg	Dist
Aluminum	0.00	0.00	0.00	0.00	0.00
Chemical	1.00	0.00	0.33	0.00	0.00
DER	2.00	0.00	0.75	0.00	0.00
Federal	0.50	0.00	0.00	0.00	0.00
Paper	1.50	0.00	0.00	0.00	0.00
Steel	1.88	2.12	0.38	0.00	0.00



	THD	Flr	UnBal	Reg	Dist
Aluminum	0.00	0.00	0.00	0.00	0.00
Chemical	15.00	0.00	6.67	0.00	0.00
DER	0.00	0.00	37.50	0.00	0.00
Federal	10.00	0.00	0.00	0.00	0.00
Paper	15.00	0.00	0.00	0.00	0.00
Steel	9.38	10.62	15.00	0.00	0.00

Sector Normalized Counts

Sector Scores

PQHI Score – Sum Results

	THD	Flr	UnBal	Reg	Dist
Aluminum	0.00	0.00	0.00	0.00	0.00
Chemical	15.00	0.00	6.67	0.00	0.00
DER	0.00	0.00	37.50	0.00	0.00
Federal	10.00	0.00	0.00	0.00	0.00
Paper	15.00	0.00	0.00	0.00	0.00
Steel	9.38	10.62	15.00	0.00	0.00

Σ

Aluminum	0
Chemical	21.6
DER	37.5
Federal	10.0
Paper	15.0
Steel	35.0

Σ

Sector Scores

PQHI
OCTOBER 2022

119.1

↓ **GOOD**

Using uniform weighting the PQHI score is 209.2

