POWER
GRID-RX INC
PRESCRIPTIONS FOR THE POWER GRID IN THE DIGITAL AGE

Intro To Power Quality

Presentation Date: 2019-11-04

Prepared By: Theo Laughner, PE

Outline

- Power Quality Definition
- PQ – Why Now?

- Grid Modernization Implications
- Susceptibility of Loads

- Standards
- Steady State Characteristics
- Events

POWER GRID-RX INC

Power Quality Definition

- From Wikipedia - Power quality determines the fitness of electric **power** to consumer **devices**.

- Theo’s definition – Study of mangled waveforms.

PQ – Why Now? Change.

- Grid is changing
  - Renewables
  - Informatics (aka Smart)
- Customers are changing
  - Expectations
  - Supply (Rooftop Solar)
  - Energy Efficiency (Demand)

"It is possible to have perfectly reliable, crappy power" -me

Grid Modernization Implications

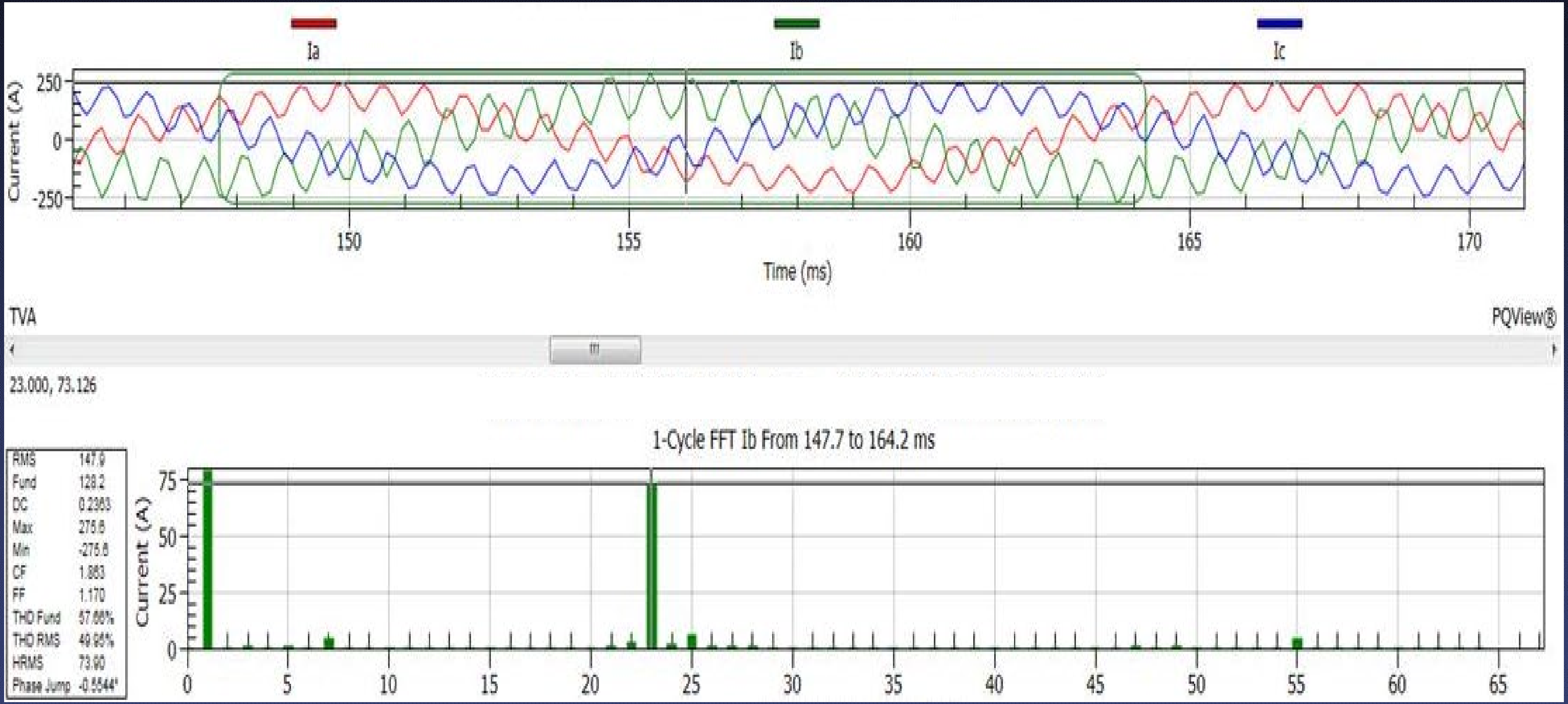
POWER
GRID-RX INC

Grid Modernization Implications

- Power Electronic Sources
  - DC -> AC Conversion is noisy
- Capacitor Deployment
  - Resonance Issues
- Demand Response
  - Voltage Unbalance

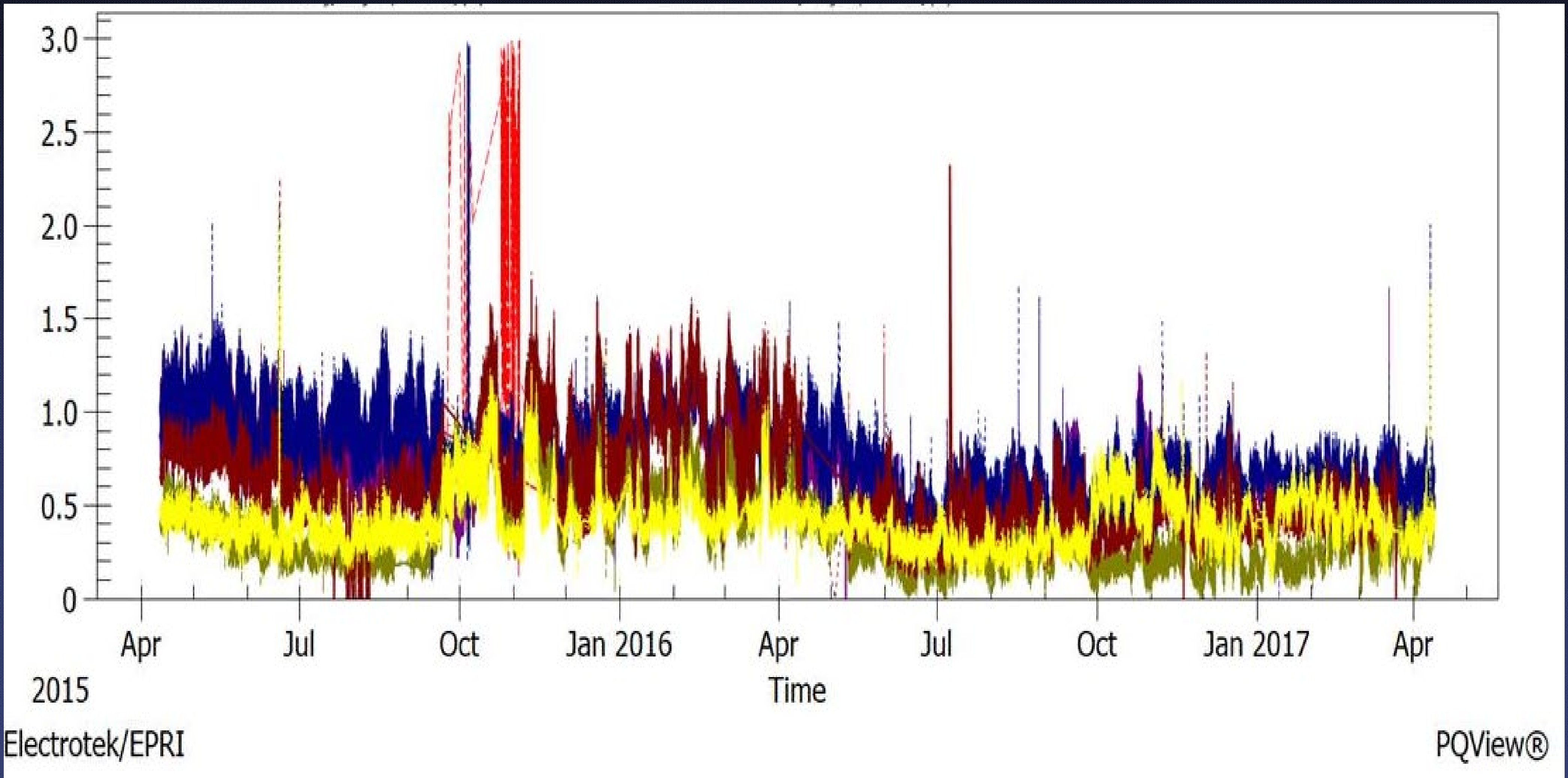
POWER GRID-RX INC

Resonance



Ia
Ib
Ic
Current (A)
250
0
-250
150
155
160
165
170
Time (ms)
TVA
PQView®
23.000, 73.126
1-Cycle FFT Ib From 147.7 to 164.2 ms
RMS 147.9
Fund 128.2
DC
Max
Min
CF
FF 1.170
THD Fund
THD RMS
HRMS 73.90
Phase Jump
Current (A)
75
50
25
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65

Voltage Unbalance

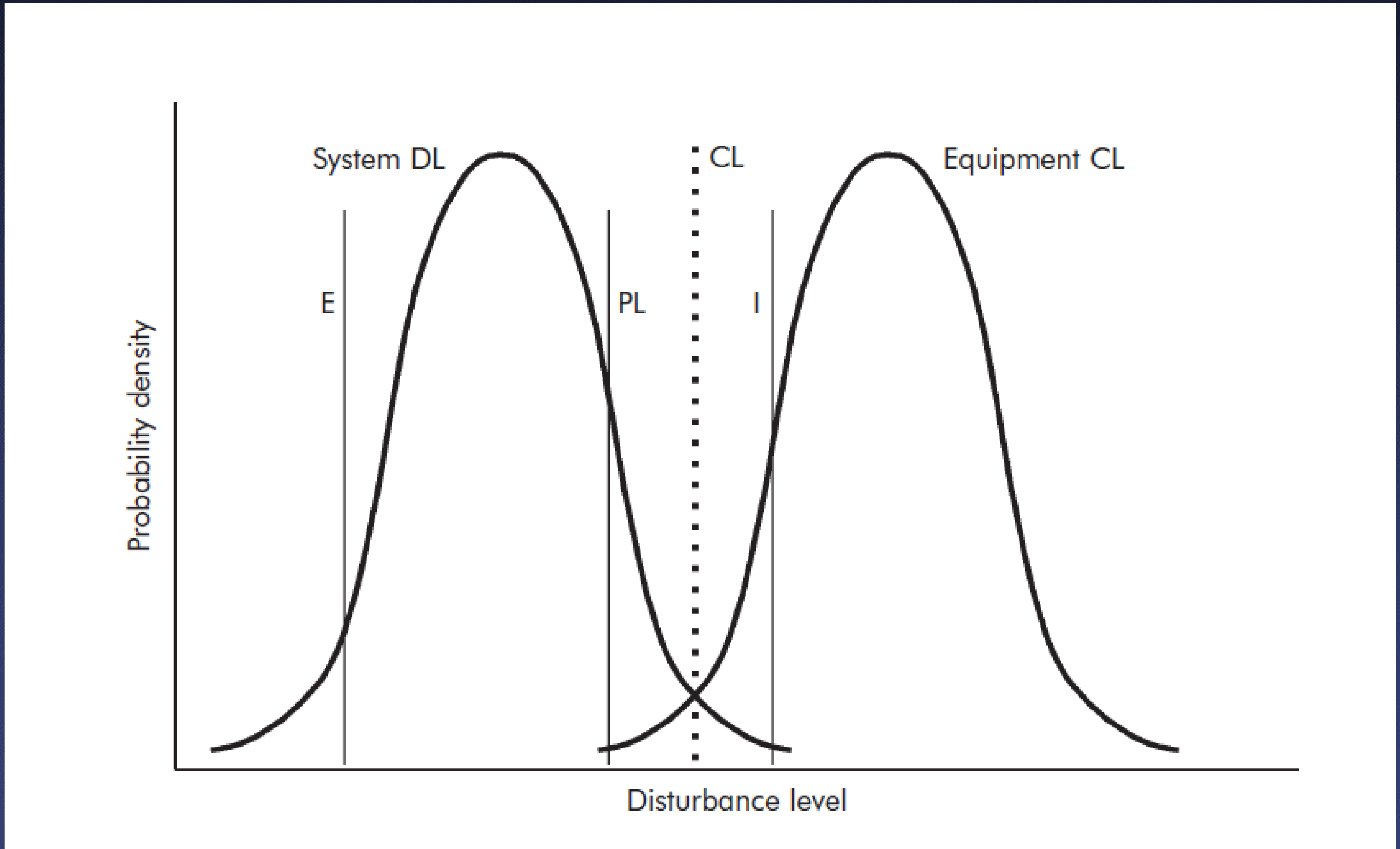


POWER GRID-RX INC

Susceptibility of Loads

POWER
GRID-RX INC

Balance Between System Performance And Equipment Ridethrough



Levels

CL – Compatibility

DL – Disturbance

E – Emission

I – Immunity

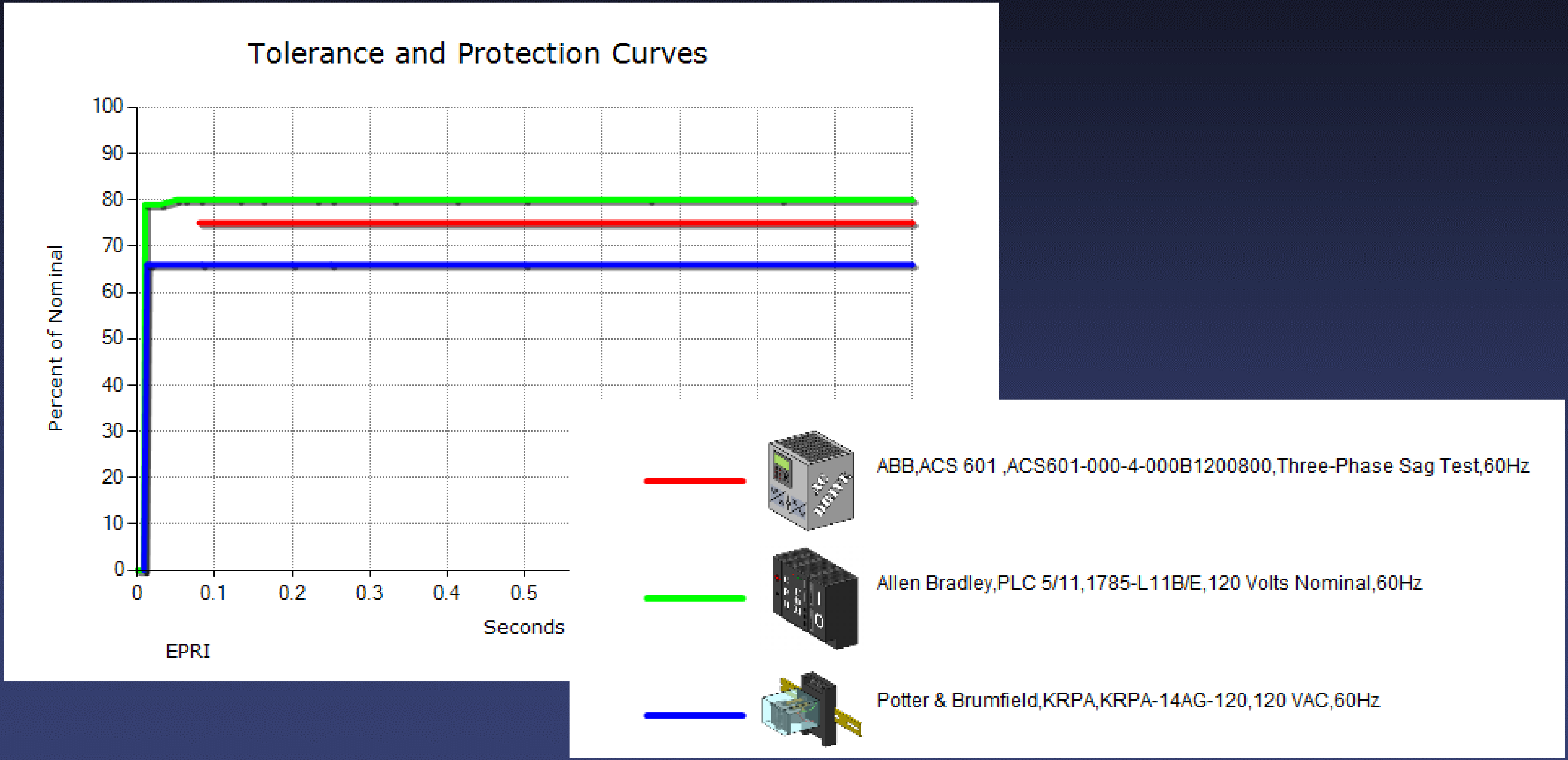
PL – Planning

IEEE 1668 – Load Resiliency

- Recommended Practice for Voltage Sag and Interruption Ride-Through Testing for End Use Electrical Equipment Less than 1000 Volts.
    - Excellent primer on PQ.

- The purpose of this recommended practice is to clearly define test methods and ride-through performance for determining electrical and electronics equipment sensitivity to voltage sags. Analysis of real world sags provides the foundation for both the test methods and the criteria, aligning themselves as closely as possible to the end user's electrical environment. The recommended practice will define the characteristics of the voltage sags depths, durations, phase angle, and vectors required to relate to real world based voltage sag events. The recommended practice will show how different voltage sag testing methods can be used to simulate real world sags. End users will be able to use the recommended practice in their purchase specifications to ensure the required level of performance. In addition, end users can use the voltage sag criteria as a performance benchmark for existing equipment.

Equipment Ridethrough



POWER GRID-RX INC

Standards

- ANSI C84.1 – Standard for Electric Power Systems and Equipment – Voltage Ratings
- IEC 61000 – Electromagnetic Compatibility
- → **IEEE 519** - Recommended Practices and Requirements for Harmonic Control in Electric Power Systems
- IEEE 1100 (Emerald Book) - Recommended Practice for Powering & Grounding Electronic Equipment
- → **IEEE 1159** - Recommended Practice for Monitoring Electric Power Quality
- → **IEEE 1250** - Guide for Service to Equip Sensitive to Momentary Voltage Disturbances
- IEEE 1346 - Recommended Practice for Evaluating Electric Power System Compatibility with Electronic Process Equipment
- → **IEEE 1453** - Recommended Practice for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems
- IEEE 1531 - Guide for Application and Specification of Harmonic Filters
- IEEE C2 – National Electrical Safety Code
- IEEE C62.41 - Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits
- IEEE 1433 – Standard Glossary of Power Quality Terminology
- IEEE 1531 – Guide for the Application and Specification of Harmonic Filters
- IEEE 1564 – Guide for Voltage Sag Indices
- NEMA LA 1 – Surge Arresters
- NEMA LS 1 – Low Voltage Surge Protection Devices
- NEMA PE1 – Uninterruptible Power Systems
- NFPA 70 – National Electrical Code
- NFPA 780 – Lightning Protection Code
- UL 96A - Standard for Safety Installation Requirements for Lightning Protection Systems
- UL 1283 - Standard for Safety Electromagnetic Interference Filters
- UL 1449 - Surge Protective Devices

IEEE 1250

- Serves as a primer to Power Quality for both utility professionals and Industrial Consumers.
- Serves as a directory to other power quality standards.

IEEE 1159

- Serves a definitions document on power quality phenomenon.

Categories			Typical Duration
Transients	Impulsive	Nanosecond	> 50 nanoseconds
		Microsecond	50 nanoseconds to 1 millisecond
		Millisecond	> 1 millisecond
	Oscillatory	Low Frequency	0.3 milliseconds to 50 milliseconds
		Medium Frequency	20 microseconds
		High Frequency	5 microseconds
Short Duration Variations	Instantaneous	Sag	0.5 cycles to 30 cycles
		Swell	0.5 cycles to 30 cycles
	Momentary	Interruption	0.5 cycles to 3 seconds
		Sag	30 cycles to 3 seconds
		Swell	30 cycles to 3 seconds
	Temporary	Interruption	3 seconds to 1 minute
		Sag	3 seconds to 1 minute
		Swell	3 seconds to 1 minute

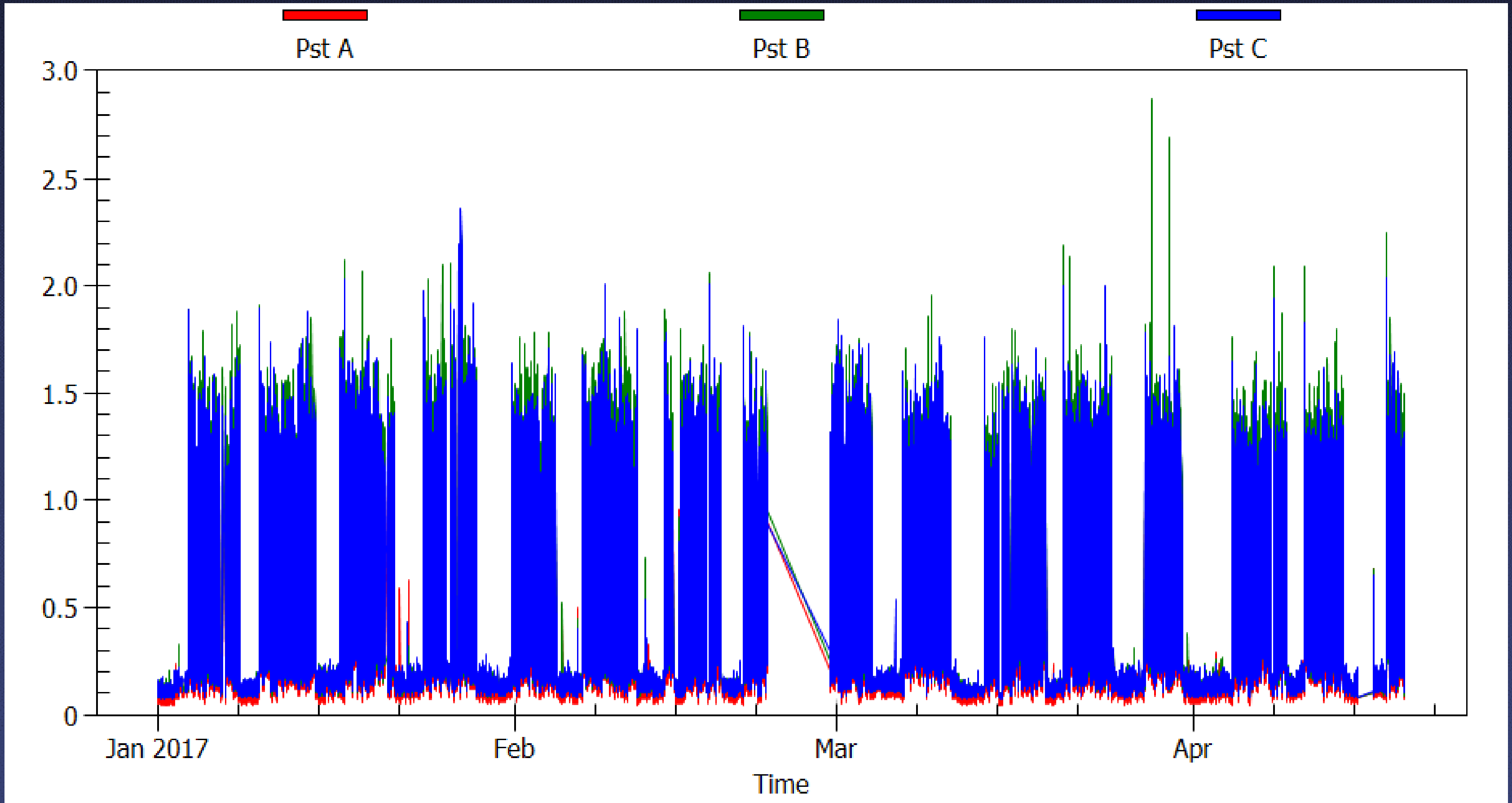
Categories		Typical Duration
Long Duration Variations	Interruption (sustained)	> 1 minute
	Undervoltages	> 1 minute
	Overvoltages	> 1 minute
Voltage Imbalance	Voltage Unbalance	steady state
Waveform Distortion	DC Offset	steady state
	Harmonics	steady state
	Interharmonics	steady state
	Notching	steady state
	Noise	steady state
Voltage Fluctuations	Voltage Fluctuations	Intermittent
Power Frequency Variations	Power Frequency Variations	> 10 seconds

IEEE 1453

- Defines flicker.
- Defines how to measure flicker.
- Provides guidelines on how to conduct flicker studies.
- Provides guidance on emission limits.

Flicker

Usually Displayed In Terms of PST or PLT, but also discussed in terms of cumulative probability.



Count	43027
Min	0.04000
Avg	0.4957
Max	2.870
Range	2.830
σ	0.4610
Avg +3 σ	1.879
Avg -3 σ	-0.8874
CP00.5	0.06000
CP01	0.06000
CP05	0.09000
CP25	0.1400
CP50	0.2100
CP75	0.9100
CP95	1.360
CP99	1.590
CP99.5	1.680
SI Range	0.3850

POWER GRID-RX INC

Flicker Sources

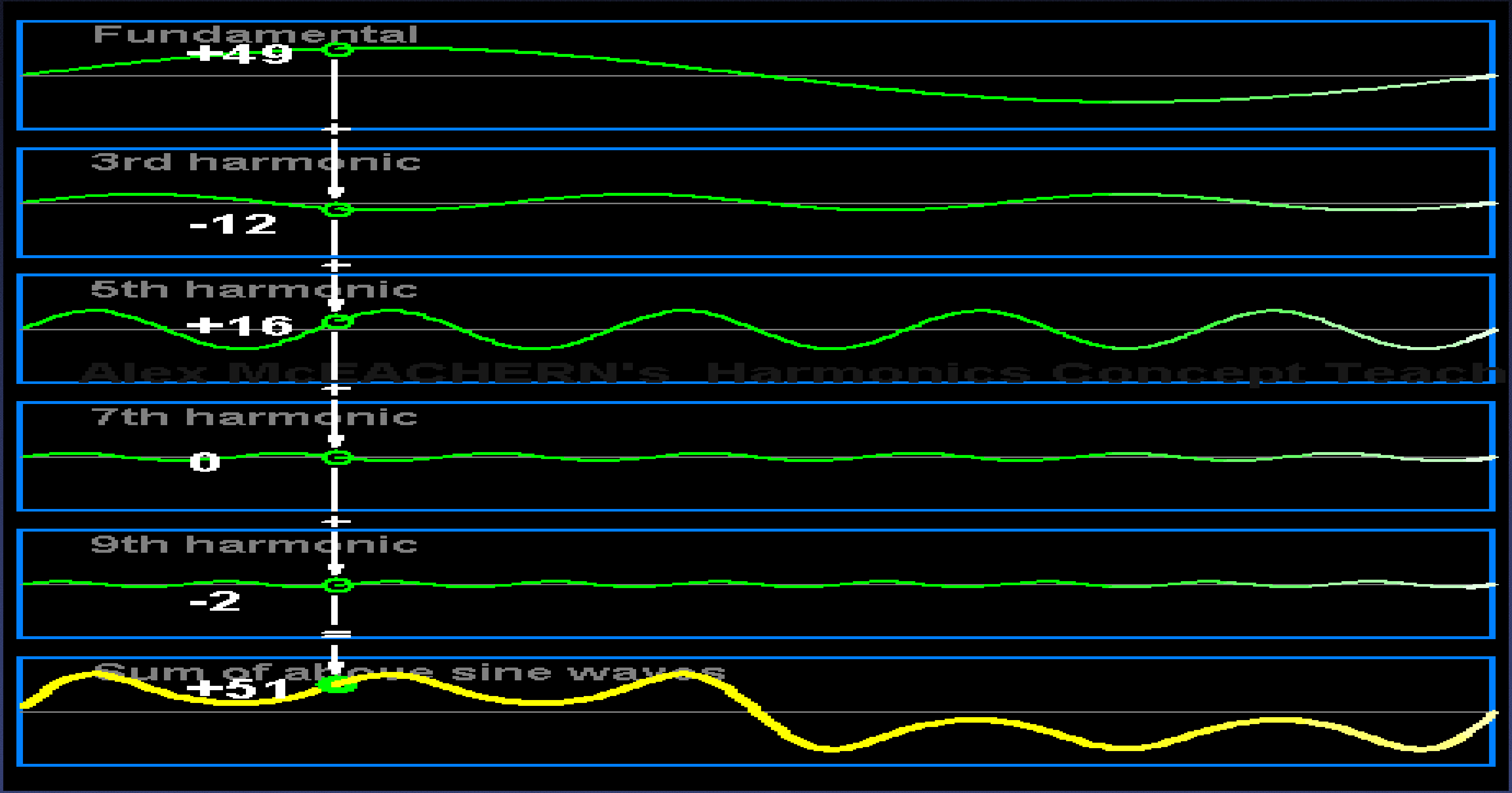
- Air-conditioning compressor motors
- Arc furnaces
- Arc welders (including spot welders)
- Electric boilers (large capacity)
- Heat-pump compressor motors
- Industrial motors (powering variable loads)
- Lasers
- Photocopying machines
- Power factor correction capacitors (switching operation)
- Presses (oscillating)
- Resistance welding machines
- Rock crushers
- Rolling mills
- Saw mills
- Tire testers
- X-ray machines

IEEE 519

- Defines Harmonics
- Defines Harmonic Measurements
- Provides guidance on emission limits based on Voltage class and Bus Strength
- Describes Interharmonic Voltage Limits
- Describes Telephone Influence Factor

POWER GRID-RX INC

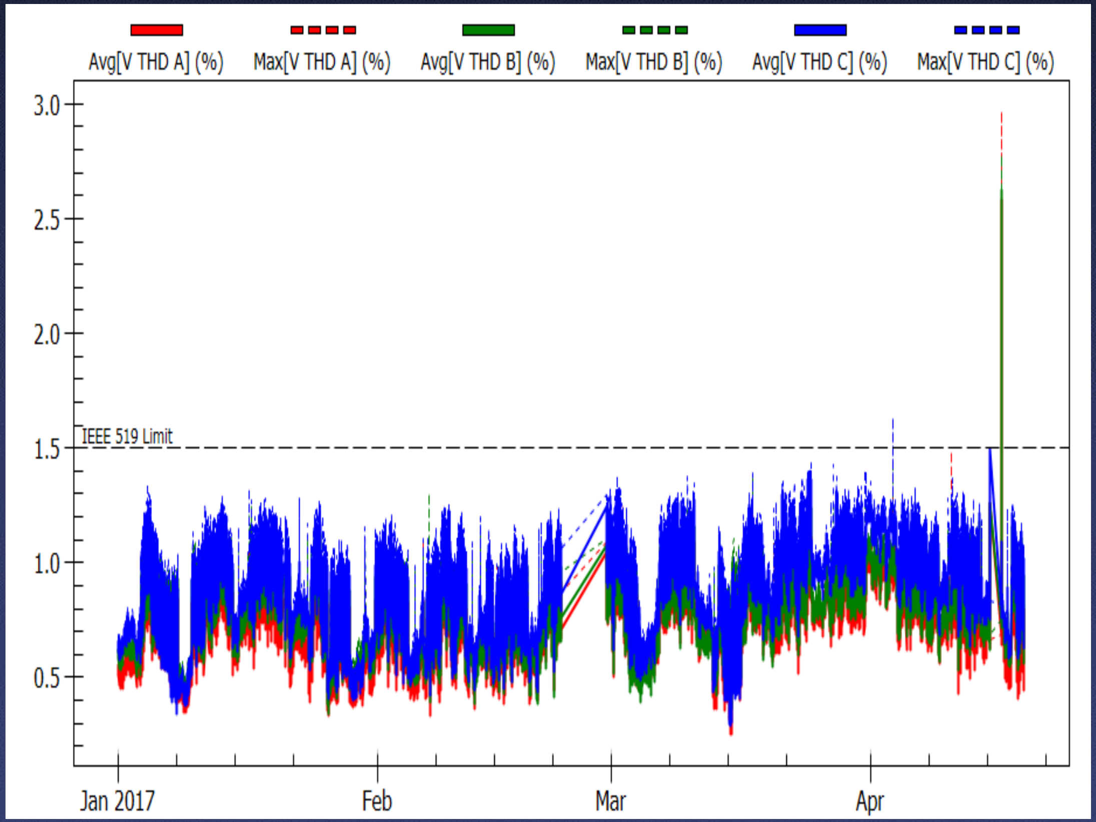
Harmonics

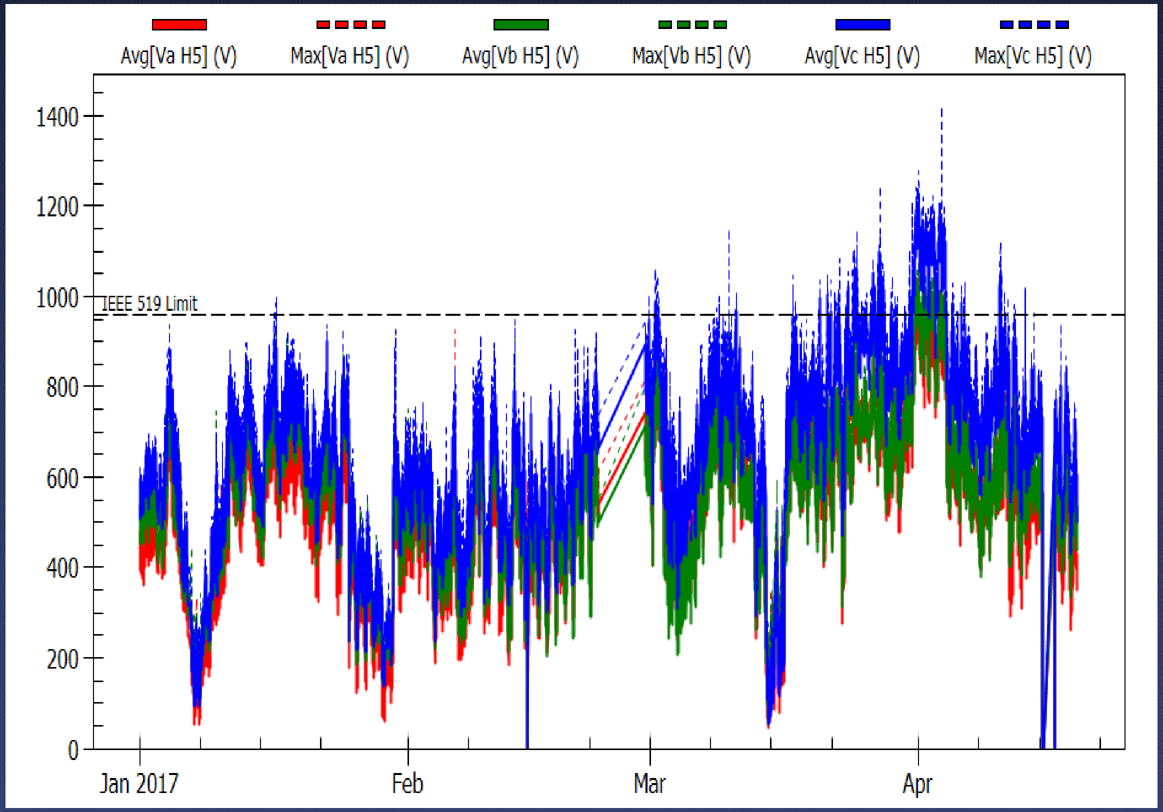


Fundamental
+49
3rd harmonic
-12
5th harmonic
+16
Alex McEACHERN's Harmonics Concept Teach
7th harmonic
0
9th harmonic
-2
Sum of above sine waves
+51

Harmonics

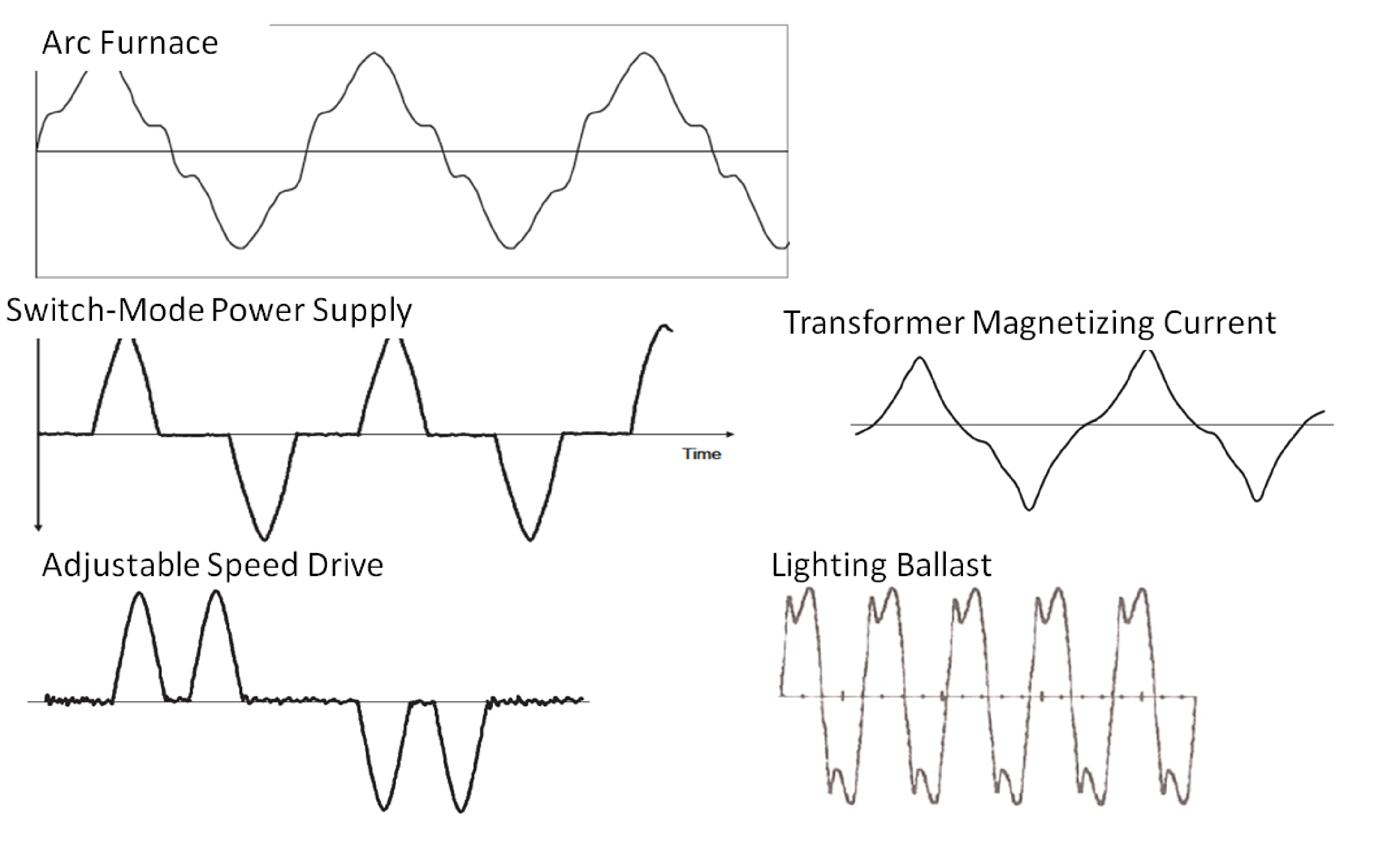
Described in terms of THD, but also in terms of individual harmonics.





POWER GRID-RX INC

Harmonic Sources



Other Harmonic Types

- Even Harmonics
  - Even integer
- Interharmonics
  - Between odd / even bins
- Subharmonics
  - Lower than fundamental
- “Superharmonics”
  - 3-150kHz.

POWER GRID-RX INC

Power Quality Measurement

Steady State

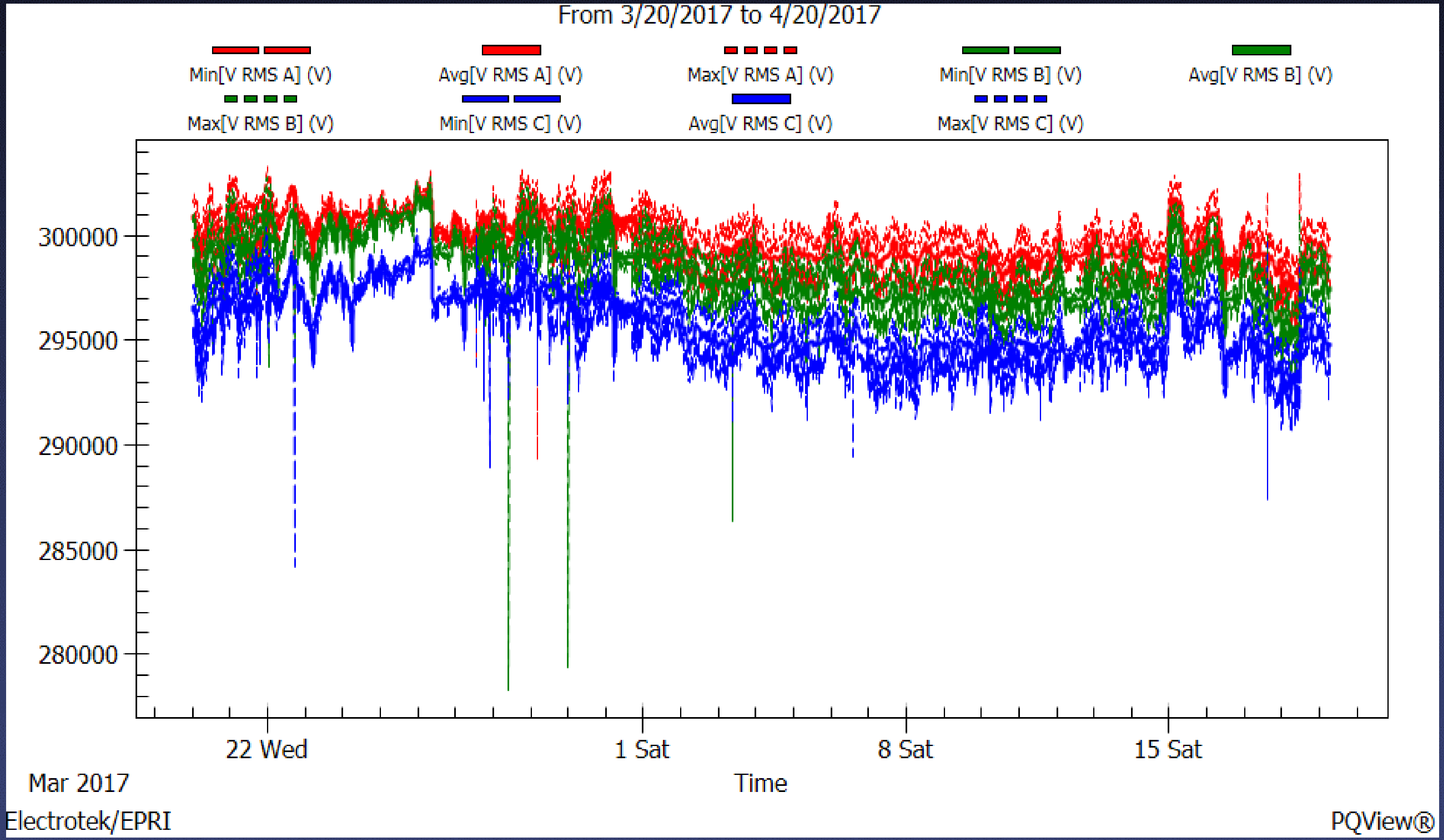
Events

POWER
GRID-RX INC

Steady State

- Measurements are sampled at a high rate of speed (128 samples per cycle or more).
- Minimum, maximum, and average measurements are stored in 10 minute increments.
- These measurements represent the system during normal conditions.
- Typical parameters measured: Voltage, Current, Harmonics, Power, Frequency, Flicker, Unbalance

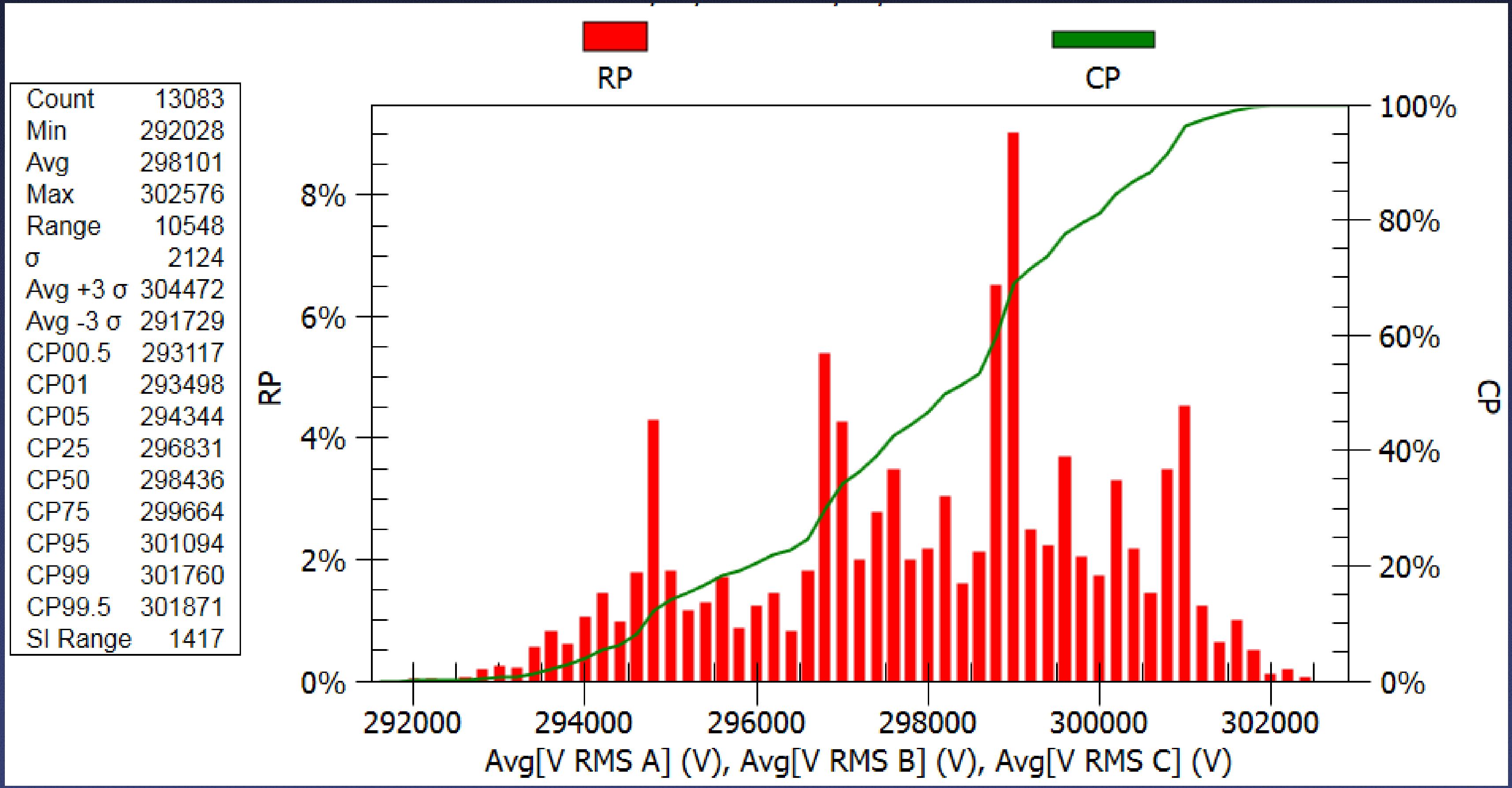
Example of Steady State Data



POWER GRID-RX INC

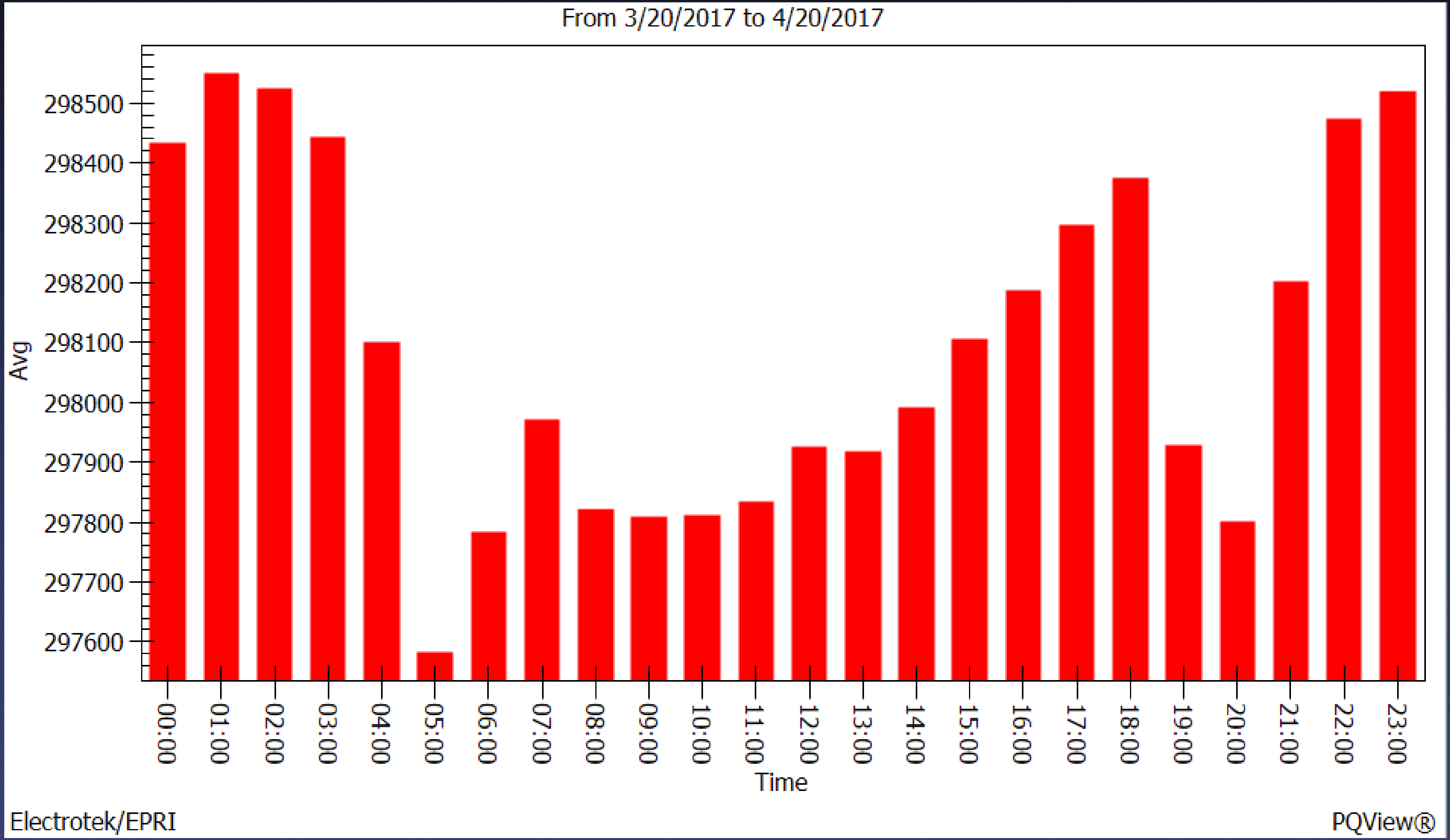
Steady State Analysis

Steady state data is frequently analyzed in terms of statistical probability.



POWER GRID-RX INC

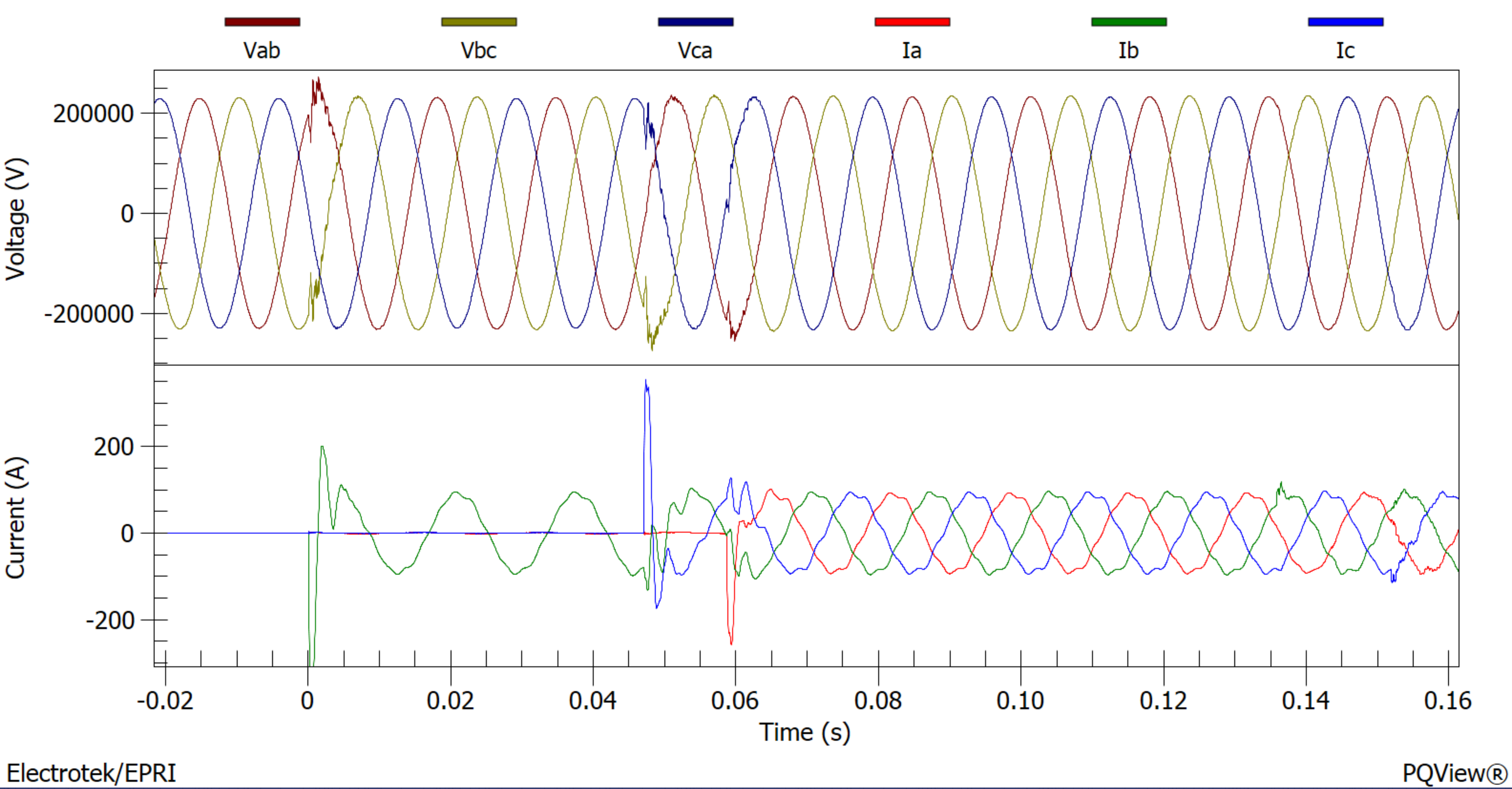
Steady State Analysis (Continued)



Events

- Transient Events / RMS Events
- Measurements are sampled at a high rate of speed (128 samples per cycle or more)
- Measurements are stored at the sampling rate for the duration of the event (up to some maximum time)
- These measurements represent the system when a predefined threshold has been exceeded
- Typical measurements include voltage and current. (Other parameters can be derived)

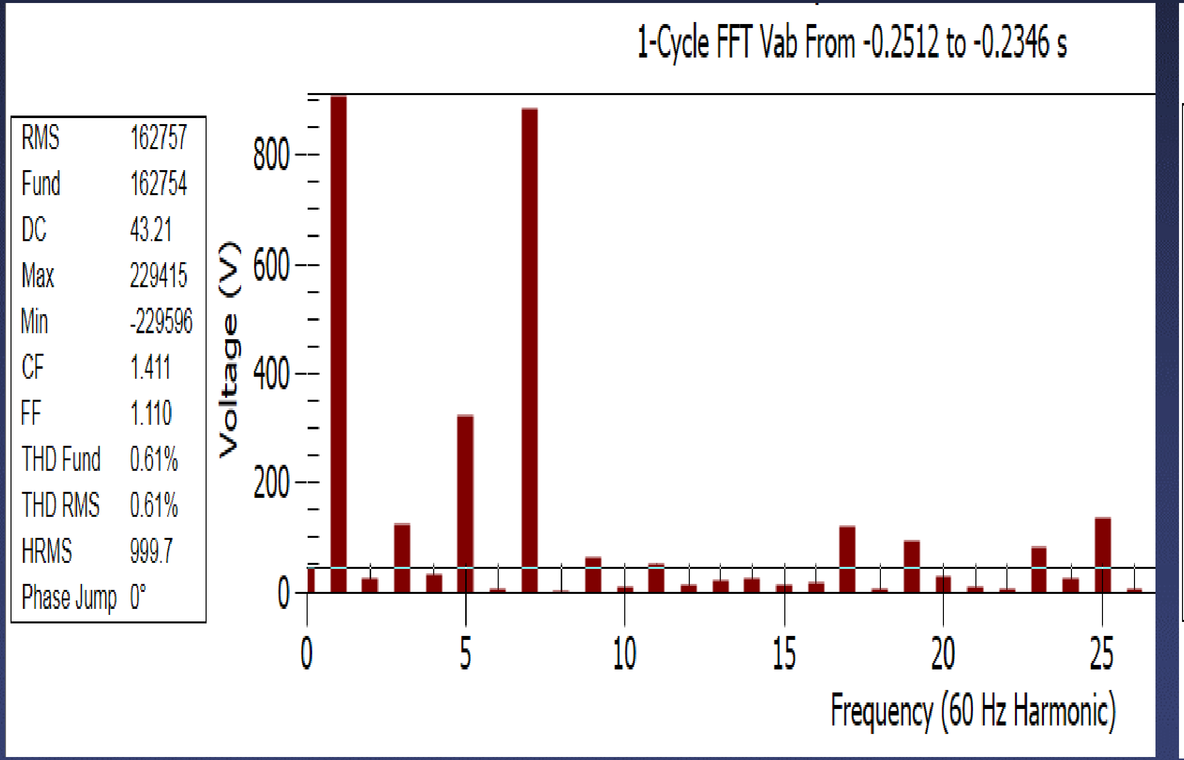
Example of Transient Event Data

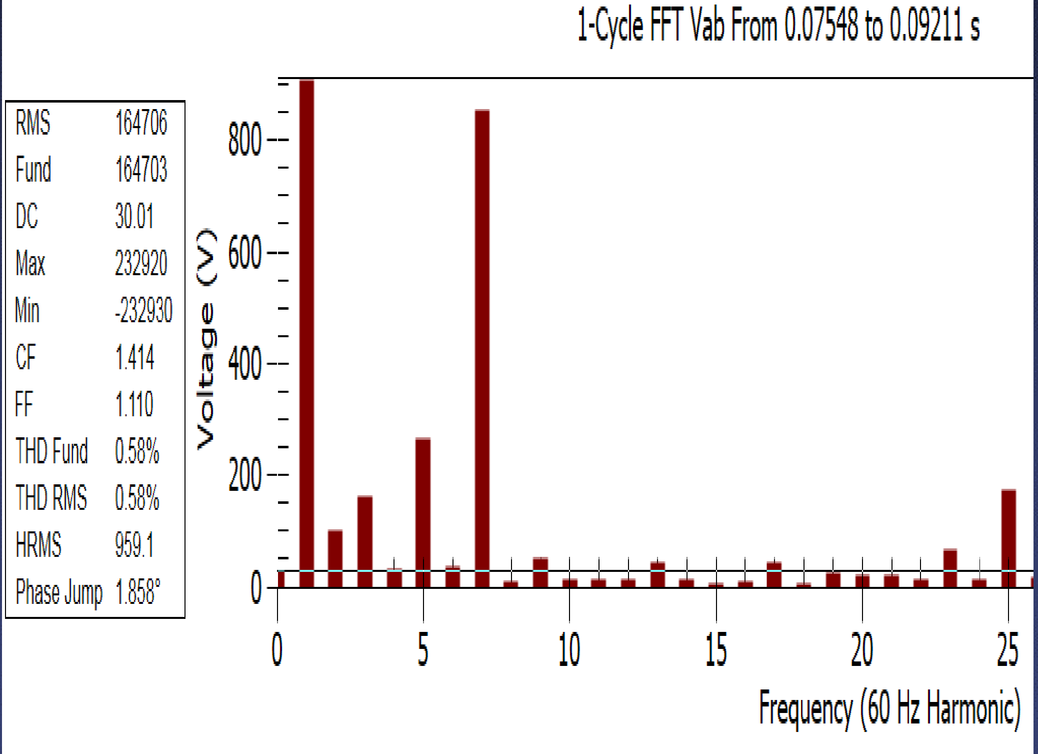


POWER GRID-RX INC

Transient Event Analysis

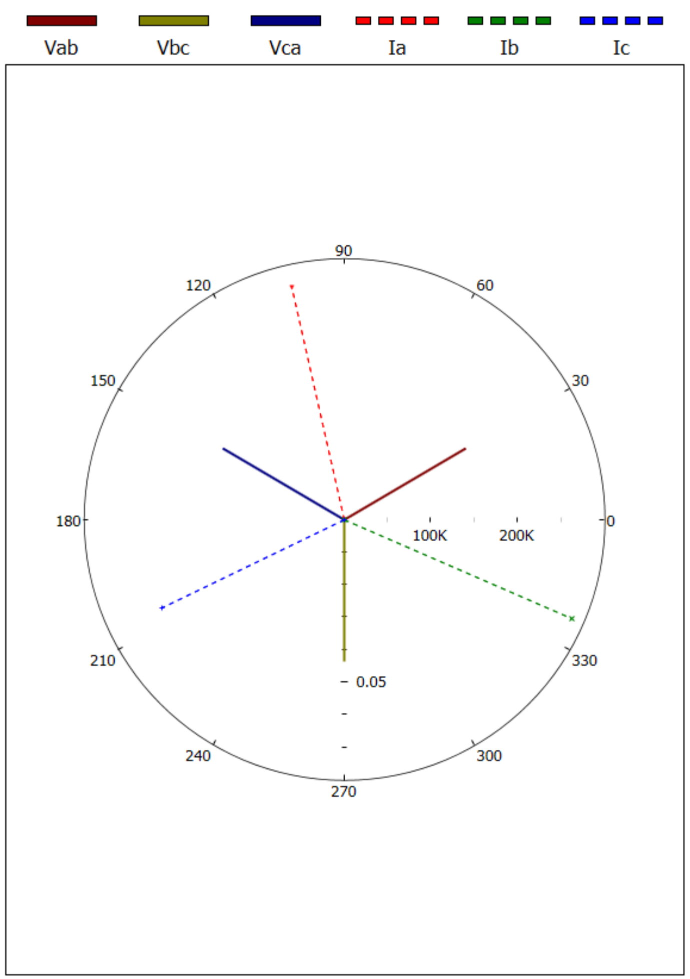
Event Data is usually viewed in terms of what is happening with the waveform. This can be described in a variety of ways. (Effects of a cap switch).



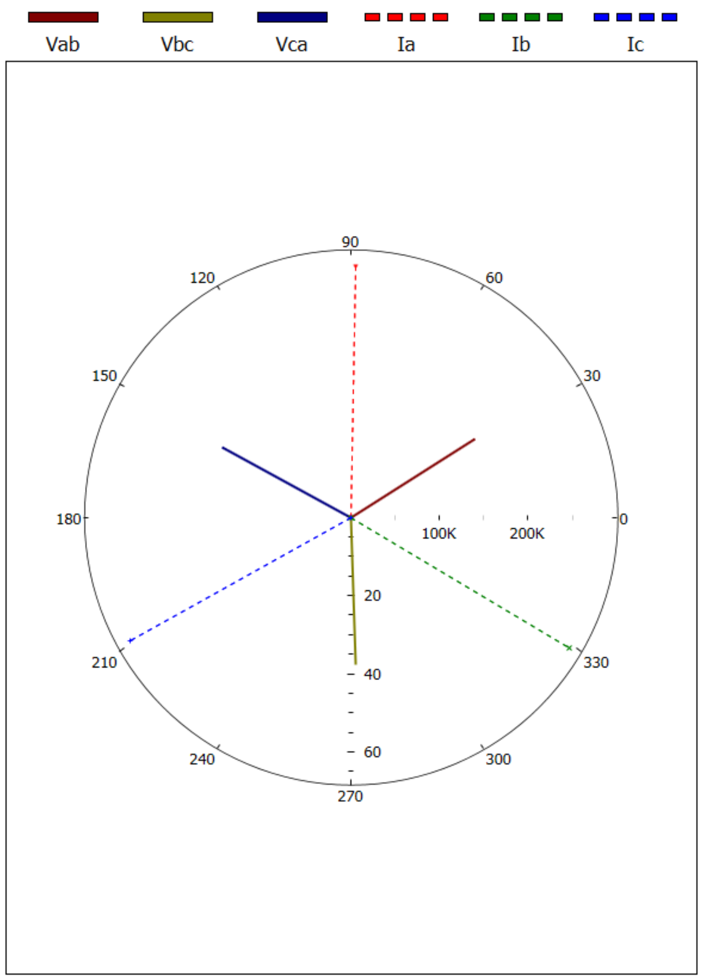


Transient Event Analysis (Continued)

Vab	162754	30.19°
Vbc	163175	-90.19°
Vca	162046	149.9°
Ia	0.07316	102.8°
Ib	0.07636	-23.58°
Ic	0.06249	-154.2°
Zab	1219713	-100°
Zbc	1292109	-88.67°
Zca	1522969	-97.99°

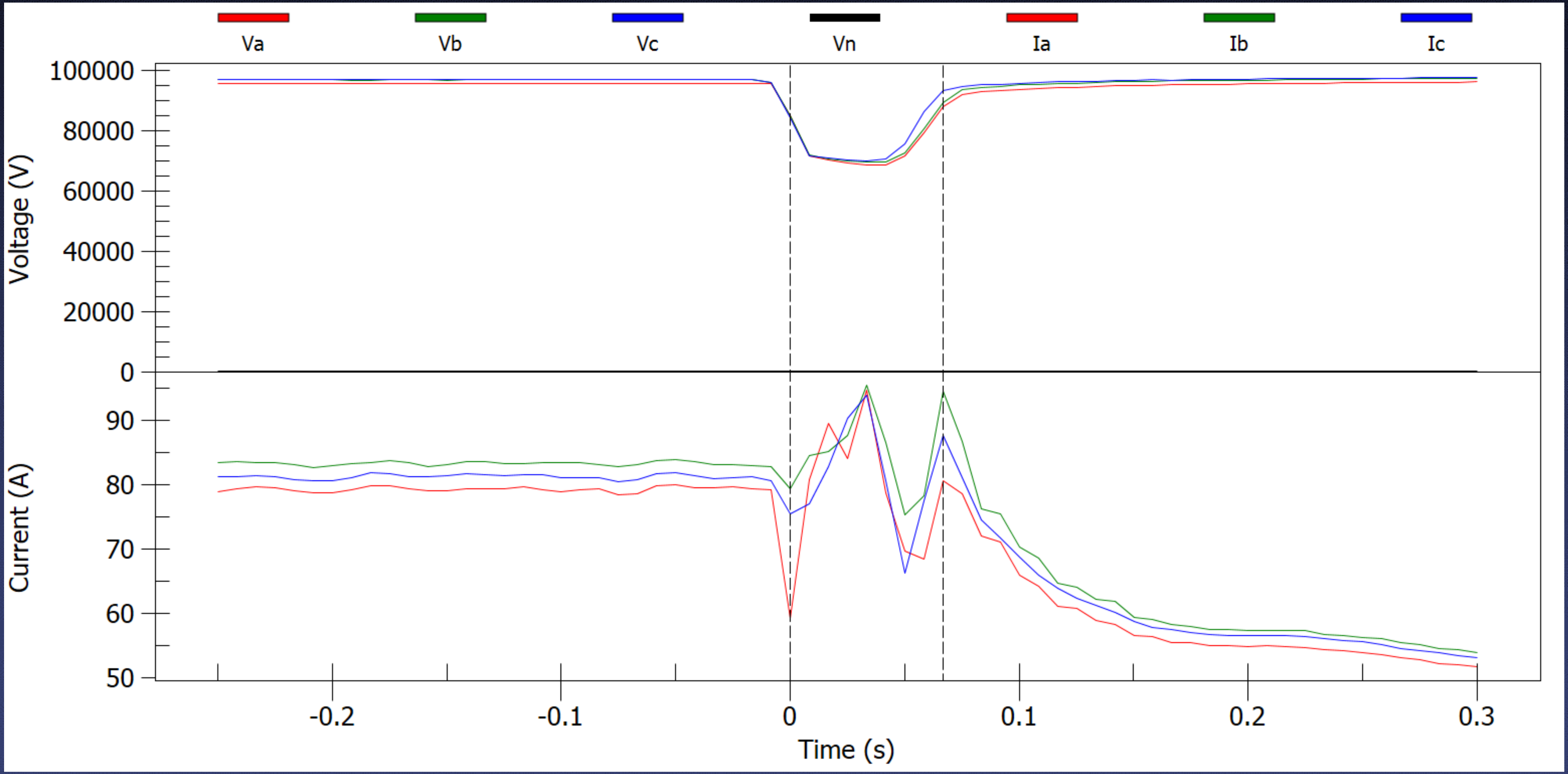


Vab	164703	32.04°
Vbc	165297	-88.36°
Vca	163994	151.7°
Ia	64.04	89.03°
Ib	65.12	-30.89°
Ic	64.70	-150.9°
Zab	1473	-87.30°
Zbc	1470	-87.36°
Zca	1470	-87.24°



POWER GRID-RX INC

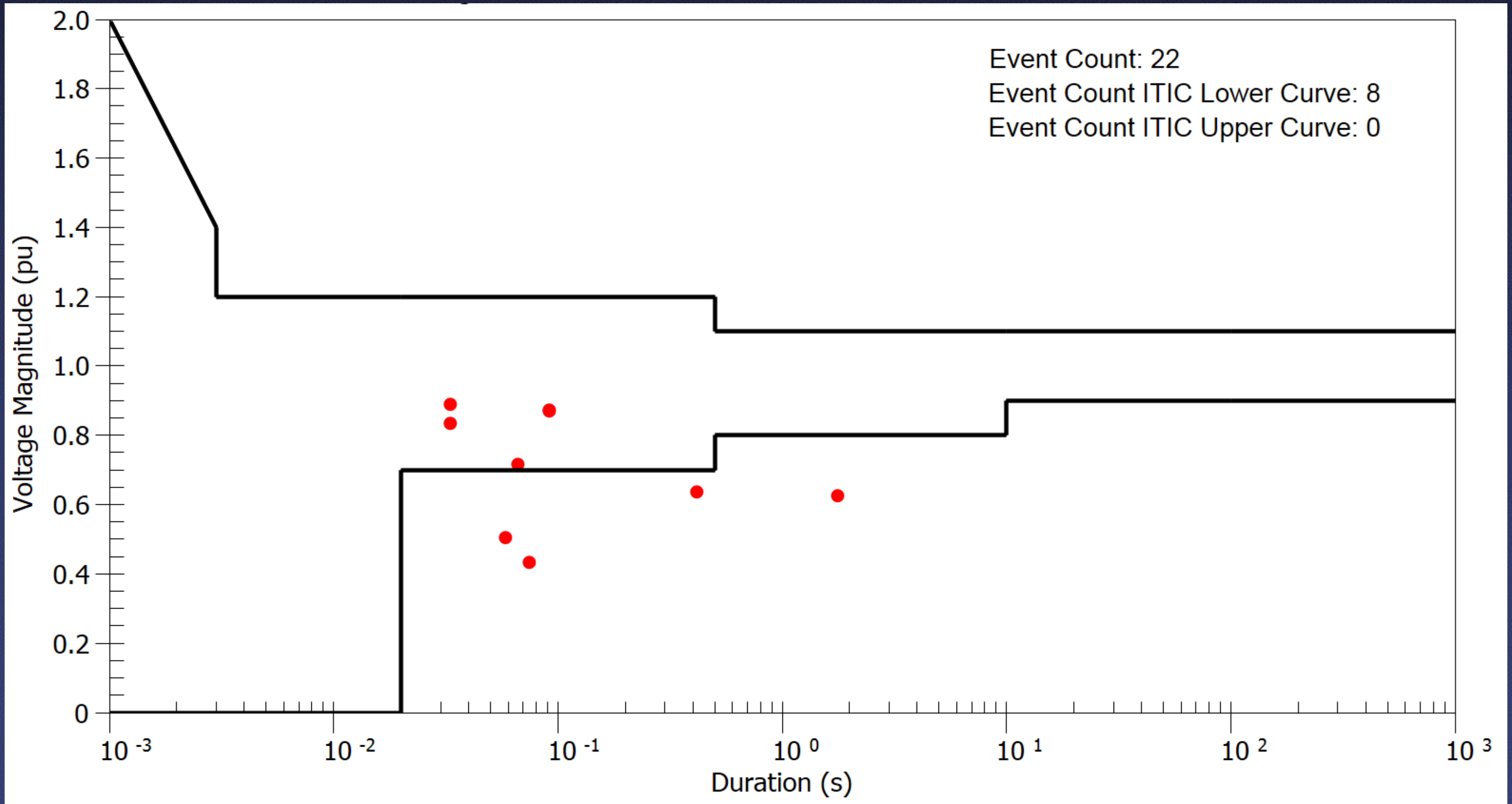
Example of RMS Event Data



POWER GRID-RX INC

RMS Event Analysis

RMS Event Data is usually viewed in terms of what is happening to the RMS Voltage/Current. This is typically viewed in the context of a magnitude/duration chart.



POWER GRID-RX INC

Questions?

POWER GRID-RX INC

PRESCRIPTIONS FOR THE POWER GRID IN THE DIGITAL AGE