POWER QUALITY
The Invisible Backbone of the Smart Grid

Empowering India's Smart Grid Vision through PQ Intelligence

Presented by Anil Kumar

Director, Enspar Energy Solutions

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- Part 1 : Understanding Power quality
- Part 2: Power Quality Monitoring
- Part 3: Case Studies

WHY POWER QUALITY IS CRITICAL FOR FUTURE GRIDS

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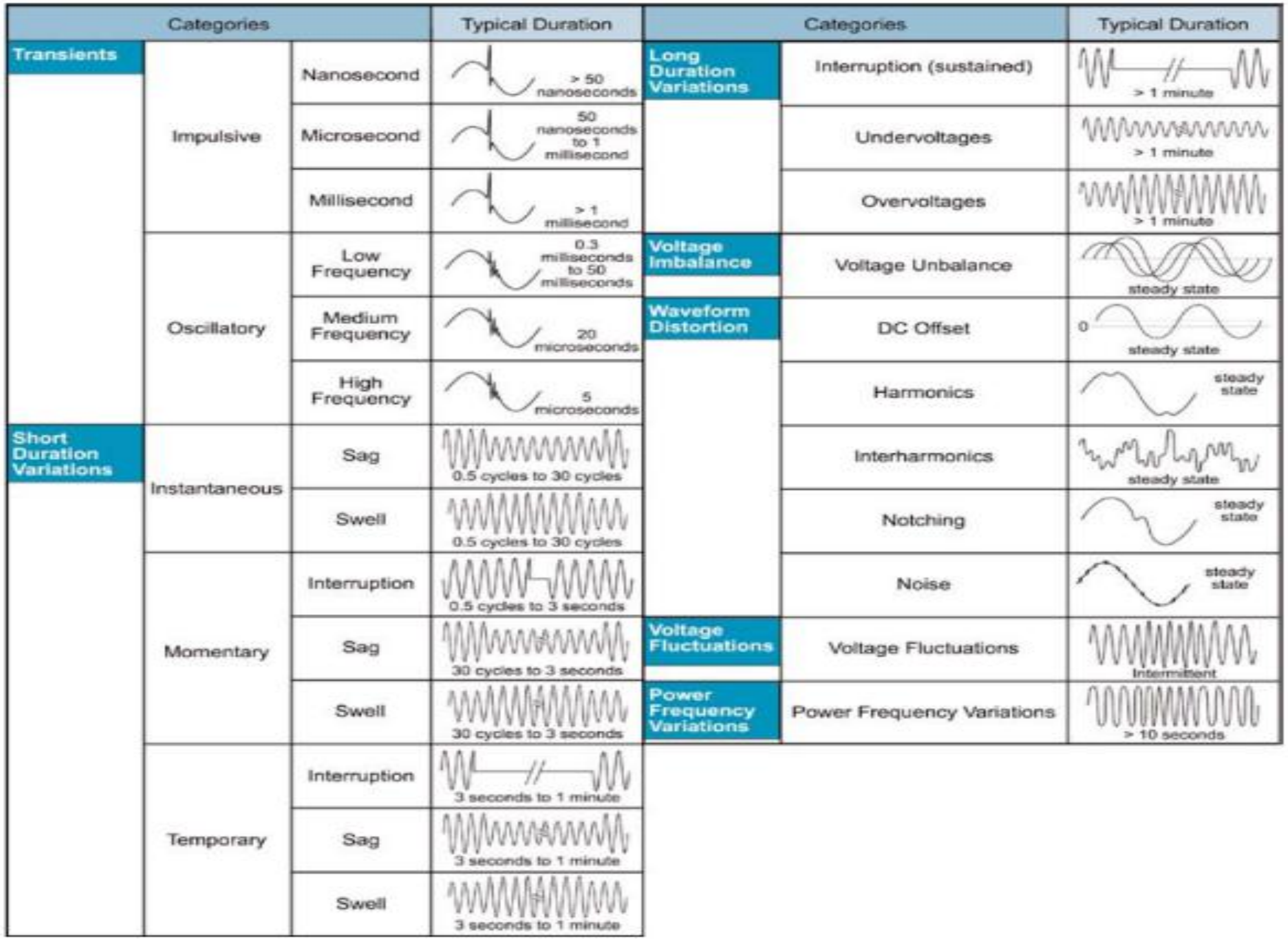
Power Quality Parameters- Classification as per IEEE-1159

IEEE & IEC have more than 102 standards and many more scheduled for release

The cost of power outages and power quality disturbances to Indian industry is USD 200 Billion (IJETMAS 2015).

Many of the outages can be foreseen and prevented by PQ Disturbance monitoring and analytics

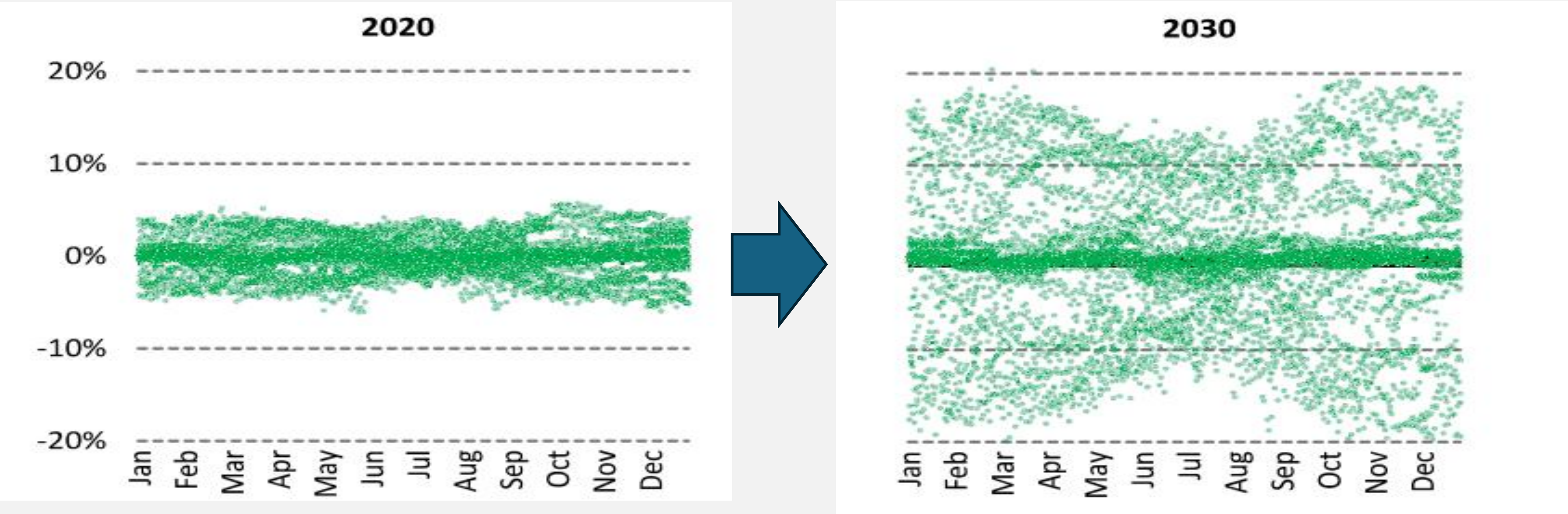


Categories			Typical Duration
Transients	Impulsive	Nanosecond	> 50 nanoseconds
		Microsecond	50 nanoseconds to 1 millisecond
		Millisecond	> 1 millisecond
	Oscillatory	Low Frequency	0.3 milliseconds to 50 milliseconds
		Medium Frequency	20 microseconds
		High Frequency	5 microseconds
Short Duration Variations	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	0 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

Impact on Grid Stability – Voltage and Frequency Variation

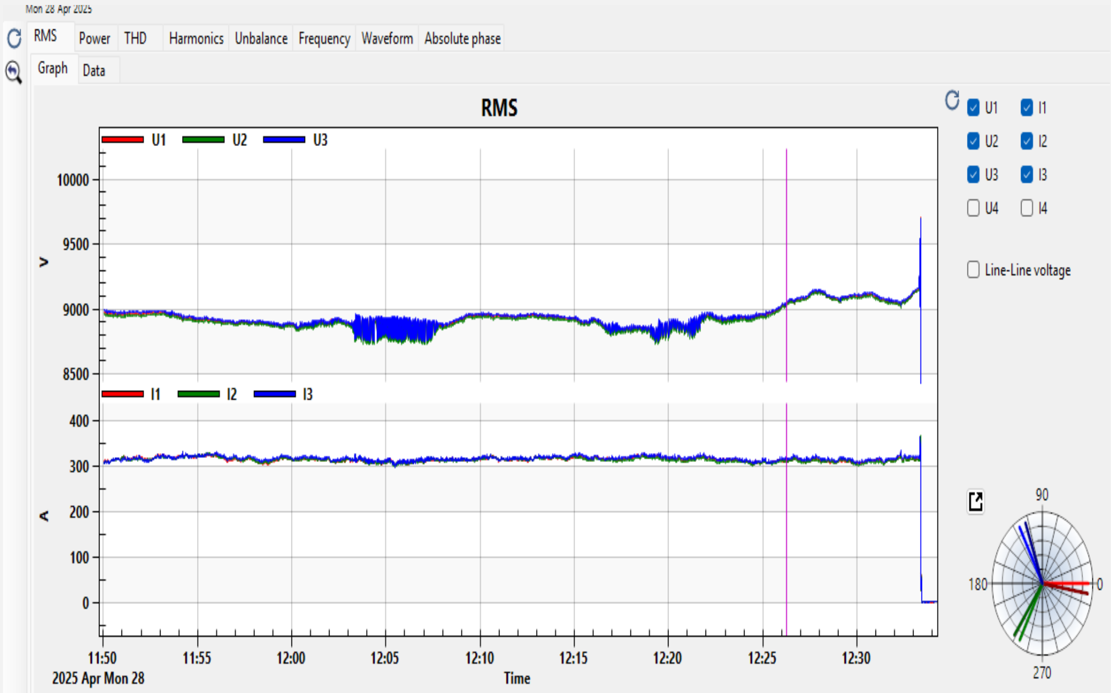
Hourly change in generation from variable renewables in India
as percentage of average annual demand in the STEPS

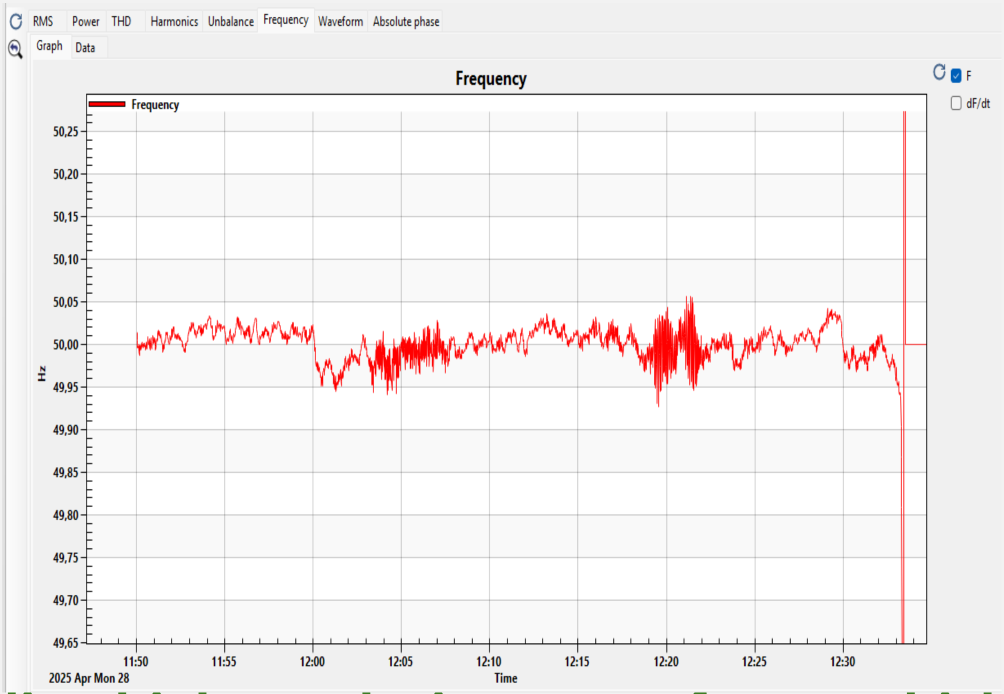


In adequate balancing and ramping solutions will impact grid stability
Installed Capacity of VRE in 2020- 71 GW. Projected 2030- 280GW

Early warning of PQ Disturbances prior to grid failure

Below is **low frequency grid oscillations in the range of 0.1- 1 Hz extracted from a PQ meter in** the Iberian peninsula. What you see in the graph is voltage and frequency variations, the critical early warning prior to black out.





The PQ Meters can provide various other data including high resolution wave forms which is not possible in PMUs. There is no trigger set up available in this case but can be developed for early warning

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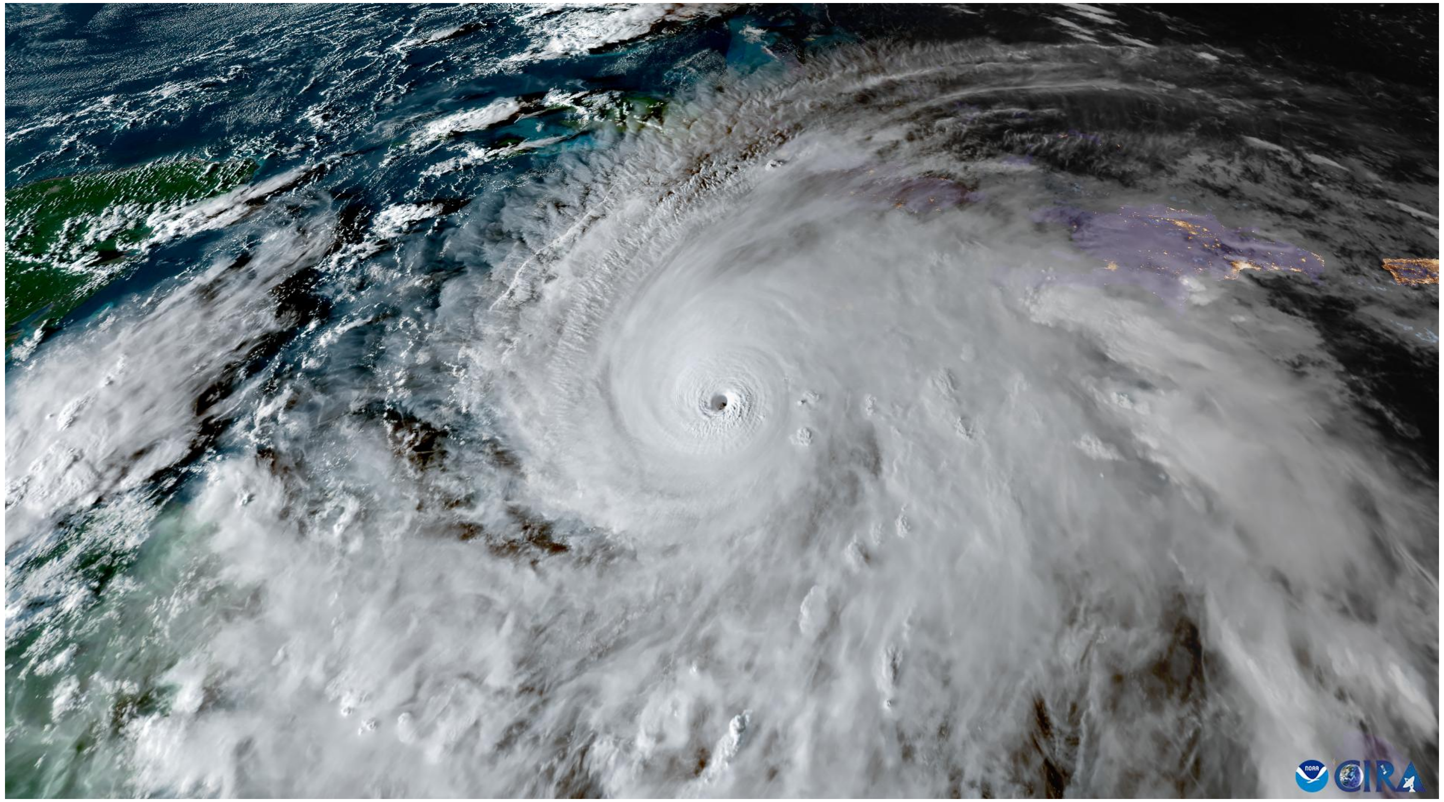
Early storm warning using satellite air turbulence data

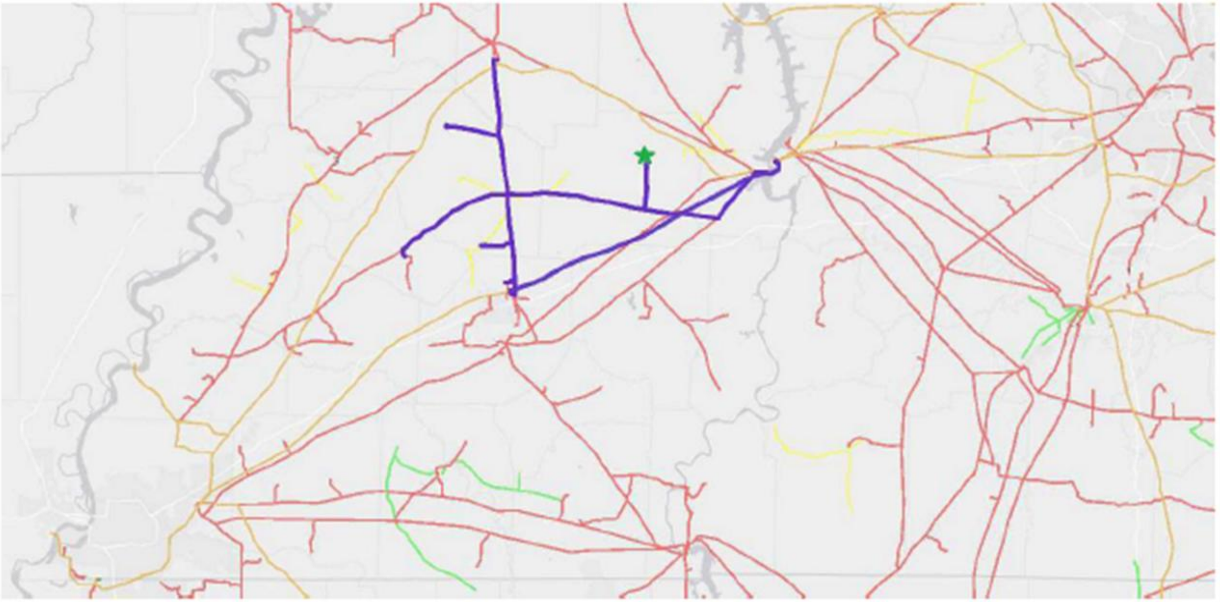
"Just as satellites track Category 5 Hurricane Melissa ahead of its record-breaking landfall in Jamaica, electrical disturbances too can be anticipated — using Power Quality Intelligence to predict blackouts and equipment failures before they occur."



Impact of Gen Plant closings on AoV – Voltage Sag Propagation

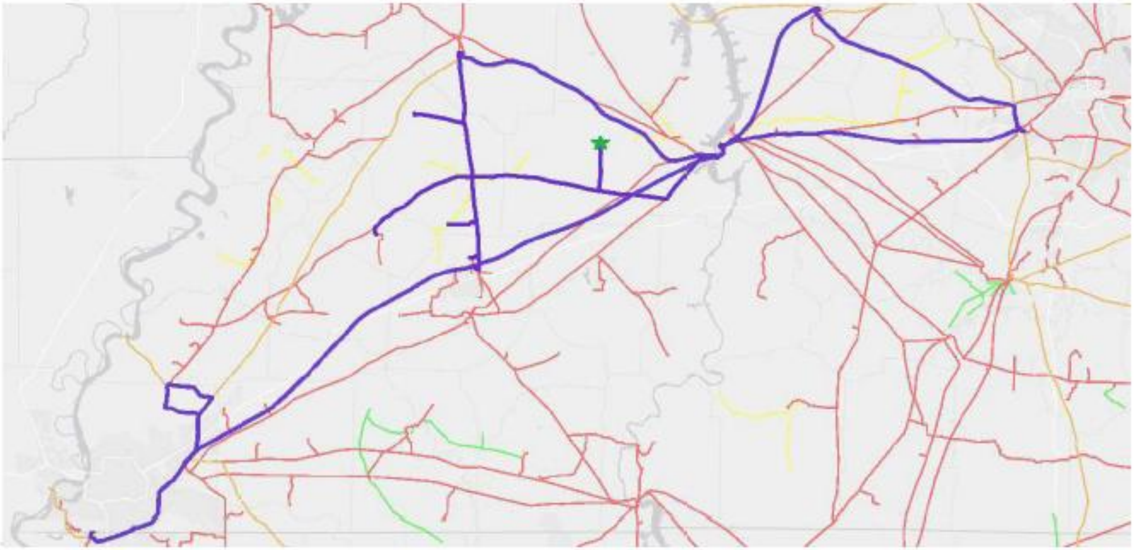
Before Local Fossil Plant Closing

- Customer (green star) is fed from a 161kV system
- Current exposure to interrupting sag (70%) from any fault on ~200 miles (322 km) of feeder (blue)



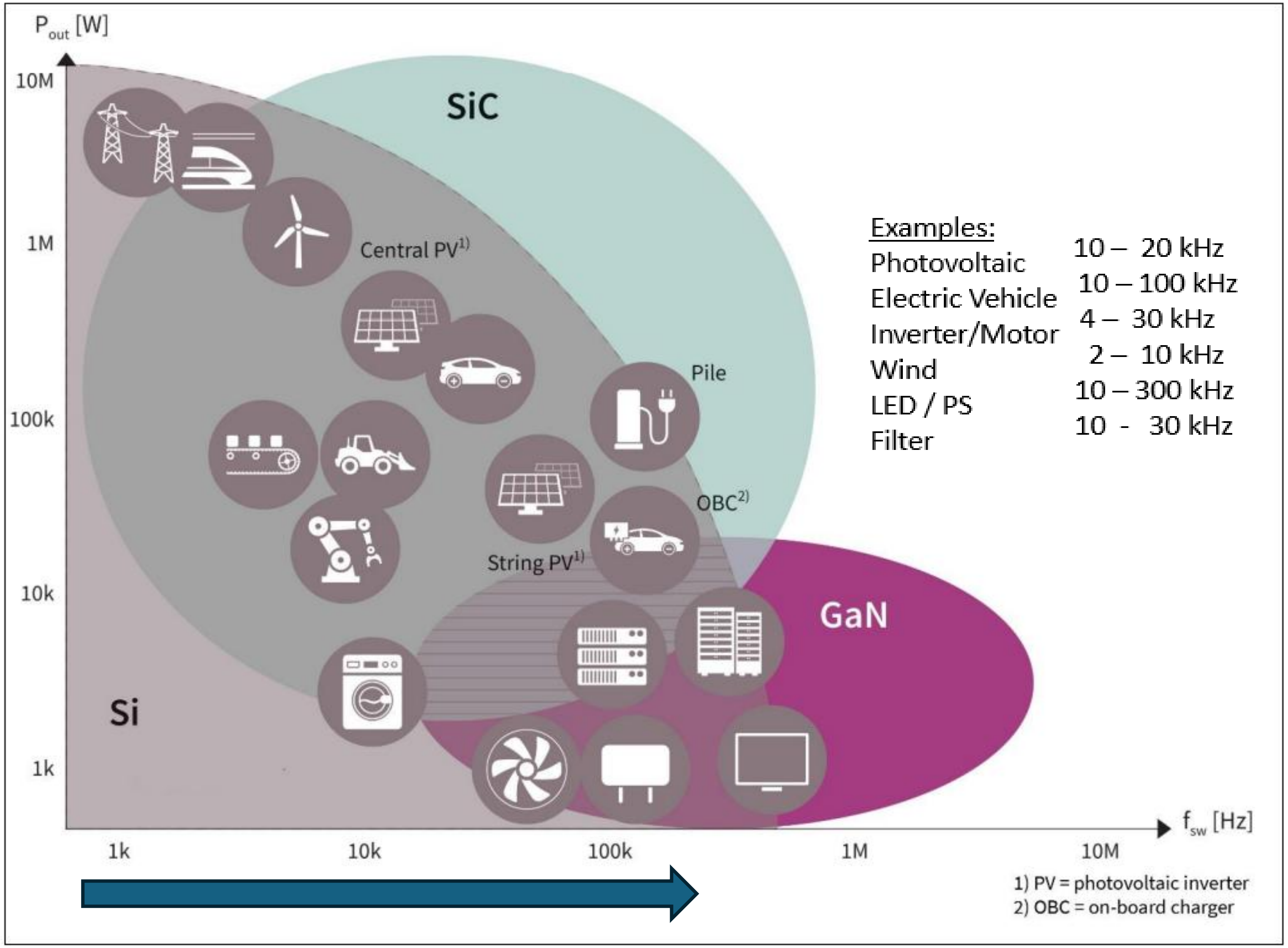
After Local Fossil Plant Closing

- Addition of new inter-tie to 500kV transmission
- New exposure to interrupting sag (70%) from any fault now ~600 miles (966 km) of feeder
- Customer is now 3X more likely to see disturbing sags, (assuming the location of faults is random)

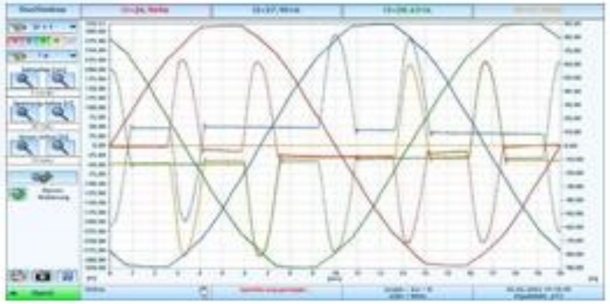


The “Power Electronics” era: Harmonic Grid

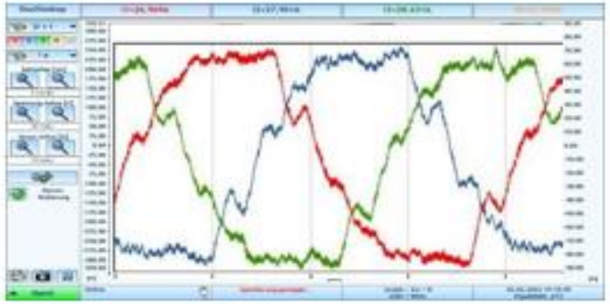
All Electrical devices are only specified for 50Hz Fundamental Frequency. “Let's not open Pandora's box”.



Harmonics
→ Passiv Power Electronics



SUPRAHARMONICS
→ Active Power Electronics



Source: https://www.infineon.com/assets/row/public/documents/24/42/infineon-mosfet-coolsic-650v-sic-trench-power-applicationnotes-en.pdf?fileId=5546d4626fc1ce0b016ff6c9a86f6e08

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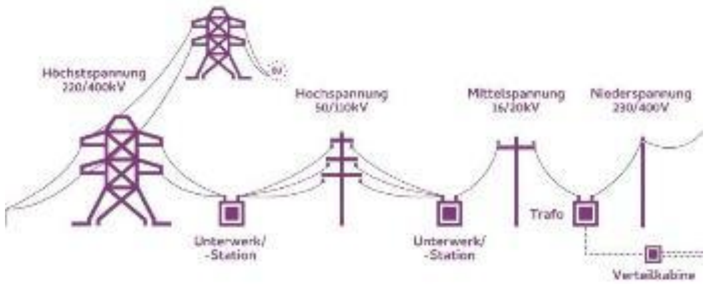
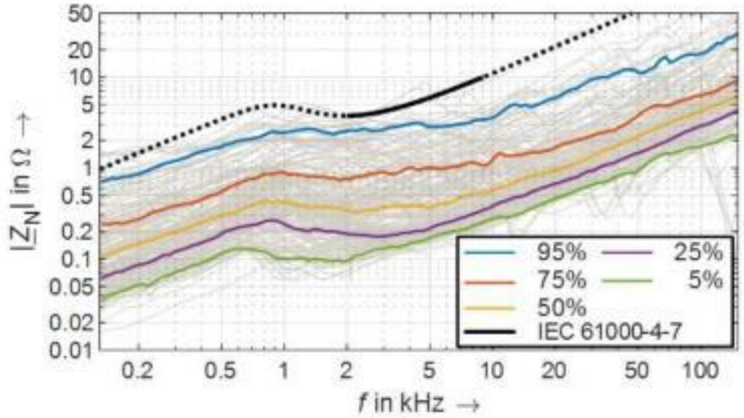
Frequency Dependent Grid Impedance

(Series Parallel Resonance occur > 2 kHZ causing EMI & instability risks)

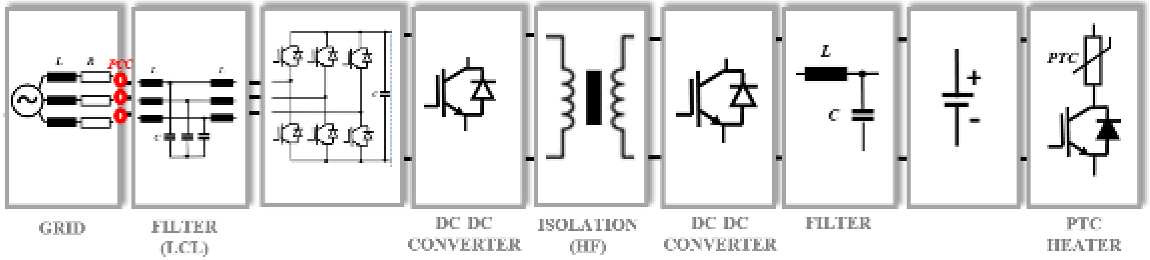
Distribution Grid



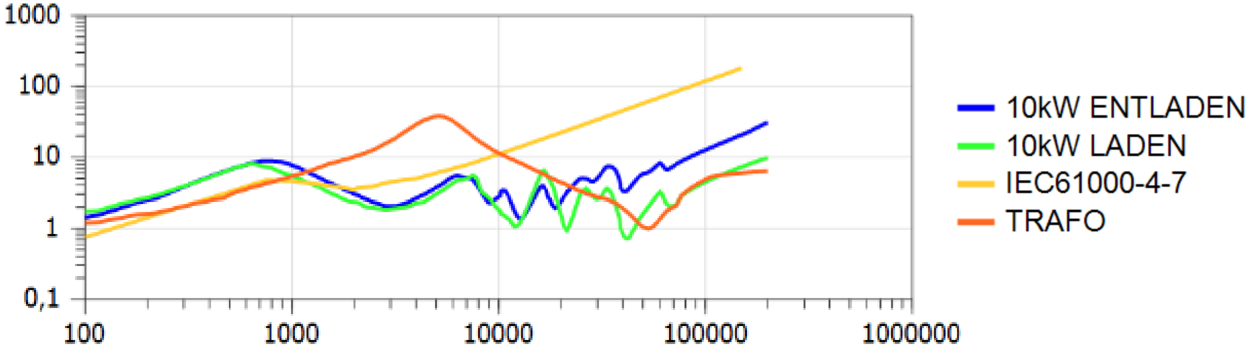


TU Dresden, Berner FH et al. (2019)SURVEY OF NETWORK IMPEDANCE IN THE FREQUENCY RANGE 2-9 KHZ IN PUBLIC LOW VOLTAGE NETWORKS IN AT/CH/CZ/GE

V2G Charger (HF transformer)



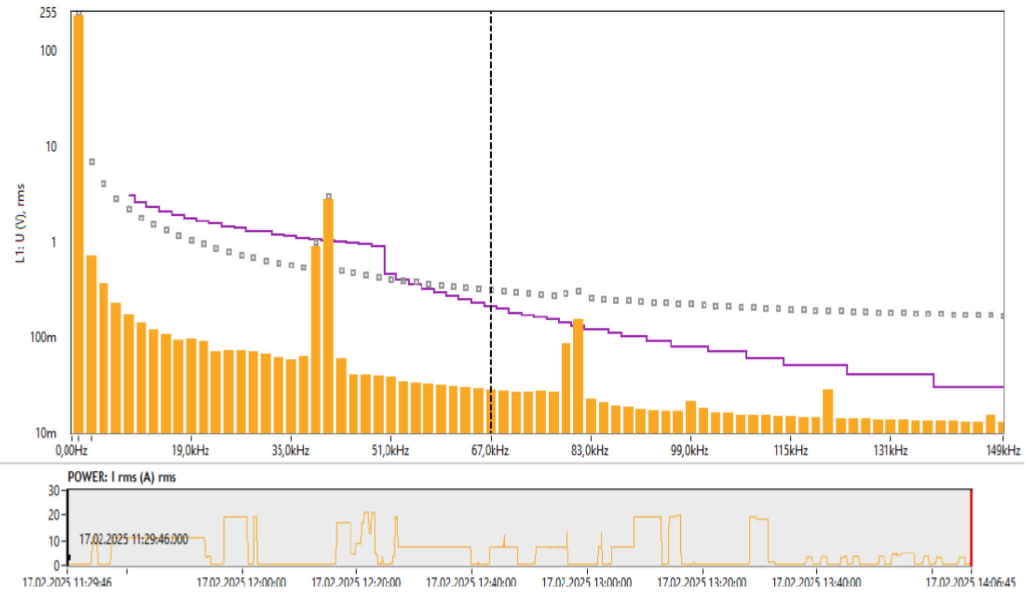
Quelle: Grasel et al. (2022) Supraharmonic and Harmonic Emissions of a bi-directional V2G chargingstation

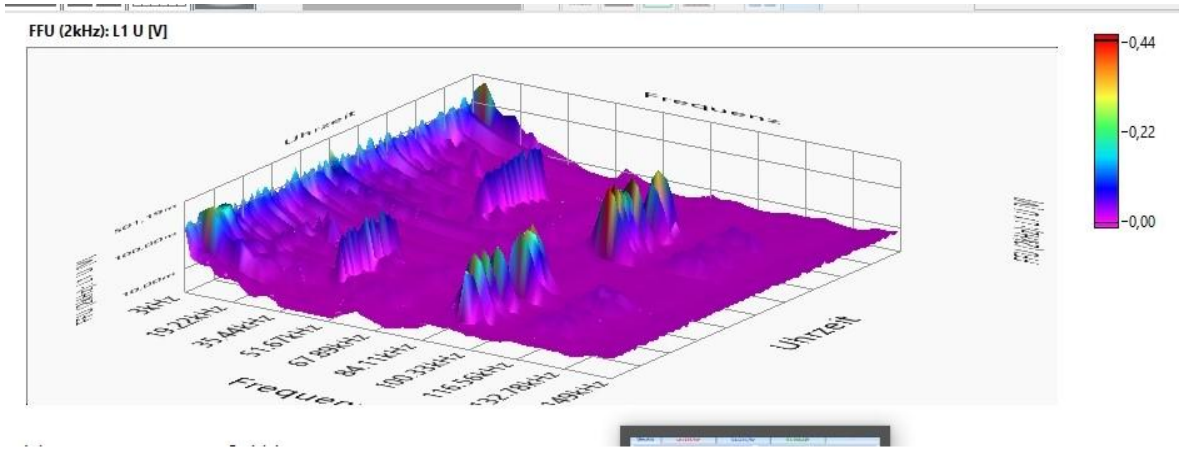


Quelle: Grasel et al. (2021) Supraharmonic Emissions of a bi-directional V2G charging station

Emerging Power quality Phenomena

Power Quality Analysis goes beyond the existing IEEE/IEC standards setting new benchmarks for power quality assessment (Impedance as a PQ Parameter) of future electricity grids





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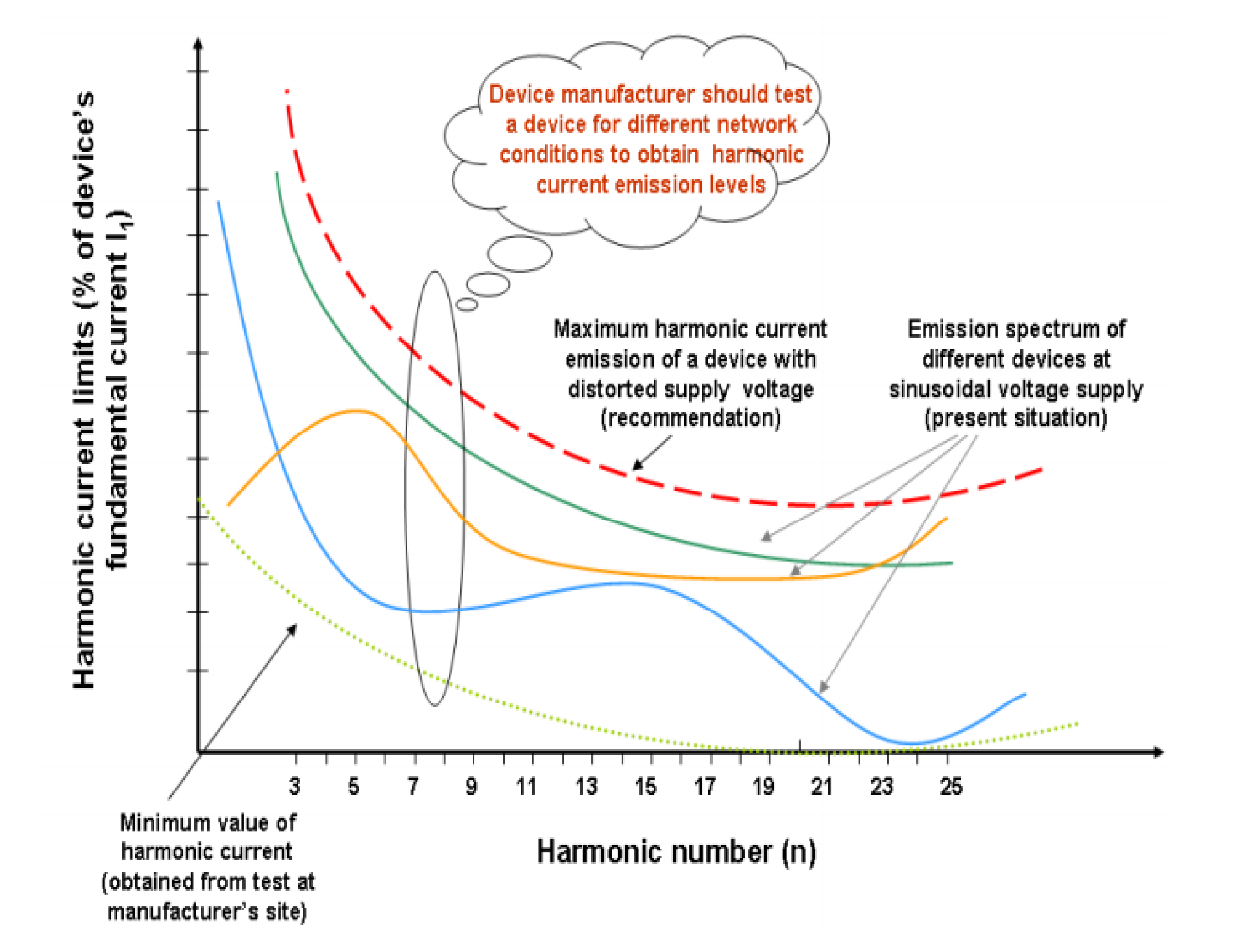
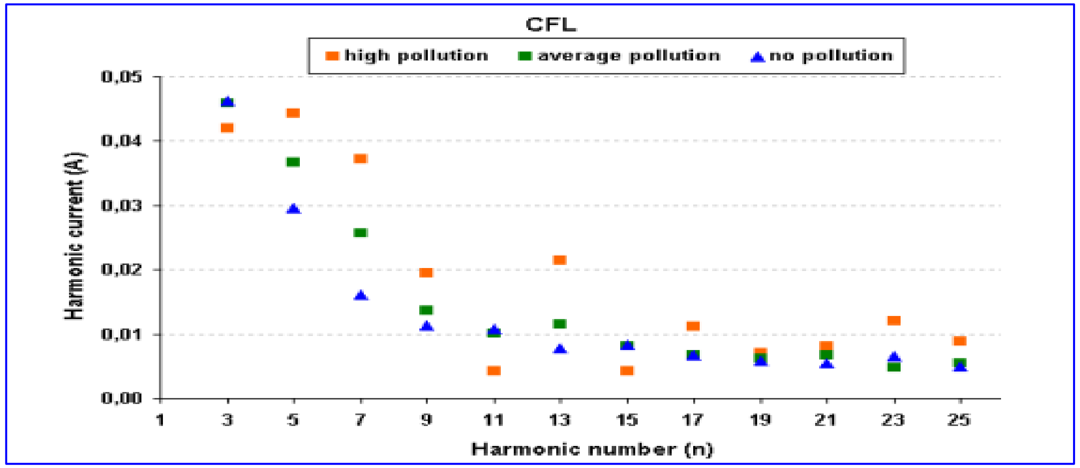
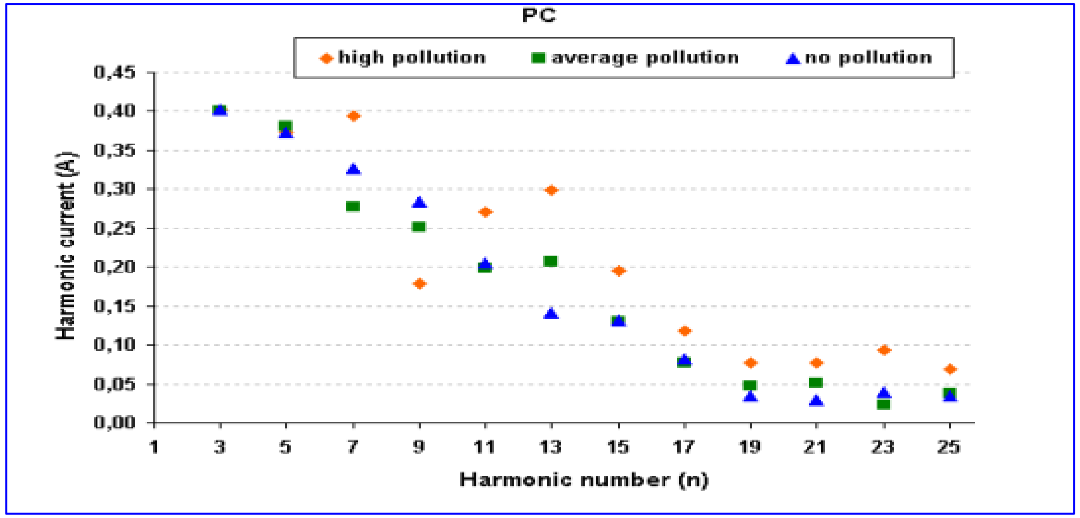
Harmonics by devices under field conditions







Frequency dependent grid impedance increases the distortion

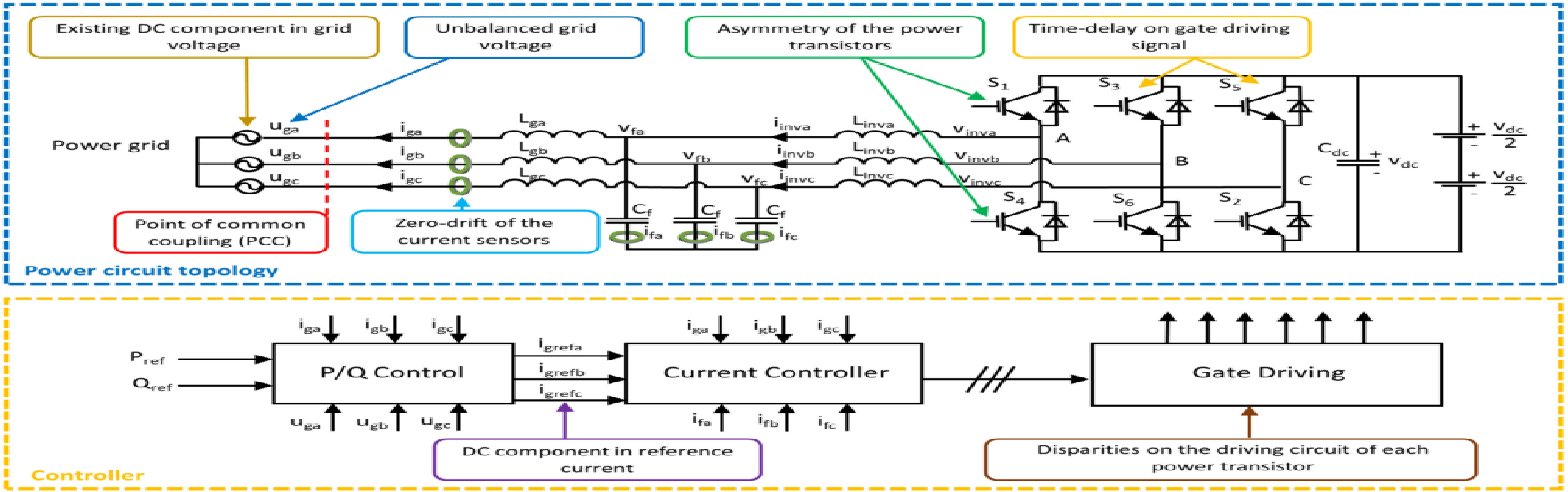
DC Offset and EMI: Hidden Killers of Power System

DC Offset (DC Components)

- DC Current injected by grid connected inverters can lead to several adverse effects including corrosion of grounding electrodes, asymmetric magnetic core saturation in transformers(causing over heating, additional power losses and premature failures) and increased harmonic distortion in power systems.

Conducted & Radiated EMI

- The switched power electronic converters enables precise control of voltage & current for different types of rectifiers and inverters (e.g EV charging, PV etc). However, their pulsed based switching technique gives raise to high frequency noises causing abnormal operation of sensitive equipment, communication and control interference



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Why PQ Monitoring?

Current Challenges of PQ Management System

Growing Penetration of Distributed Energy Resources and EV Charging Stations

- Voltage regulation, system protection, and power quality are expected to pose new challenges
- Wide Area PQ monitoring that integrates PQ Data with other sources such as SCADA/AMI/ IEDs, Disturbance event recorders is essential to achieve system reliability and resilience
- To validate and refine mathematical models developed for power system simulation studies

CEA Regulation for PQ Monitoring

- CEA Regulation on Distributed Generation, EV charging Stations, prosumers connected to 11 KV and above, stipulates PQ Meters to be installed by the DISCOM and Bulk consumers, and the reports shall be in a transparency manner.

Open platform for PQMS

- Single vendor Vs Device Agnostic Approach and scalable
- PQMS to integrate PQ data from multi-vendor devices/ Protective Relays/ Smart Meters/ SCADA

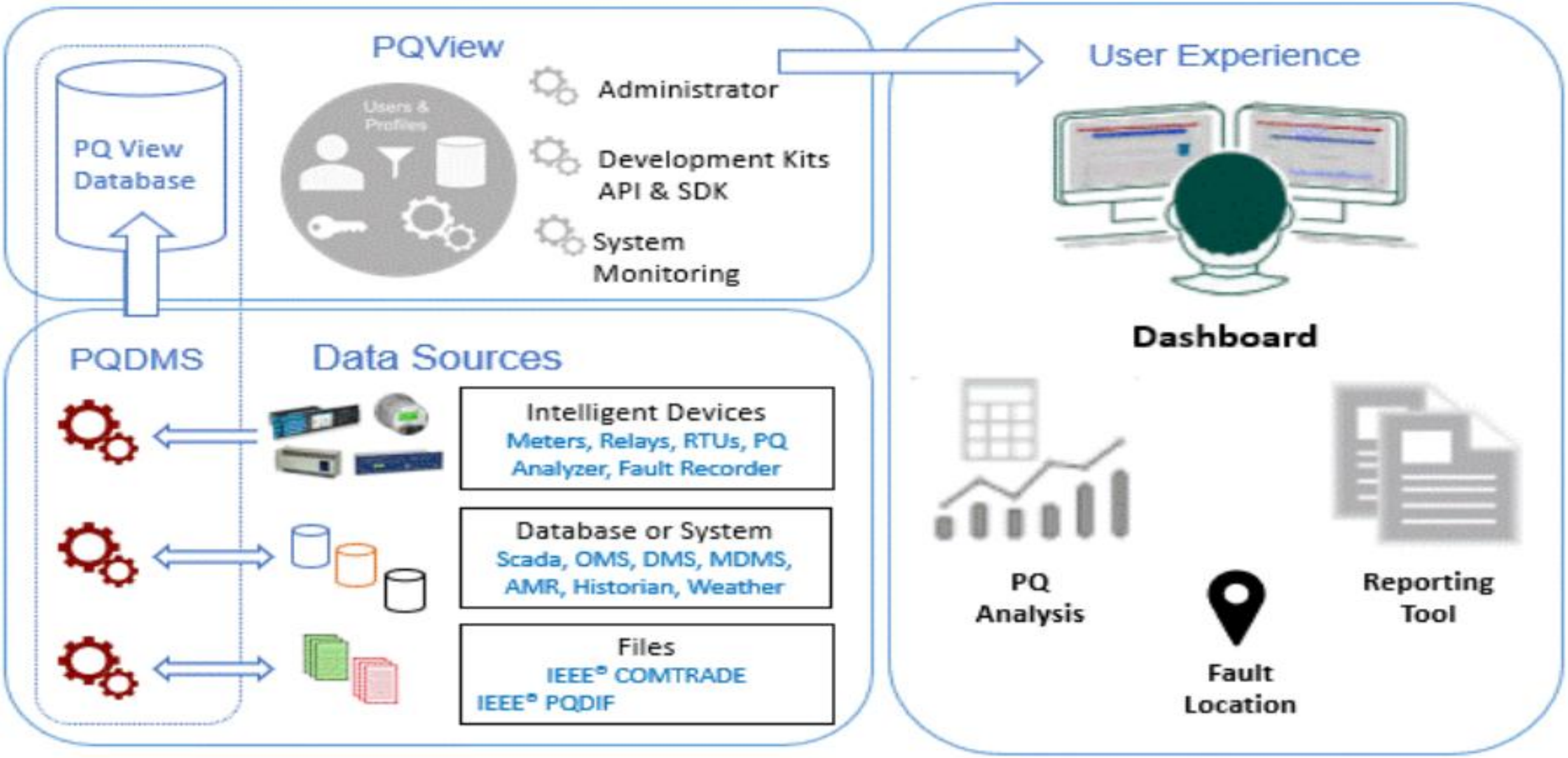
Grid Stability

- Intermittent supply makes it difficult to maintain the stability of energy passing through the grid
- Intermittent power increase, leads to challenges such as voltage and frequency variations , blackouts and significant capacity overbuilds

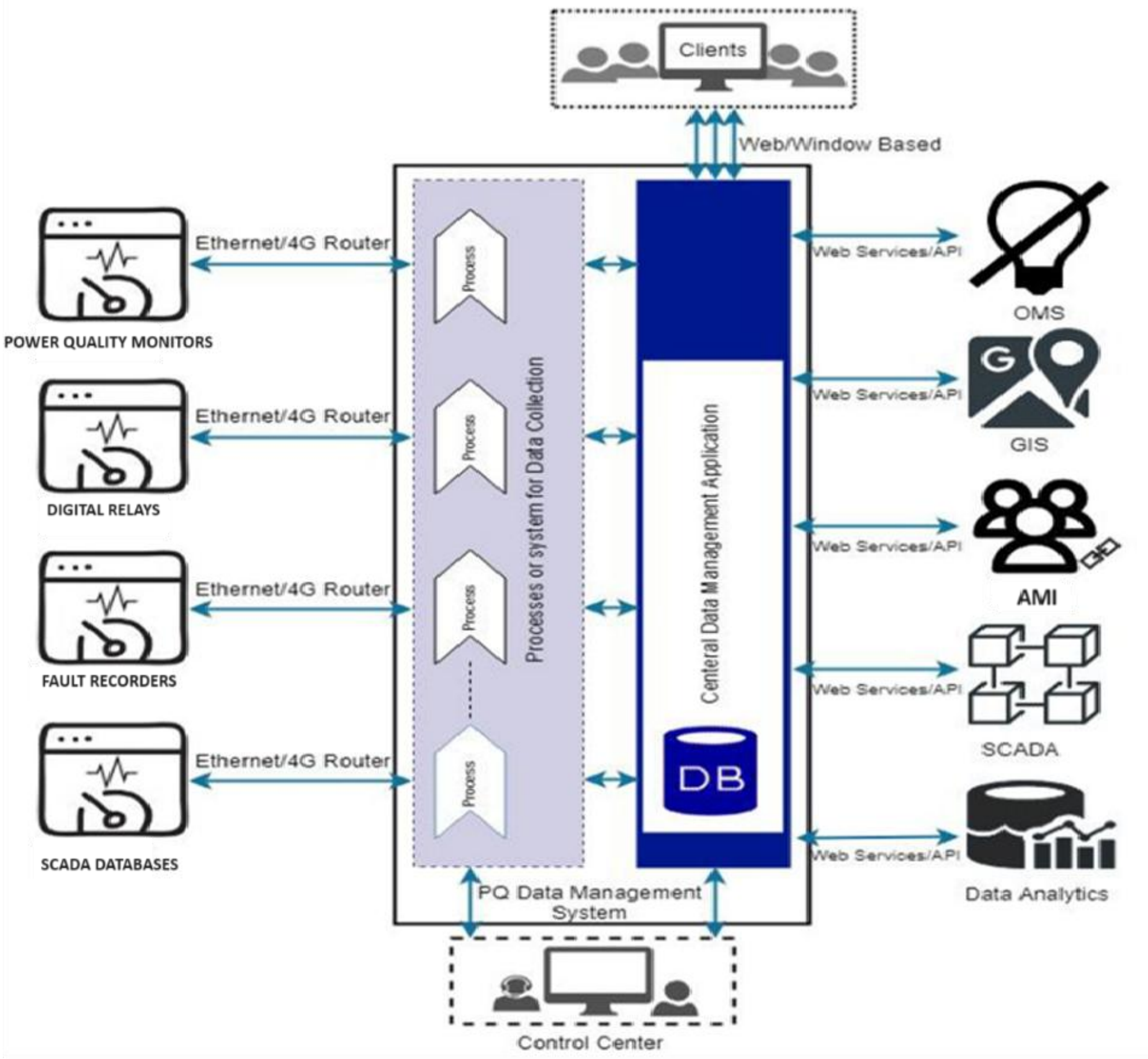
Cyber Security

- Cyber security/VAPT compliance for complete package
- Security at measuring devise level (IEC 27001)

Turning Data into Information

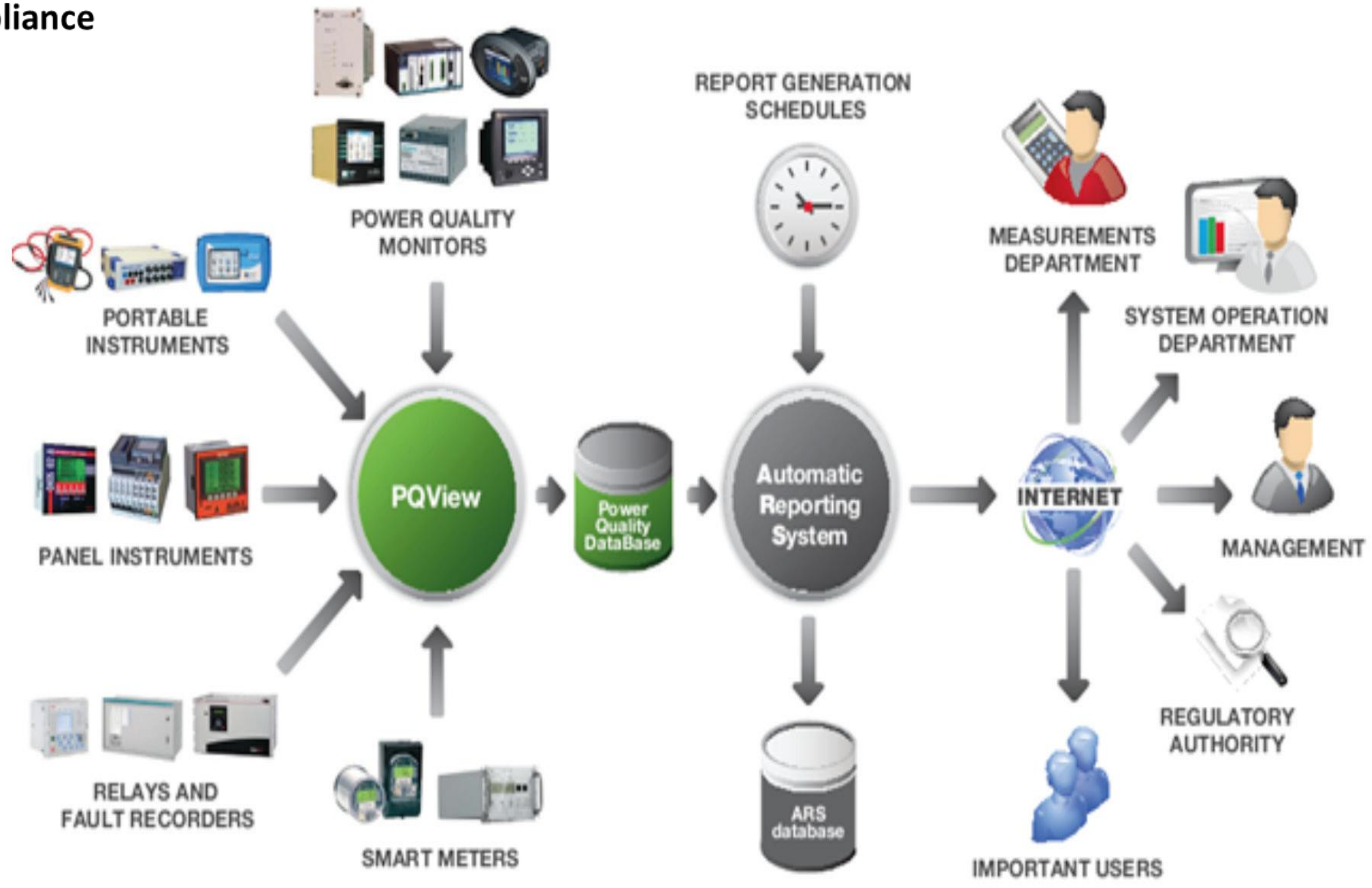


Power Quality Monitoring: Data Base Integration



Automatic Reporting System

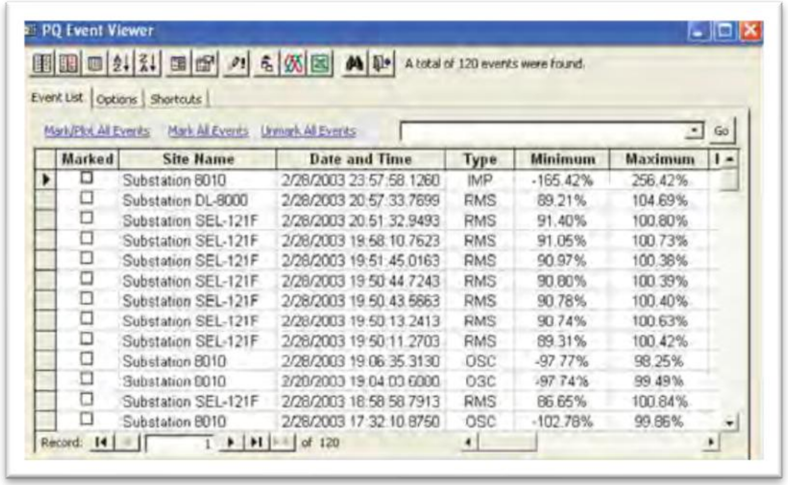
- **ARS supports unlimited number of different compliance criteria sets.**
- **Predefined compliance criteria files are available:**
  - EN 50160
  - IEEE 519
  - IEEE 1159
  - IEC 61000-3-7
  - IEEE 1564
- **Customer compliance criteria files can be defined**
  - Internal utility regulation
  - Contracts
  - National and regional standards
- **Compliance of**
  - Steady state parameters
  - RMS Events
  - Rapid voltage changes



PQ Event Analysis

Event Management

PQView® collects from multiple PQDMS instances in order to analyze data across multiple systems or manage communications with more than one monitoring system.



PQ Event Viewer

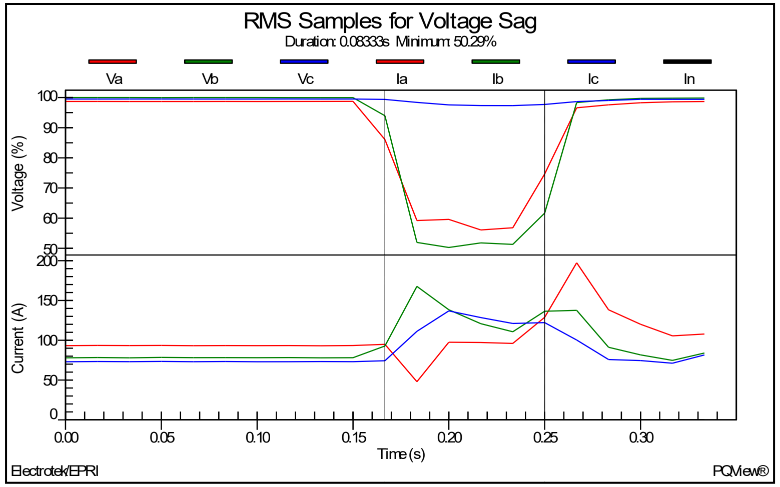
A total of 120 events were found.

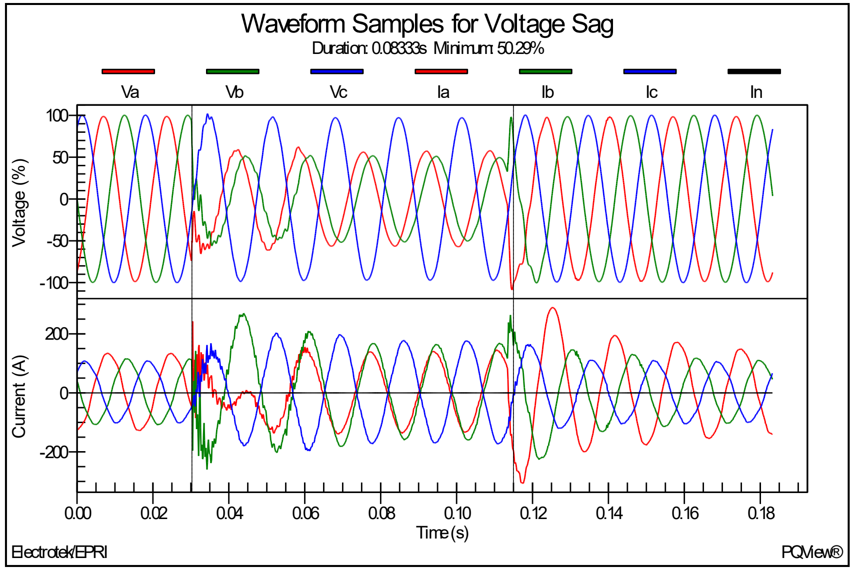
Event List | Options | Shortcuts

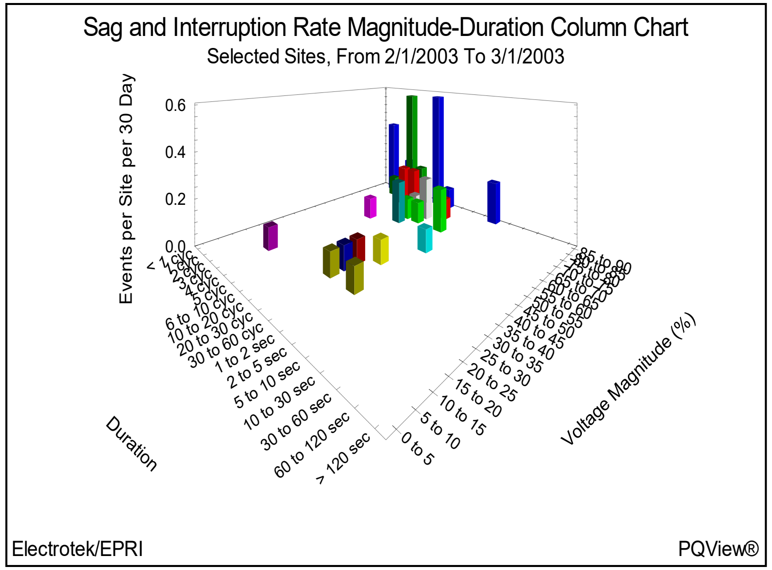
Mark/Plot All Events Mark All Events Unmark All Events Go

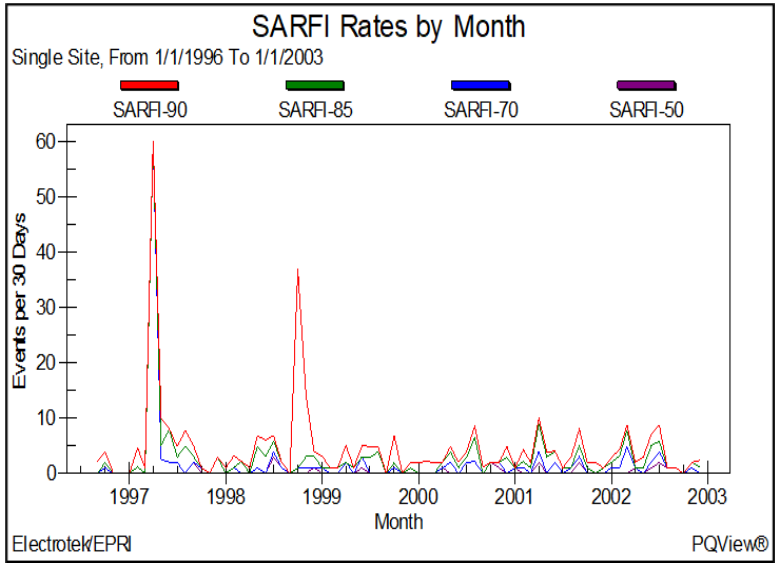
Marked	Site Name	Date and Time	Type	Minimum	Maximum
☐	Substation 8010	2/28/2003 23:57:58.1260	IMP	-165.42%	256.42%
☐	Substation DL-8000	2/28/2003 20:57:33.7699	RMS	89.21%	104.69%
☐	Substation SEL-121F	2/28/2003 20:51:32.9493	RMS	91.40%	100.80%
☐	Substation SEL-121F	2/28/2003 19:58:10.7623	RMS	91.05%	100.73%
☐	Substation SEL-121F	2/28/2003 19:51:45.0163	RMS	90.97%	100.38%
☐	Substation SEL-121F	2/28/2003 19:50:44.7243	RMS	90.80%	100.39%
☐	Substation SEL-121F	2/28/2003 19:50:43.5663	RMS	90.78%	100.40%
☐	Substation SEL-121F	2/28/2003 19:50:13.2413	RMS	90.74%	100.63%
☐	Substation SEL-121F	2/28/2003 19:50:11.2703	RMS	89.31%	100.42%
☐	Substation 8010	2/28/2003 19:06:35.3130	OSC	-97.77%	98.25%
☐	Substation 8010	2/28/2003 19:04:03.6000	OSC	-97.74%	99.49%
☐	Substation SEL-121F	2/28/2003 18:58:58.7913	RMS	86.65%	100.84%
☐	Substation 8010	2/28/2003 17:32:10.8750	OSC	-102.78%	99.86%

Record: 1 of 120









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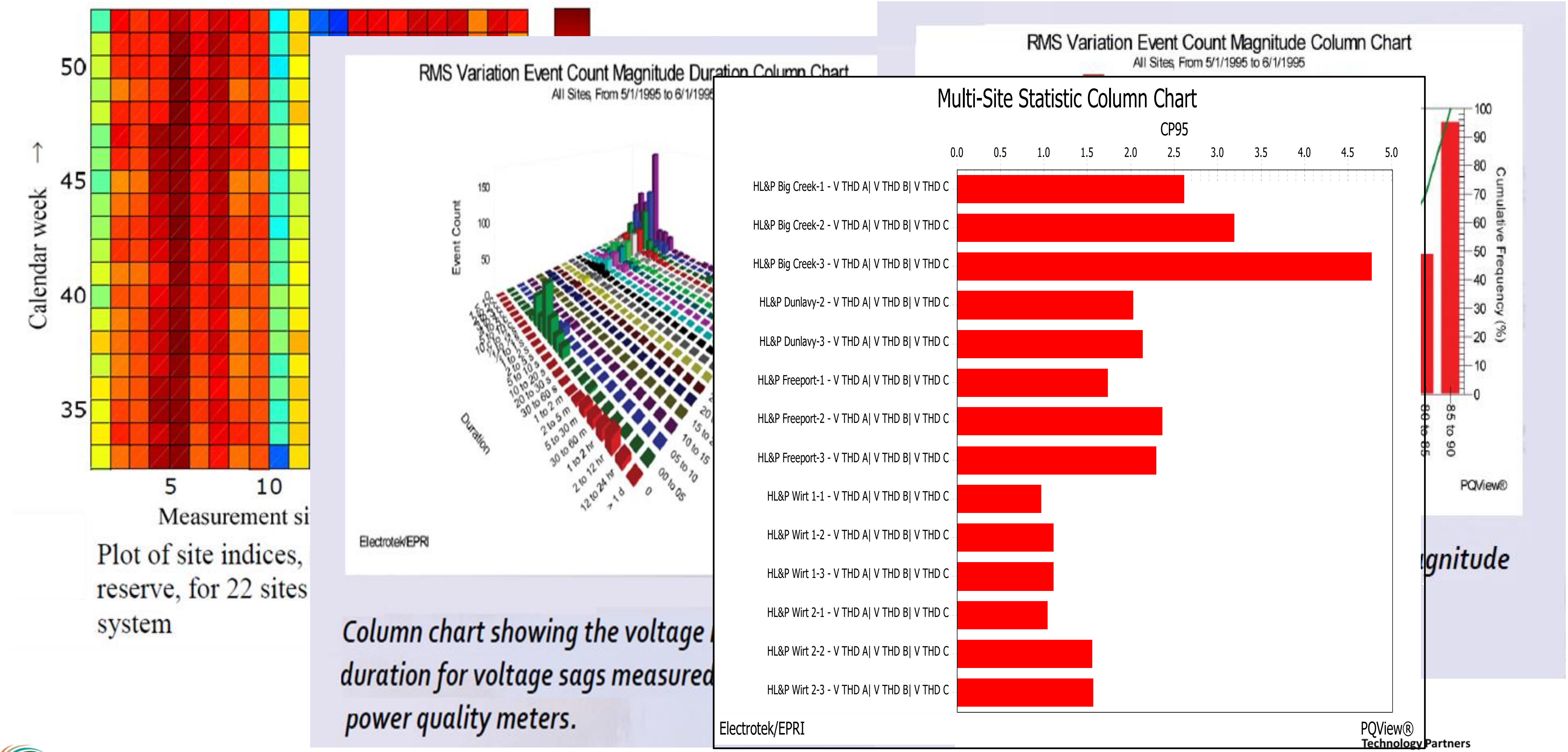
Statistical Evaluation of PQ data logs



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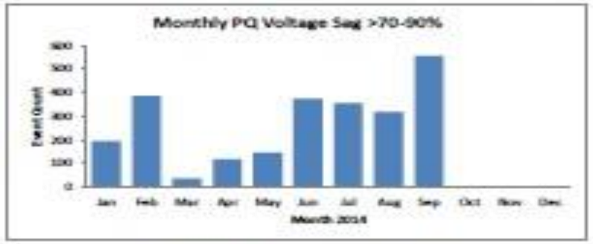
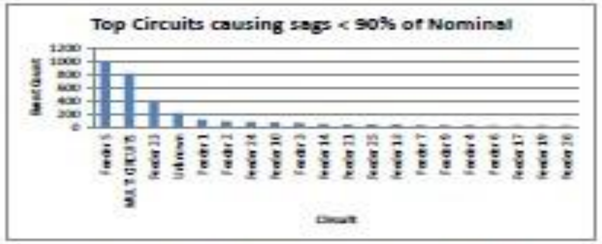
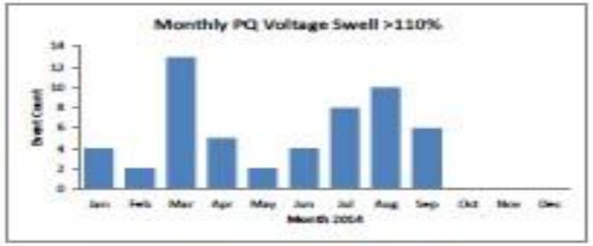
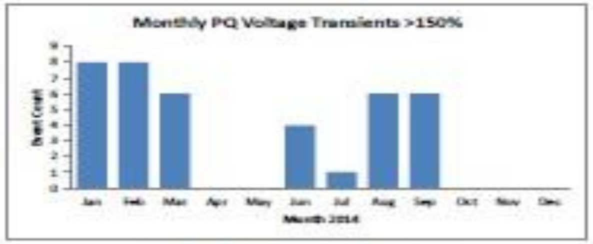
“Big Data” Sample Monthly Event summary

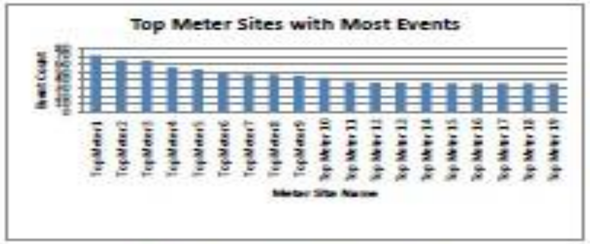
DEMO_Sept PQ Event Report.xlsx as of September 30 2014

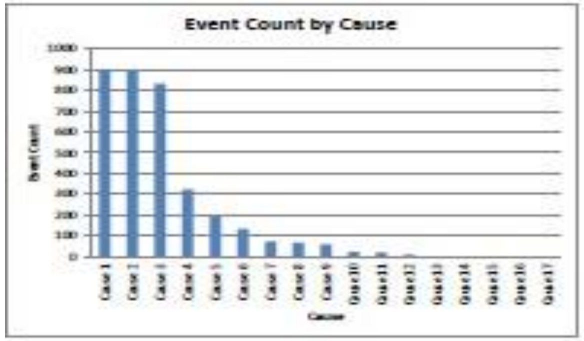


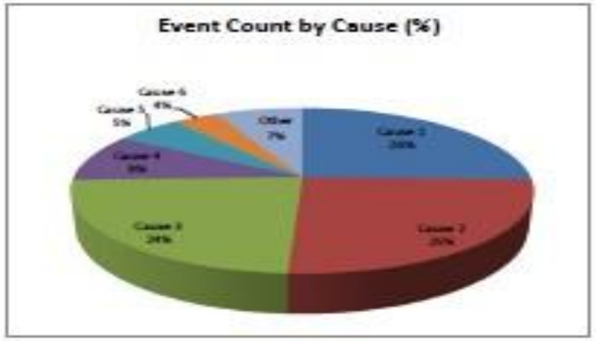


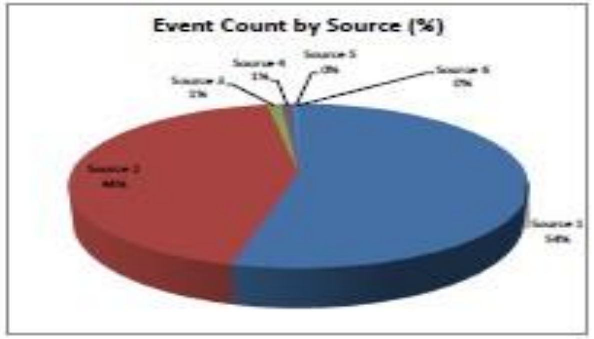












Total Sites Yearly Average	
Percent Of Total Meters Availability as of end of month	Availability 99.17%

Sites Below Yearly Average				
Site Name	Monitor Days	First Date	Last Date	Availability
Site 1	317	01/01/2014	30/09/2014	83.15%
Site 2	340	01/01/2014	30/09/2014	87.95%
Site 3	340	01/01/2014	30/09/2014	87.95%
Site 4	347	01/01/2014	30/09/2014	92.48%
Site 5	347	01/01/2014	30/09/2014	92.48%
Site 6	356	01/01/2014	30/09/2014	93.77%
Site 7	362	01/01/2014	30/09/2014	95.97%
Site 8	362	01/01/2014	30/09/2014	95.97%
Site 9	362	01/01/2014	30/09/2014	95.97%
Site 10	364	01/01/2014	30/09/2014	96.72%
Site11	366	01/01/2014	30/09/2014	97.44%
Site 12	366	01/01/2014	30/09/2014	97.44%
Site 13	367	01/01/2014	30/09/2014	97.82%
Site 14	368	01/01/2014	30/09/2014	98.17%
Site 15	369	01/01/2014	30/09/2014	98.52%
Site 16	369	01/01/2014	30/09/2014	98.52%

All meters not identified above [illegible] availability

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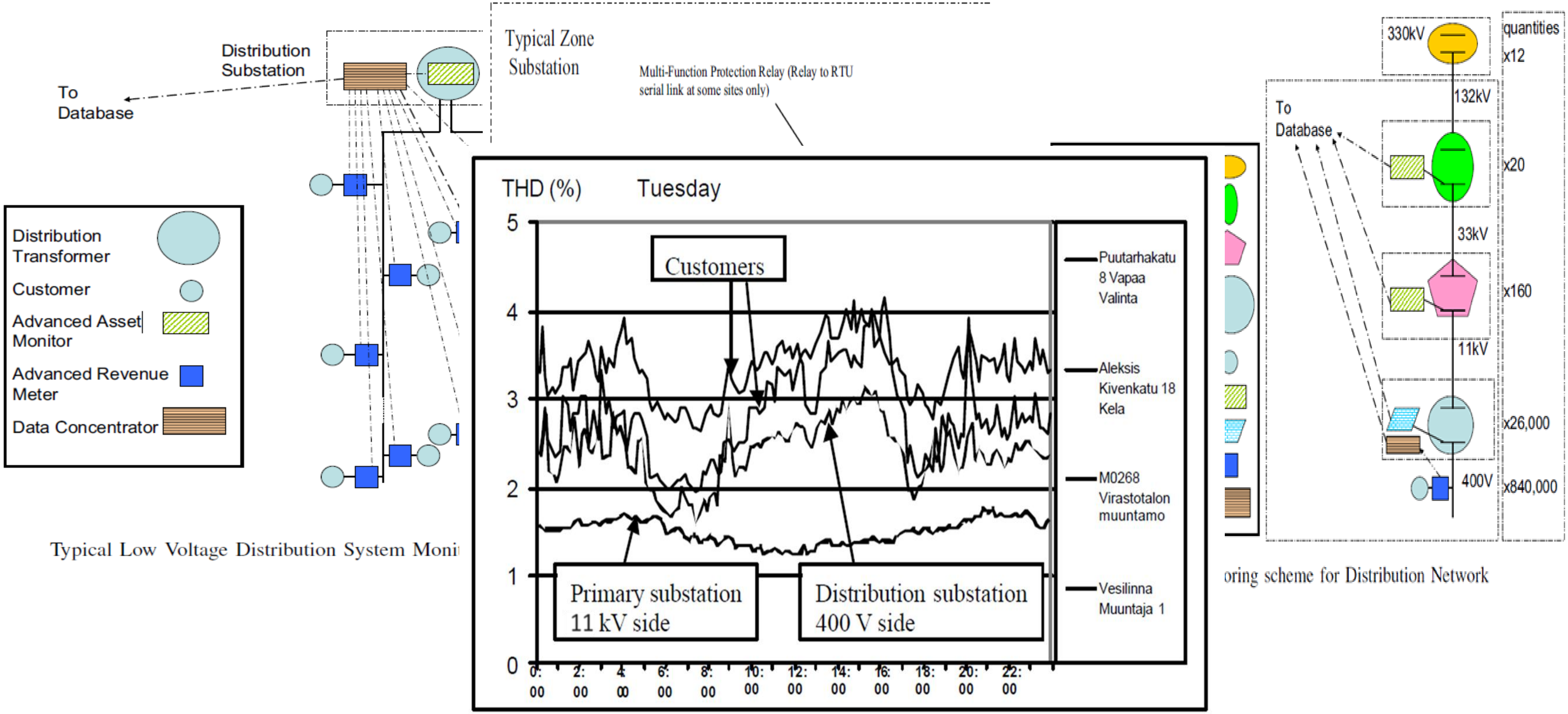
Case Studies

- AMI Integration for power quality
- Fault location module
- Wave Form Signature Analysis

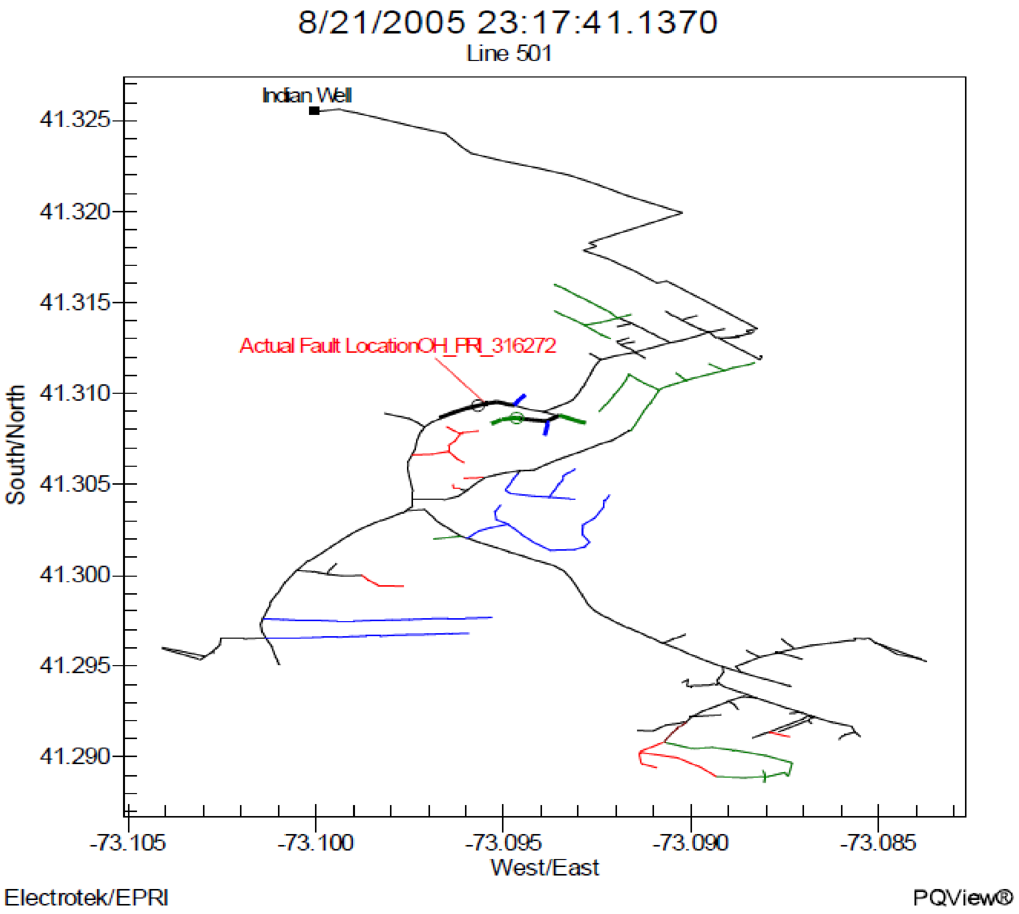
AMI Integration interfaces for power quality



Variations of the total harmonic distortion

Fault Location

ONE-LINE DIAGRAM SHOWING ESTIMATED AND ACTUAL FAULT LOCATION



ACTUAL AND ESTIMATED FAULT LOCATIONS AS VIEWED EXPORT FROM PQVIEW TO GOOGLE EARTH

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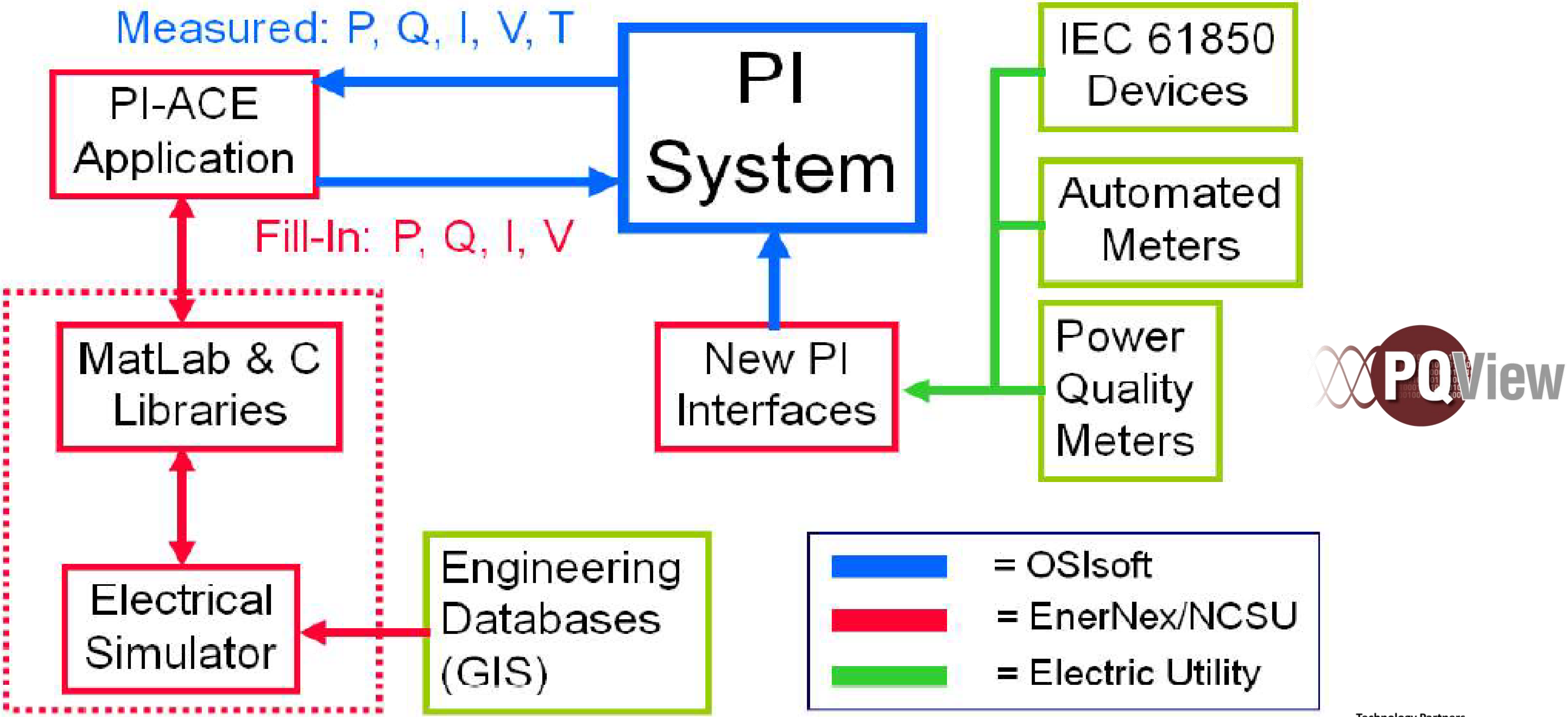
Using Big Data

Fault locations shaded by age. Brightest are the most recent

Recent lightning strike correlates with known fault location and auto-relocate

Rash of events in same area Trees?Bad insulators? Large population of squirrels?

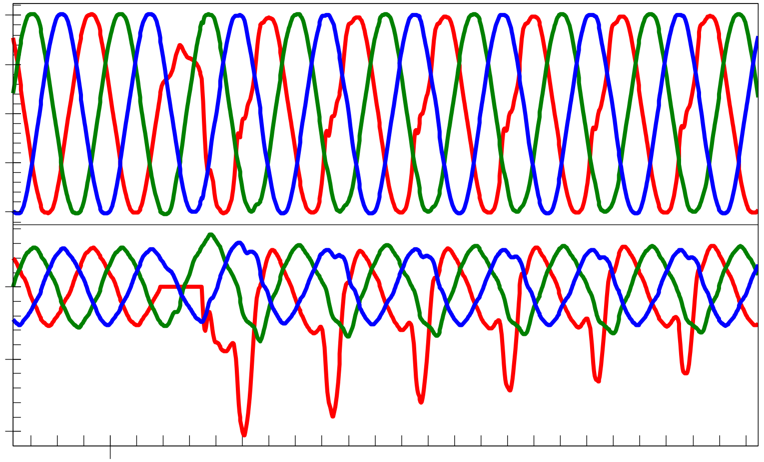
Interface Historian and feeder Model for State Estimation

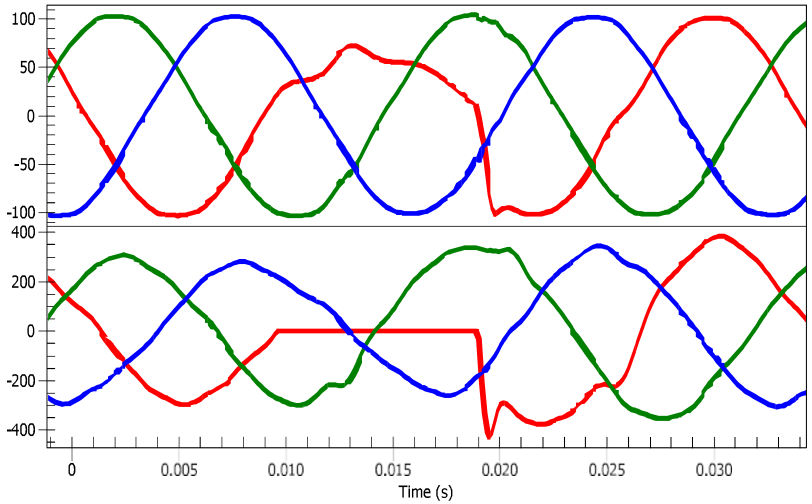


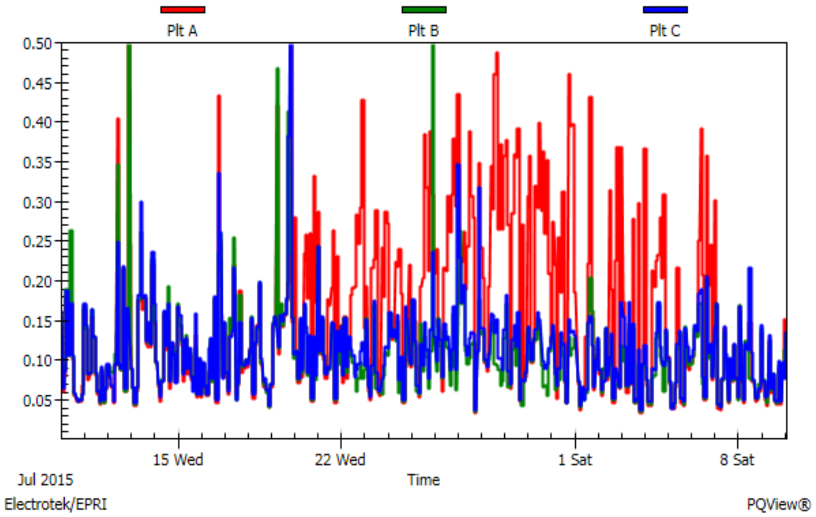
Proactive Systems Analysis (Wave Form Signatures)

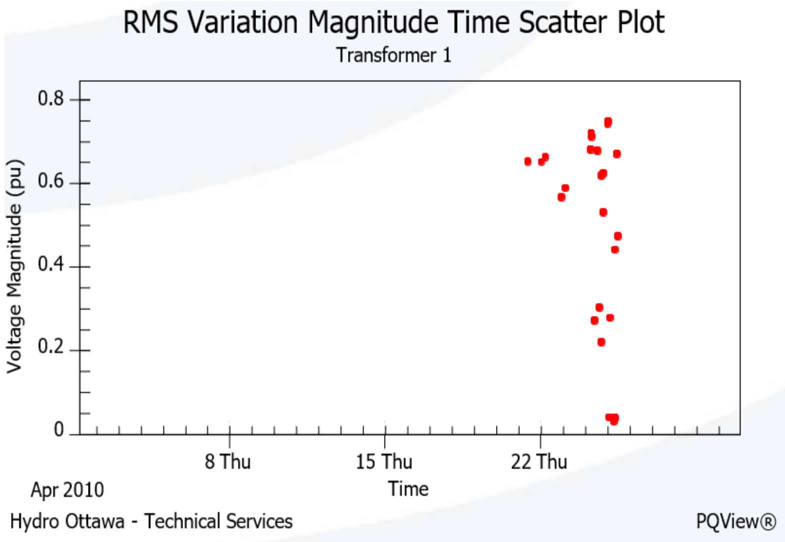
- **Incipient Fault Detection**
  - Short ¼ cycle events have been demonstrated to indicate an Incipient (coming) fault. Most common underground splices with water present.
- **Breaker Health**
  - The number of operations, combined with changing performance time and arcing can provide indication that the breaker may need replacement.
- **Transformer Health**
  - Oil analysis, temperature, vibration along with harmonic and waveform analysis provide evidence of transformer health.
- **Capacitor Bank Health**
  - Reactive power balancing, Switch restrikes, Synchronous Closing Control, Cap energization, Harmonic Resonance detection

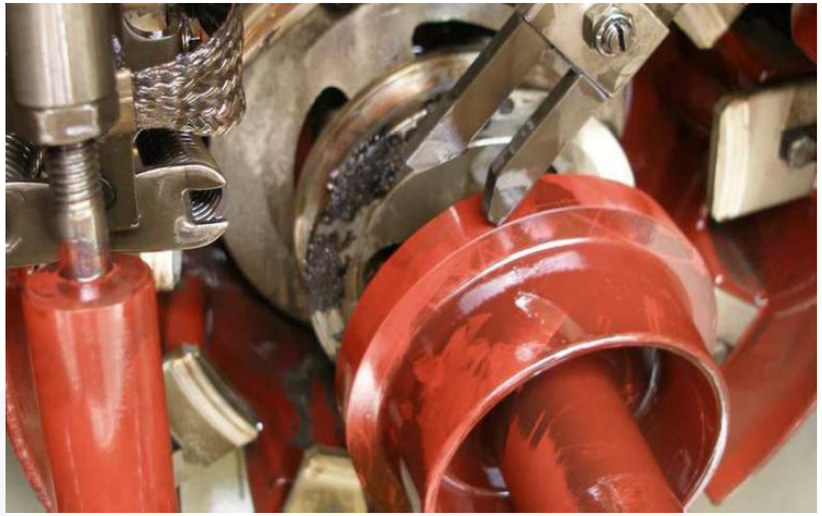
Wave Form Signatures : Tap Changer Failure











Load Tap Changer Failure- Due to a pin shearing and blocking contact movement to next position

PQView Users

BSES YAMUNA POWER LIMITED

adani Electricity

PSPCL Punjab State Power Corporation Ltd.

United States/Canada

- American Electric Power
- Alabama Power Company
- Baltimore Gas and Electric
- CMS Energy
- CPS Energy San Antonio
- Consolidated Edison Company of New York
- Detroit Edison Company
- Dominion Virginia Power
- Duke Energy Corporation
- East Kentucky Power Cooperative
- EnerNex Corporation
- Entergy Services
- EPRI
- Federal Aviation Administration
- FirstEnergy
- Georgia Power Company
- Hawaiian Electric Company
- Hydro One Networks
- Hydro Ottawa
- Knoxville Utilities Board
- Maui Electric Company
- Mississippi Power Company
- NIST
- Nebraska Public Power District
- Northeast Utilities
- Pepco Holdings, Inc.
- Public Service Electric and Gas Company
- Public Service of New Hampshire
- Salt River Project
- San Diego Gas and Electric
- Southern California Edison
- Southern Company
- Tennessee Valley Authority
- United Illuminating Company
- Wisconsin Public Service
- Wireless from AT&T

Asia-Pacific

- Companhia de Electricidade de Macau (CEM)
- Guangdong Power
- Hebei EPRI
- Henan EPRI
- Northern China EPRI
- Orion New Zealand Ltd.
- Provincial Electricity Authority
- Shanghai Municipal Electric Power Company
- Shanghai Jiu Long Electric Power Science & Technology Company
- Shanxi EPRI
- Transpower New Zealand

Latin America

- Central Hidroeléctrica de Caldas
- Operador Nacional do Sistema Eléctrico

Europe

- Agder Energi Nett AS
- BKK Nett AS
- CEE Energiteknikk AS
- Central Networks (E.ON)
- Elektro Slovenia
- Elektrobistand
- Hålogaland Kraft AS
- Helgelandskraft AS
- Hydro Aluminium AS
- Hrvatska Elektroprivreda (HEP)
- Istad Nett AS
- Lyse Nett AS
- Nordmøre Energiverk AS
- Notodden Energi AS
- PSE-Operator
- Rødøy-Lurøy Kraftverk AS
- SFE Nett AS
- Skagerak Nett AS
- SINTEF
- Statnett
- StatoilHydro
- Sunnfjord Energi AS
- Sweco Grøner AS
- Tafjord Kraftnett AS
- Tussa Nett AS

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THANK YOU.

Empowering India's Smart Grid Vision through PQ Intelligence

Presented by Anil Kumar

Director, Enspar Energy Solutions

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