Various and Sundry PQ Ruminations

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Power Quality

Transmission & Distribution PQ | PQ Data & Analytics | PQ Compatibility | PQ Knowledge

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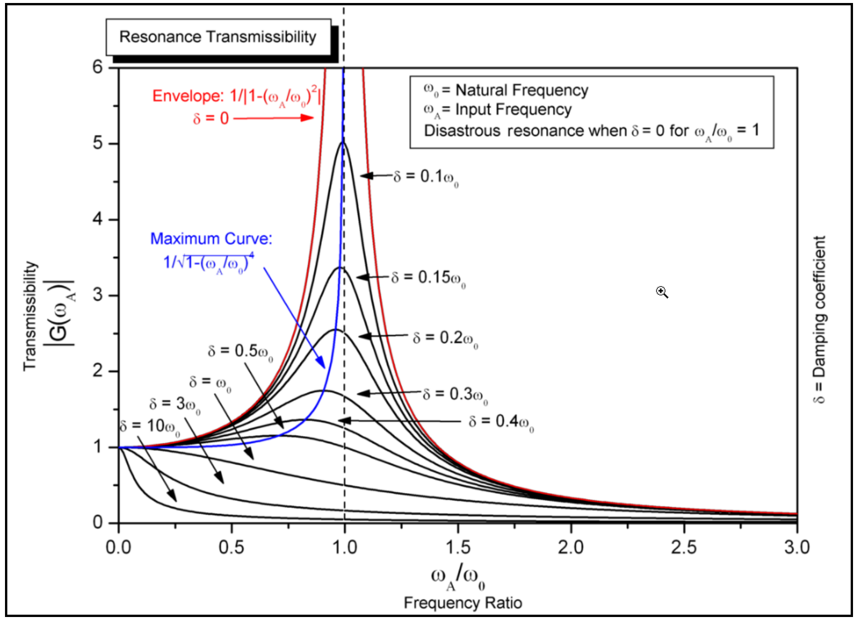
Harmonics: THD vs. Resonance

- Grid THD levels have increased
- Distribution levels have not been broadly excessive (not a problem)
- Transmission levels are approaching limits in standards (probably a problem)
- **Resonance** is the "elephant in the room"
  - Not quantified
  - Not tracked
  - Only crude management strategies
- **Need**: Nuanced approach to monitoring, measuring, and *managing* resonance broadly across the grid

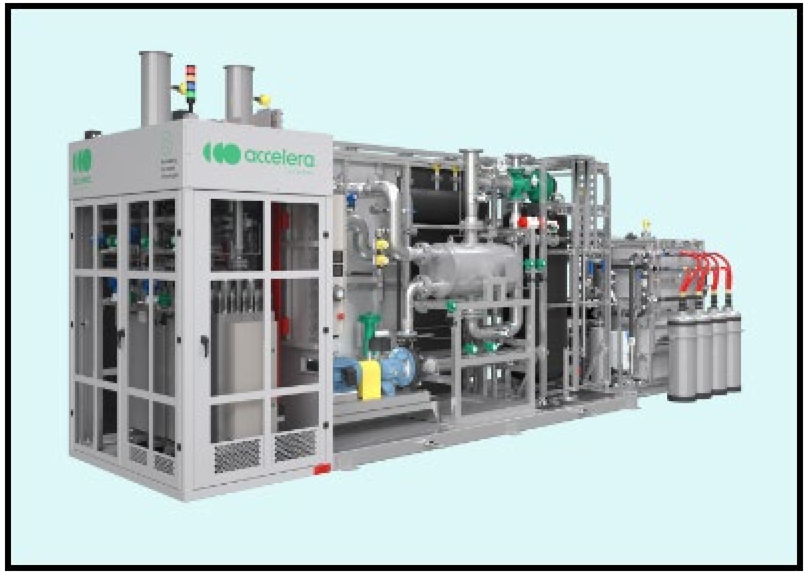


Our PQ Starting Point is Changing

- Power produced by large rotating generators is essentially perfect when created
- Allocations for DER-generated power is essentially equivalent to that for loads
- We have yet to collectively process this different starting point
  - Supply-side contribution to PQ
  - Background PQ levels are increasingly likely to exceed thresholds
- Harmonic performance of end-use devices *change* when powered with non-perfect power
- **Need**: Updated PQ management strategies when electric power itself is a contributor

Massive IBR and Inverter-Connected Systems

- Inquiry to EPRI:
  - 100s of 1,000+ vehicle charging parks worldwide
  - How to avoid grid impacts for all grids?
- Hydrogen:
  - EPRI Low Carbon Resource Initiative (LCRI) estimates a doubling of electric power requirements
- Inverter switching frequencies are the emerging "wild west" of electric power
- High frequency noise appears to be coupling through radiated/conducted emissions and via grounding pathways
- **Need**: Updated models for direct grid-connected IBR and high frequency noise



PQ as the new limiting factor for connecting load

- Classic approach:
  - Substation/system MVA ≈ Max. Load MVA
- Emerging new reality:
  - PQ constraints encountered before power capacity reached
  - Harmonic distortion / resonance
  - Voltage imbalance
  - Flicker
  - Inrush
  - Voltage/frequency stability
    - Australia PV example
- **Need**:
  - Proactive PQ, or massively overbuild
    - E.g. K-rated transformers
  - Utility compensation for managing PQ

PQ Standards are Antiquated

- Today’s PQ Standards are all based on vanishing assumptions:
  - Perfect power when created
  - Centrally generated power: Stiff / high inertia
  - Well behaved, well understood classic loads
  - Unidirectional power flow
  - Harmonics dominated by 5/7 and 11/13
- Emerging new reality:
  - DER-generated power is imperfect
  - Distributed generation with little/no resiliency
  - IBR and inverter-connected loads
  - Bi-directional and mixed phase power flow
  - High frequency noise
- Example: There is essentially no meaningful PQ standards for islanded operation
- Example: IEEE 519 applies only to the 50^{th} harmonic (3kHz/3.6kHz)
  - Evidence that inverter switching frequencies being pushed higher to avoid compliance issues
- **Need**: Updated approach to PQ Standards and management
  - Not just threshold based

Harmonics (IEEE 519-2014)

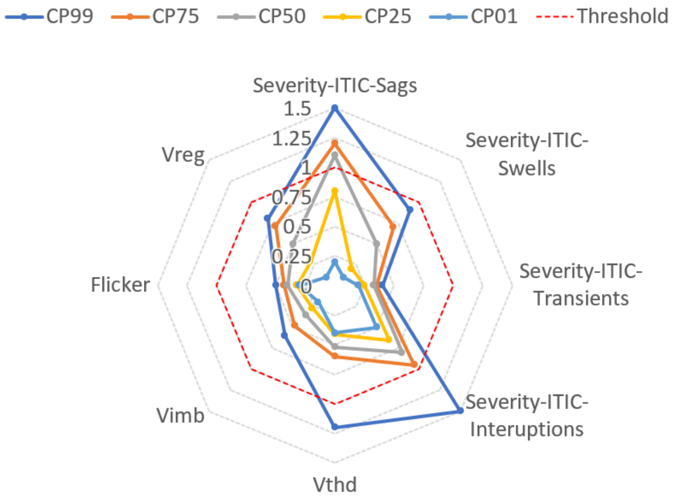
Table 1—Voltage distortion limits

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV $< V \leq$ 69 kV	3.0	5.0
69 kV $< V \leq$ 161 kV	1.5	2.5
161 kV $< V$	1.0	1.5[a]

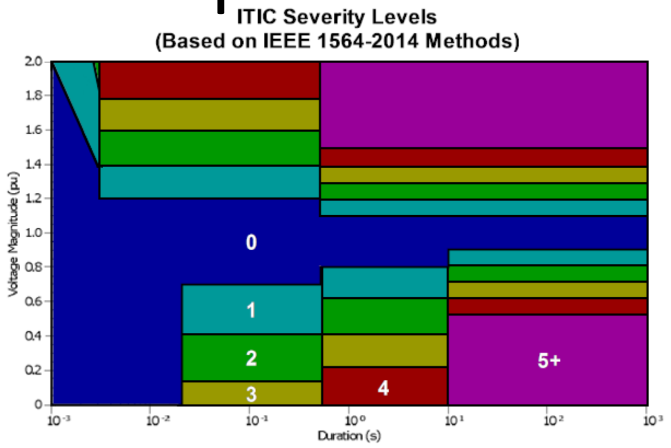
[a]High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.

PQ Phenomena are Treated as Isolated/Separate

- **Need**: “PQ Health Index”
- Combine PQ event and trend indices to form an overall PQ health index that can be used in PQ monitoring enterprise systems.



PQ Health Index: Analysis Steps

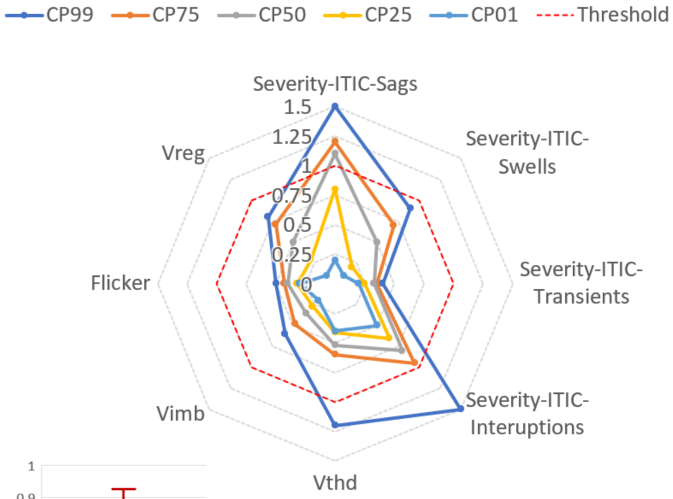


1 Normalize our Categories of PQ Data

- Event Data: IEEE 1564-2014
- Parameter Trends: Universal Limit = 1

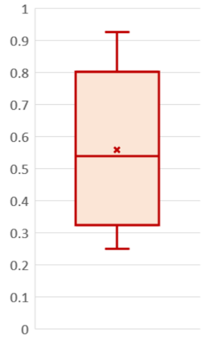
2 Temporal Aggregation

- Daily Cumulative Percentile with emphasis on CP99, 75, 50, 25, and 1.
- For events, most severe hourly event. CP's include each hour with no events.



3 Phenomena Aggregation

Average of each CP level. Box and Whiskers represents spread. The average of those represents the Single PQ Health Index (x) for the site.



4 Geospatial Aggregation

Average of Spider Diagram, Box and Whiskers, or the Index Average

PQ Health Index: Phenomena Normalization

PQ Health Index - Normalization	Vreg	Freq	Flicker	Vimb%	VTHD% IEEE-519				Sags IEEE-1668			Swells ITIC		Transients ITIC		
		Deviation (Hz)	PST		$V \leq 1.0$ kV	1 kV $< V \leq$ 69 kV	69 kV $< V \leq$ 161 kV	161 kV $< V$	TIII:10 – 50ms TII:10 – 200ms TI:10 – 200ms	TIII:50 – 100ms TII:200 – 500ms TI:200 – 500ms	TIII:0.1 – 2s TII:0.5 – 2s TI:0.5 – 2s	3 – 500ms	0.5 – 2s	0.16 – 1ms	1ms	1 – 3ms
									$V_{curve}(d) = 0.5pu$	$V_{curve}(d) = 0.7pu$	$V_{curve}(d) = 0.8pu$	$V_{curve}(d) = 1.2pu$	$V_{curve}(d) = 1.1pu$	$V_{curve}(d) = \sqrt{0.004/d}$		$V_{curve}(d) = -300\,d + 2.3$
3.0	15%	0.108	3.0	9%	24%	15%	7.5%	4.5%	NA	10%	40%	160%	130%	1300%	400%	220%
2.0	10%	0.072	2.0	6%	16%	10%	5%	3%	0%	40%	60%	140%	120%	900%	300%	180%
1.2	6%	0.043	1.2	3.6%	9.6%	6%	3%	1.8%	40%	64%	76%	124%	112%	580%	220%	148%
1.0	5%	0.036	1.0	3%	8%	5%	2.5%	1.5%	50%	70%	80%	120%	110%	500%	200%	140%
0.8	4%	0.029	0.8	2.4%	6.4%	4%	2%	1.2%	60%	76%	84%	116%	108%	420%	180%	132%
0.5	2.5	0.018	0.5	1.5%	4%	2.5%	1.25%	0.75%	75%	85%	90%	110%	105%	300%	150%	120%
0	0	0	0	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%

IEEE-1564

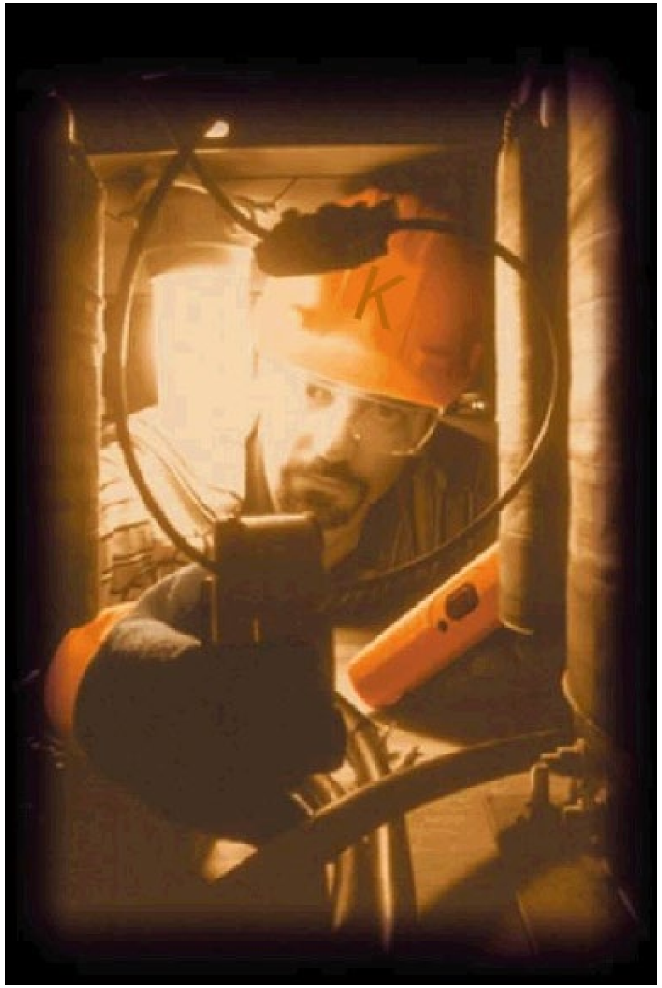
$$S_e = \frac{1 - V}{1 - V_{curve}(d)}$$

Getting Paid for PQ Management

- Classic approach:
    - PQ today is a reactive practice funded as an overhead/operations expense
- Emerging new reality:
    - The economic model for modern electric utilities is radically changing
    - Sources of ENERGY are proliferating
    - Sales of kWh are challenged
    - The only viable resource for ensuring the quality of POWER is the centralized, expert utility
- **Need**:
    - Capitalization of PQ efforts
    - "Rate Basing" of PQ
    - Bottom line: The utility needs to get **paid** for PQ

PQ Expertise: Business Models

- Electric utilities have a unique resource: PQ Expertise
- Leveraging PQ expertise through services:
  - PQ Walkthrough Studies
  - Comprehensive PQ Assessment Studies
  - Harmonic Diagnostics and Mitigation Studies
  - Grounding and Bonding Studies
  - Transient Surge Protection Studies
  - Temporary PQ Monitoring Diagnostic Services
  - Premium PQ Monitoring Service
  - Infrared Diagnostics and Testing Service
  - PQ Design Review
  - Customer PQ Training
- **A word of caution**:
  - Don’t compromise the core missing of existing PQ teams, i.e. solving customer problems
  - Don’t try to make existing technical staff into sales people
  - The goal is added revenue, not “profit”



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