# ECE 528 – Understanding Power Quality

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Lecture 20





## Today:

- Reliability and Power Quality Benchmarking
  - References
  - Benchmarking issues
  - Reliability indices
  - Power quality indices
  - Looking at real-world data

## References:

- Reliability indices and benchmarking
  - Text: PSQ section 3.8.6 (pg. 100+)
  - Standard: IEEE 1366 (2022)
- Power Quality indices and benchmarking
  - Text: PSQ Chapter 8
  - Standards:
    - IEEE 1159 – General PQ definitions
    - IEEE 1250/EN50160 – General PQ with performance ranges
    - IEEE 1453 – Flicker
    - IEEE 1564 – Voltage Sags and Swells



## Benchmarking issues

- Power quality and reliability may be inversely related
  - Recloser fuse saving versus trip saving
- Customers do not classify events the way utility engineers do
  - Process interruption versus power interruption
- Impact of events may vary from customer to customer
- A single “event” may contain numerous “components” and they may be different on different phases
  - Simultaneous sags and swells during ground faults

## Benchmarking issues

- Not reasonable to expect the same performance across all transmission and distribution systems
  - Geography
  - Weather
  - System density/feeder length
  - Underground/overhead
  - Protection scheme
  - Animals/vehicles/vegetation



## Commonly used reliability indices (IEEE Std. 1366-2022)

- SAIFI – System Average Interruption Frequency Index
  - How many sustained interruptions the average customer has per year
- SAIDI – System Average Interruption Duration Index
  - How long the average customer is interrupted per year (hours)
- MAIFI – Momentary Average Interruption Frequency Index
  - How many momentary interruptions the average customer has per year

## Commonly used reliability indices
(IEEE Std. 1366-2022)

$$\text{SAIFI}=\frac{\sum \text{Total Number of Customers Interrupted}}{\text{Total Number of Customers Served}}$$

$$\text{SAIDI}=\frac{\sum \text{Customer Minutes of Interruption}}{\text{Total Number of Customers Served}}$$

$$\text{MAIFI}=\frac{\sum \text{Total Number of Customer Momentary Interruptions}}{\text{Total Number of Customers Served}}$$ (Not in PSQ).

Sustained versus momentary may vary from 1-5 minutes.





## Power Quality and reliability indices - Trends

- Standards have been and are being developed which combine power quality and reliability indexes and benchmarks
- In Europe, EN 50160: “Voltage characteristics of electricity supplied by public distribution systems”
- In the US – IEEE 1250-2018: “Guide for Identifying and Improving Voltage Quality in Power Systems”

# EN50160 (pg. 322)

- Specifies acceptable limits, measurement interval, length of recording, and acceptance percentage.
- Example: Voltage sampled every 10 minutes for a week will be within 10% of nominal 95% of the time.
- Sets limits for:
  - Frequency
  - Voltage sags/swells
  - Interruptions (short and long (>3 min))
  - Voltage unbalance
  - Voltage harmonics, and more





# US Service Quality Benchmarking

- IEEE-1250-2018: Steady-state characteristics

| Voltage Metric | Benchmark | Target |
|---|---|---|
| Regulation | +/-5% for normal conditions<br>+/-10% for unusual conditions | CP95% |
| Unbalance | 2% negative sequence | CP95% |
| Distortion | 5% THD<br>3% individual harmonics | CP95% |
| Fluctuation/flicker | Pst < 1.0<br>Individual step changes less than 4% | CP95% |
| Frequency | +/-0.015Hz | CP95% |

Targets are based on 10-minute sample intervals

## Existing US power quality indices

- RMS variation indices
  - SARFIx: System Average RMS (variation) Frequency Index

$$SARFI_X = \frac{\sum N_i}{N_T}$$

$\sum N_i$ — customers experiencing qualifying events; $N_T$ — total customers served

  - Standard values:
    - 140, 120, and 110 – Overvoltage per ITI curve
    - 90, 80, and 70 – Undervoltage per ITI curve
    - 50 – typical motor contactor drop-out level
    - 10 – IEEE interruption
    - CBEMA, ITIC, SEMI
  - Note – each event is counted so SARFIx can be larger than 1.



## Existing US Power quality indices

- The duration of the RMS variation can be incorporated into the preceding indices
  - SIARFIx
    - System **Instantaneous** Average RMS (Variation) Frequency Index
  - SMARFIx
    - System **Momentary** Average RMS (Variation) Frequency Index
  - STARFIx
    - System **Temporary** Average RMS (Variation) Frequency Index

## Applications of RMS variation indices

(see pg. 100+ of PSQ for reliability indices)

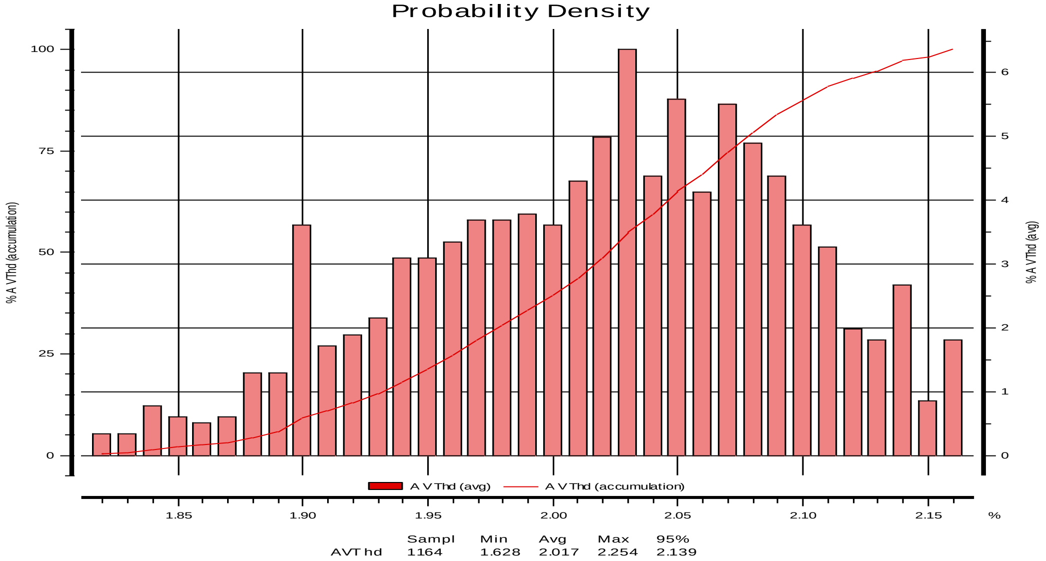
- SARFIx, SIARFIx, SMARFIx, and STARFIx can be determined for the system and for individual feeders or areas
- Feeders with below-average values can be targeted for improvement
- Feeders with above-average values can be studied for best practices



## Statistics

- Cumulative probability or frequency
  - Many standards, including IEEE 519-2022, EN50160, and IEEE-1250 allow the measured THD, voltage, frequency, etc. to fall outside the steady-state limits for short periods of time.
  - Cumulative probability
    - The sum of the probabilities of values above, below, or between specific points, depending on the limit in question
  - CP95
    - The point at which the "cumulative probability" equals 95%.

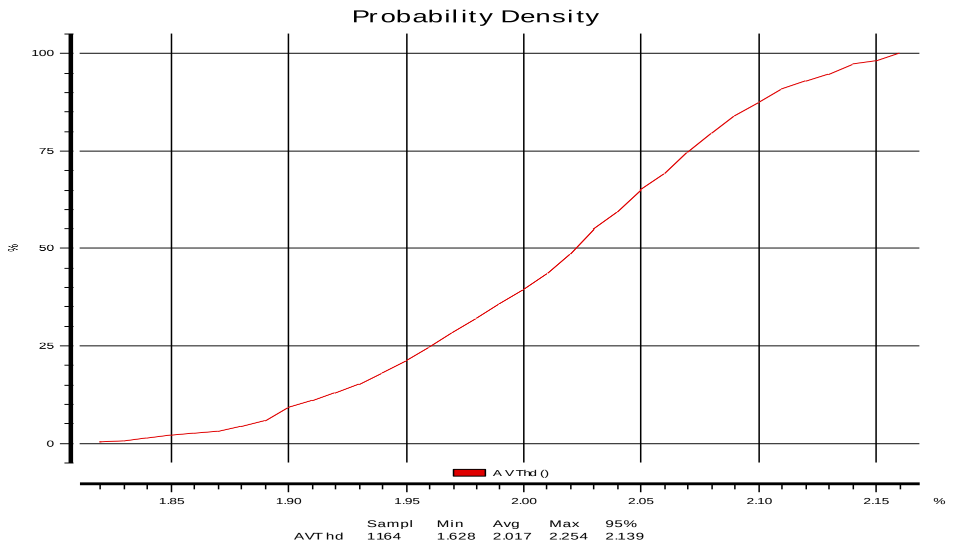
# A CP95 example




15 Lecture 20

15

# A CP95 example




16 Lecture 20

16

## Real-world benchmarking
## EN50160 report – application of CP95

**Power Frequency**

| Range | Threshold | Compliance | | | |
|---|---|---|---|---|---|
| 60 Hz +1%/-1% | 99.5% | 100.0% | | | PASSED |
| 60 Hz +4%/-6% | 100.0% | 100.0% | | | PASSED |

**Supply Voltage Variations**

| | | Compliance: | | | |
|---|---|---|---|---|---|
| Range | Threshold | CHA | CHB | CHC | |
| 277 V +10%/-10% | 95.0% | 100.0% | 100.0% | 100.0% | PASSED |
| 277 V +10%/-15% | 100.0% | 100.0% | 100.0% | 100.0% | PASSED |

**Rapid Voltage Changes**

Not available

**Flicker**

| | | Compliance: | | | |
|---|---|---|---|---|---|
| Range | Threshold | CHA | CHB | CHC | |
| <1 | 95.0% | 97.5% | 98.8% | 97.5% | PASSED |

**Supply Voltage Unbalance**

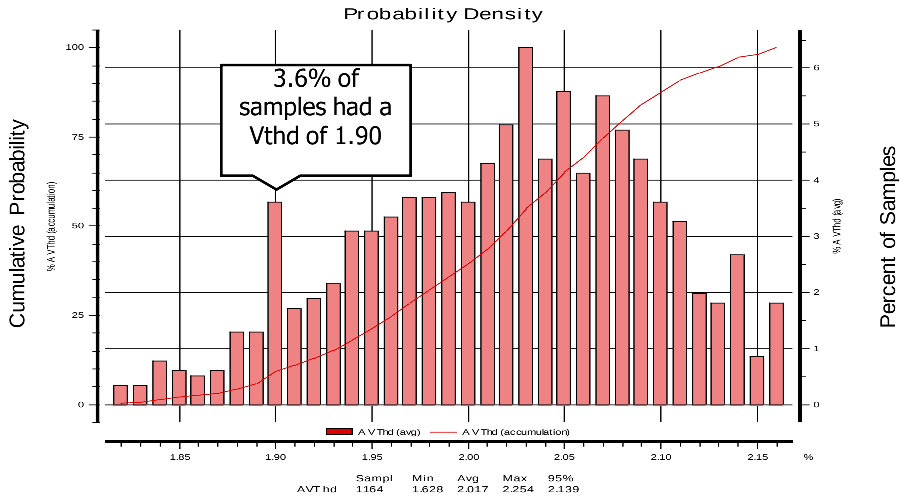
| Range | Threshold | Compliance | | | |
|---|---|---|---|---|---|
| 0-2% | 95.0% | 100.0% | | | PASSED |



## Harmonic indices (PSQ section 8.4)

- STHD95 – System Total Harmonic Distortion CP95
  - Example use:
    - Comparing $V_{THD}$ between different substations, is the substation's $V_{THD}$ above or below the STHD95 value?
  - Calculation:
    - For each substation, the CP95 value of the $V_{THD}$ recorded at the substation is calculated and weighted based on substation loading
    - The STHD95 is the "net CP95" value of all of the individual weighted CP95 values for individual substations

# Harmonic indices: $V_{THD}$ CP95








# Harmonic indices

- SATHD – System Average Total Harmonic Distortion
  - An “average of averages”
  - Example use:
    - Similar to STHD95 – find the mean THD of a group of feeders or substations
  - Calculation:
    - Sum the kVA-weighted, average THDs and divide by the total system kVA

## Use of harmonic indices

- STHD95 and SATHD describe the overall voltage THD on a system, but not the voltage THD experienced by individual customers
- Benchmarks may be chosen for these indices to help prioritize system improvements
- The data used to calculate STHD95 and SATHD can help identify areas of high and low distortion within a system
- Monitoring indices over time can help identify trends





## Benchmarking: Real-world data issues

- Voltage THD may not be the same on all three phases
  - General approach is to average the voltage THD.
    - Simpler reporting (one number)
    - May mask high values on one phase
- Numbers versus statistics
  - Some outliers may still require attention
  - Some outliers may get unnecessary attention
  - A statistician can be helpful

## Including Power Quality and reliability in distribution planning – the concept

- Additional utility system costs will be offset by reduced customer costs
  - More frequent tree-trimming
  - Shorter spans
  - Longer cross-arms
  - Increased animal guards
  - Reclosers/sectionalizers/fuses
  - Designing for higher wind-loading



## Including Power Quality and reliability in distribution planning - difficulties

- Accurate customer costs are difficult to obtain
  - Labor to respond to events
  - Production quantity and quality
  - Equipment damage
  - Disposal of waste
  - Failure to meet delivery obligations, and more…
- Certain PQ or reliability improvements may only benefit one customer or a small group of customers
- Normal statistical variation can mask the true impact of system changes in the short term

## Including Power Quality and reliability in distribution planning - contracts

- In the case of power quality contracts, costs are assigned to specific events
- Utility can analyze the cost of power quality events accurately and select improvements accordingly
- Offsetting utility costs, in the form of contract penalties, provide incentives to maintain or improve power quality and reliability





## Power quality contract example: Sag score

- What counts:
  - 75% or less on one or more phases
  - 15-minute aggregation
  - No minimum duration
  - All three phases are included, regardless of voltage
  - Voltages over 1pu set to 1pu
- What does not count:
  - Sags on unloaded feeders
  - Customer-caused sags

(See PSQ, section 8.5)

$$SagScore = 1 - \frac{V_A + V_B + V_C}{3}$$

Try one:

Va=0.818 pu

Vb=0.574 pu

Vc=0.823 pu

Sag score?:

But how much does it cost?...

## Power quality contract example:

### Calculating Payments

- SGPA (Service Guarantee Payment Amount) = $50,000
- Target sag score = 3.000
- Prior to sag, the score was 2.900 (no payment due)
- Payment starts for sag scores above target.
- For this example: Payment = (new sag score - target) x $50,000

________ = (2.9000+________ - 3.000) x $50,000

- After the target is reached: Payment = (individual sag score) x $50,000





## Next time…

- Start Distributed Generation (Distributed Resources) and Power Quality
  - Read Chapter 9
  - Homework 6 available