ECE 528 – Understanding Power Quality

http://www.ece.uidaho.edu/ee/power/ECE528/

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Lecture 19

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Today…

- Flicker
- Power quality and reliability benchmarking
  - Definitions
  - Motivation
  - Issues

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Flicker - definitions

- IEEE-100 definitions:
  - "A perceptible change in electric light source intensity due to a fluctuation of input voltage."
  - "A variation of input voltage sufficient in duration to allow visual observation of a change in electric light source intensity."
- In summary
  - "Flicker" refers to both: 1) a perceptible change in electric light intensity, and 2) the voltage variation responsible for that change in electric light intensity

Some useful flicker references

- IEEE-519-1992
- IEEE-141-1993
- IEEE-1453-2011/IEC 61000-4-15:2010 (Flickermeter)
- IEEE-1453-2022: (*IEEE Standard for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems*)
- *Flicker Interaction Studies and Flickermeter Improvement,* Rong Cai, PHd. Thesis -2009 http://alexandria.tue.nl/extra2/200911297.pdf
  - *Interesting reading…*

Flicker – new challenges

- Goal – predict human perception of changes in luminance AND light spectrum resulting from measured voltage variations
- Voltage variations may include:
  - RMS Dips
  - Interharmonics
  - Amplitude modulation (see PSQ fig. 7.15)
  - Notches
- Challenges:
  - Different lighting technologies respond differently
  - Seemingly identical lighting technologies may respond differently
  - Lighting changes may occur <u>without</u> voltage variations

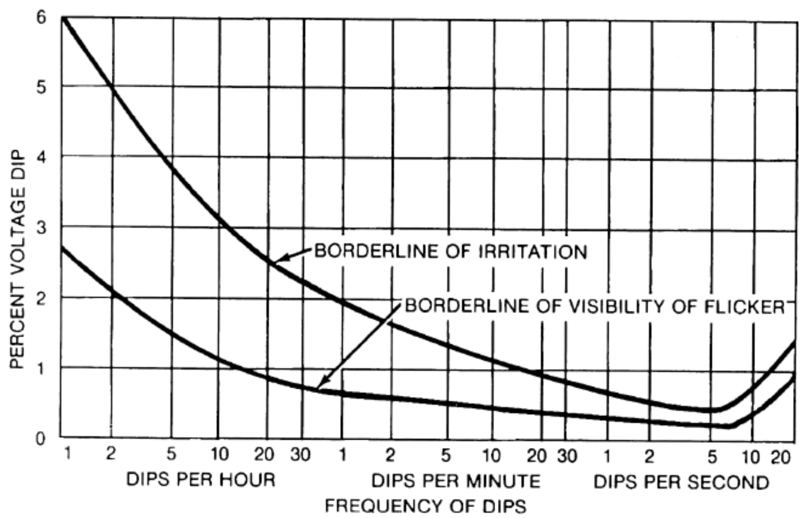
The evolution of flicker

Voltage Disturbance	+	Path	+	Vulnerable Equipment	=	PQ Problem
Voltage dip		Transformers/ wiring		Incandescent Lamp		Flicker (voltmeter)
Voltage dips (variable)		Transformers/ wiring		Incandescent Lamp		Flicker (Flickermeter)
Voltage dips Notches Harmonics (Ballast/Driver)		Transformers/ wiring + Ballast/Driver		Ballast/Driver Flourescent and LED lamps		Flicker?

Flicker

- Ch 7 (PSQ) discusses "traditional" flicker
  - Thresholds of objection and perception based on the frequency and the magnitude of the voltage variations (see figure 7.14)
  - Traditional curves are convenient for simple checks of one or two devices
  - Combined effect of multiple magnitudes and frequencies is not reflected in traditional curves

GE flicker curve from IEEE 1453-2015



Continuous, cyclic, or intermittent

- Continuous or cyclic
  - Results in voltage modulation or higher frequency voltage fluctuations
- Intermittent
  - Occasional voltage variations caused by faults, or motor-starts
  - Low to very low frequencies

Traditional flicker calculations

- Modulation

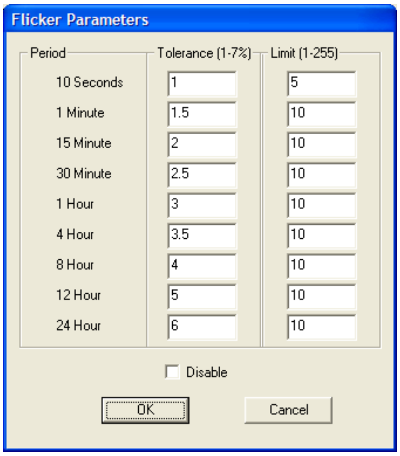
$$Percent\ voltage\ modulation = \frac{Vmax - Vmin}{Vo} x100\%$$

- Flicker

$$Percent\ voltage\ flicker = \frac{Vpre - Vmin}{Vpre} x100\%$$

Vo = average voltage

Investigating traditional flicker

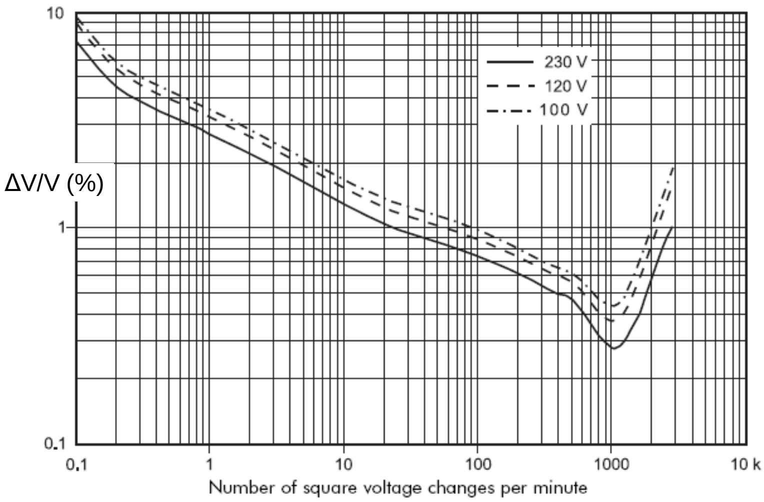


- Measure “pre” and minimum RMS voltage, and record or estimate frequency
- Some PQ recorders approximate threshold curves

Complex voltage variations and flickermeters IEEE Std. 1453

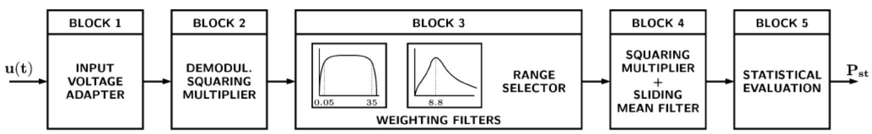
- Employs a special “flickermeter” (IEC 61000-4-15:2010)
- Threshold of irritation is still quite similar to IEEE-519-1992 or IEEE-141-1993 thresholds
- Advantages:
  - Includes the effect of multiple frequencies/magnitudes
  - Simplifies pass-fail testing provided the measuring or analysis tools are available
- Disadvantages:
  - Pass/fail assessment may correspond to lamp behavior

IEEE 1453/ IEC 61000-4-15 curves



IEEE 1453 Flicker evaluation

- Standard specifies a flickermeter
  - Processes voltage measurements to simulate their effect on <u>incandescent</u> bulbs, and the response of the human eye to those effects
  - Includes response to multiple flicker events of different magnitudes and frequencies
  - See pg. 517 in PSQ for a block diagram



From: ***Linearity of the IEC Flickermeter Regarding Amplitude Variations of Rectangular Fluctuations***
J. J. Gutierrez, *Member, IEEE, J. Ruiz, Member, IEEE, and S. Ruiz de Gauna*

The IEEE 1453 flicker values

- Flickermeter produces two important values:
  - Pst: The short-term flicker – calculated over a 10-minute interval. Value is normalized so that Pst > 1 indicates irritating flicker, for a 60-watt incandescent lamp.

$$P_{st} = \sqrt{0.0314P_{0.1} + 0.0525P_{1s} + 0.0657P_{3s} + 0.28P_{10s} + 0.08P_{50s}}$$

    - $P_{0.1}$, P_{1s}, P_{3s}, P_{10s}, and P_{50s} are the flicker levels exceeded 0.1%, 1.0%, 3.0%, 10.0%, and 50.0% of the time, respectively.
  - Plt: The long-term flicker, used for devices with duty cycles longer than 10 minutes.

$$P_{LT} = \sqrt[3]{\frac{\sum_{i=1}^{N} Pst_i^{\,3}}{N}}$$

IEEE 1453 uses N=12

Statistical compliance evaluations

- Compliance is based on statistical analysis of samples over a short period of time
  - IEC and IEEE compliance: 95% probability that Pst and Plt will be in the acceptable range
  - IEEE planning level: IEEE uses a 99% probability for planning purposes in flicker compliance evaluations.
    - When planning for new loads at the MV, HV, or EHV level, the expected flicker should be limited to lower levels 99% of the time.

IEEE-1453 planning and compatibility levels for Pst and Plt

	Planning Level (99%)		Compatibility Level (95%)
	MV	HV-EHV	LV
Pst	0.9	0.8	1.0
Plt	0.7	0.6	0.8

Concept: Design to the planning level to help ensure that the compatibility level limits are not exceeded.

Rapid voltage changes – another type of flicker

- Tend to be intermittent
  - Motor starts, regulator stepping, capacitor switching

Planning levels from IEEE Std. 1453-2022

Number of Changes, N	ΔV/V(%)	
	MV	HV-EHV
N ≤ 4 per day	5-6	3-5
N ≤ 2 per hour	4	3
N ≤ 10 per hour	3	2.5

Flicker sources

- Typical sources
  - Motors, welding or arc furnaces, compressors, some laser printers, car shredders, etc.
- PSQ mentions three conditions for noticeable light flicker:
  - A variable load
  - System impedance
  - Frequency of the voltage fluctuations
- A fourth condition:
  - Response of the lighting – Seemingly equivalent LED lamps may vary

Flicker mitigation

- Address the three conditions
  - Variable loads
    - Motor soft-starters or ASDs
    - Line reactors on arc furnaces
    - Design specifications in new equipment
    - Break up the load
  - Change the lighting
    - Fluorescent lamps flicker about 25% as much as an incandescent lamp for similar small voltage fluctuations
    - LEDs – try another make/model

Flicker mitigation

- System impedance/capacity
  - Reconductor
  - Larger transformers
  - Static VAR compensators
    - Inject reactive power during motor starts
    - May also correct power factor and filter harmonics
  - Thyristor switched capacitors

Flicker mitigation

- Variation frequency
  - Modify control system –
    - Increase bandwidth on pressure, temperature, level, etc. to reduce number of starts
  - Modify mechanical system – to reduce number of starts
    - Match equipment to the load
    - Build "inertia" into the system
      - Thermal mass
      - Increased storage of compressed air

Power Quality and Reliability Benchmarking: Defining terms (PSQ Ch. 8)

- Index or metric
  - A specific measured parameter
    - Voltage distortion, voltage unbalance, temperature, etc.
- Benchmark
  - A standard against which performance is measured
  - Typically, a single value, a range, or an upper or lower limit
- Target
  - Goals for specific indices based on benchmarks, local constraints, and specific objectives
  - Typically, a range, an upper or lower limit, or a probability
  - Rarely a specific value unless zero

Defining terms

- Benchmarking
  - The process of evaluating performance against some standard level of performance
  - Uses one or more defined indices or metrics
    - For each index or metric, we need to know:
      - What is measured and how
      - How often it is measured
      - The benchmark for that index
      - The target for that index
- Aggregation
  - Grouping events within a time period or only considering the worst event in the time period

Some examples:

Index or metric	Benchmark	Target
Temperature (deg F)	Thermostat setting (68F)	Room at +/-1 deg. of setting
Speed in MPH	80mph (highway in Southern Idaho)	Cruise control – speed limit +/- 2mph.
Voltage THD	<8%	<8% for 95% of 10-minute average values over 1-week

A target may be more or less restrictive than the corresponding benchmark.

More restrictive target: The voltage benchmark is +/-5%. The distribution engineer designs the system to operate in a voltage range of +/-3%.

Less restrictive target: IEEE-519 allows harmonics to exceed the table values 5% of the time.

Motivation – why benchmark?

- Benchmarking helps drive improvement
  - Under-performing areas can be identified
  - "Best practices" can be determined
- Helps ensure fact-based decision making
  - The power quality may seem good or bad, but is it?
  - How good or bad is it, specifically?
- Benchmarking helps establish a common set of measurable expectations
  - Regulators, utilities, and customers can agree to, and document indices, benchmarks, and targets

Motivation – why benchmark?

- Performance-based ratemaking
  - Links a portion of utility rates and profits to performance against specific benchmarks
- Power quality contracts (see example – PSQ section 8.5.3)
  - Contracts with individual customers that ensure a certain level of power quality and reliability, or refunds, in exchange for long-term contracts
  - Example: Sag Score
    - Aggregation interval is 15 min.

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

Benchmarking issues

- Power quality and reliability may be inversely related
  - Recloser fuse saving versus trip saving
- Customers do not classify events the way that 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

Next time…

- More on benchmarking
- Examples