Application of IEEE Std 519-1992 Harmonic Limits

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IEEE IAS Atlanta Section
September 17, 2007

IEEE IAS 52nd Pulp & Paper
Appleton, Wisconsin *June 19, 2006*

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Outline

- Introduction
- Harmonic Limits
- Point of Common Coupling (PCC)
- I_{SC}/I_L Ratio
- Total Demand Distortion (TDD)
- Harmonic Limit Enforcement
- Conclusion

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Introduction

- Harmonics cause problems in power systems
- IEEE Std 519-1992 provides a basis for limiting harmonics
- Harmonics basics
  - Voltage or current harmonics? Be clear!
  - Add in a "root-sum-square" fashion
  - Usually expressed as % of fundamental
  - Often better to express as Volts or Amps

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Harmonic Limits

- Utility is responsible for providing "clean" voltage
- Customer is responsible for not causing excessive current harmonics
- Utility can only be fairly judged if customer is within its current limits

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Harmonic Limits

Voltage Distortion Limits

Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5
NOTE: High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user.		

- Stricter limits at higher voltage
- Individual harmonics limited to lower levels than THD

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Harmonic Limits

Current Distortion Limits for General Distribution Systems (120 V Through 69000 V)

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	<11	11≤*h*<17	17≤*h*<23	23≤*h*<35	35≤*h*	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0
Even harmonics are limited to 25% of the odd harmonic limits above.						
Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.						
* All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.						

Where

I_{sc} = maximum short-circuit current at PCC.

I_L = maximum demand load current (fundamental frequency component) at PCC.

TDD = Total demand distortion (RSS), harmonic current distortion in % of maximum demand load current (15 or 30 min demand).

PCC = Point of common coupling.

Harmonic Limits

- Current harmonic limits vary
  - System short circuit vs. load size (I_{SC}/I_L)
    - Larger load: stricter limits
    - Weaker system: stricter limits
  - Higher order current harmonics
    - Stricter limits for higher order harmonics
  - Even order current harmonics
    - Stricter limits: 25% of odd harmonics
  - Dc offset
    - Not allowed

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Point of Common Coupling

- PCC is where harmonic limits are assessed
- Very misunderstood and misapplied part of IEEE 519
- Prevent one customer from harming another
- Not intended to be applied within a user's system

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Point of Common Coupling

- PCC definition, clarified by IEEE working group:

"The Point of Common Coupling (PCC) with the consumer/utility interface is the closest point on the utility side of the customer's service where another utility customer is or could be supplied. The ownership of any apparatus such as a transformer that the utility might provide in the customer's system is immaterial to the definition of the PCC."

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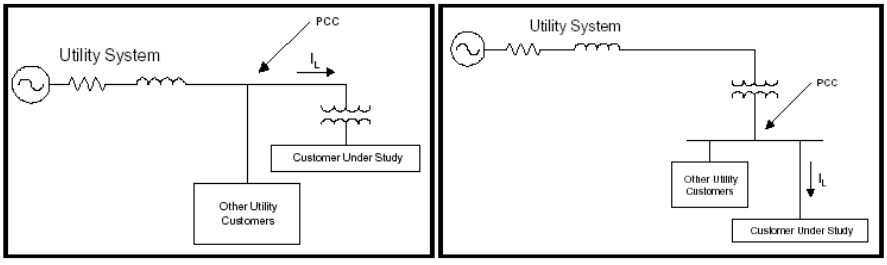
Point of Common Coupling

- PCC is where another customer can be served



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Point of Common Coupling

- IEEE 519-1992, Section 10.1:
  "The recommendation described in this document attempts to reduce the harmonic effects at any point in the entire system by establishing limits on certain harmonic indices (currents and voltages) at the point of common coupling (PCC), a point of metering, or any point as long as both the utility and the consumer can either access the point for direct measurement of the harmonic indices meaningful to both or can estimate the harmonic indices at point of interference (POI) through mutually agreeable methods. Within an industrial plant, the PCC is the point between the nonlinear load and other loads."

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Point of Common Coupling

- Section 10.1 definition
  - Assess harmonics anywhere?!
  - Used to apply 519 limits to individual loads
    - Significantly, and unnecessarily, increases users' costs
  - Not consistent with the intent of IEEE 519
- Good to voluntarily limit harmonics in your system, but not strictly required

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Point of Common Coupling

- Application advice
  - True PCC will often be at MV transformer primary
    - Regardless of transformer ownership or meter location
  - Not often practical to perform MV measurements
  - Common to measure on LV secondary
    - Do what we can safely and easily
    - Use I_{SC}/I_L ratio from primary to determine current limits
    - LV measurements are sufficient most of the time
  - If dispute between utility and customer, it may be necessary to measure or calculate harmonics at the MV transformer primary

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I_{SC}/I_L Ratio

- I_{SC}/I_L ratio shows relative size of the load compared to the utility system
  - Larger loads have greater ability to cause voltage distortion on the utility system
- Can use MVA_{SC} and MVA_L for this calculation

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I_{SC}/I_L Ratio

- I_{SC}: Three-phase fault current
- I_L: Maximum demand current
  - 15 or 30 minute demand, not momentary peak current
  - Common to use transformer full load current if planning for new load
  - Fundamental frequency component

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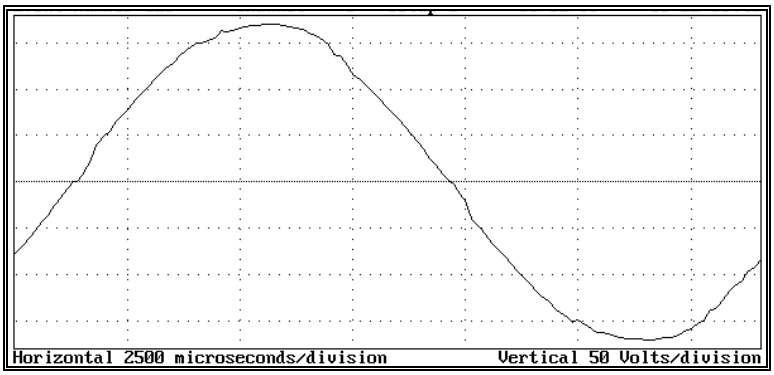
I_{SC}/I_L Ratio

- Load on utility power (high I_{SC})
  - Little voltage distortion: 2.3% THD_V



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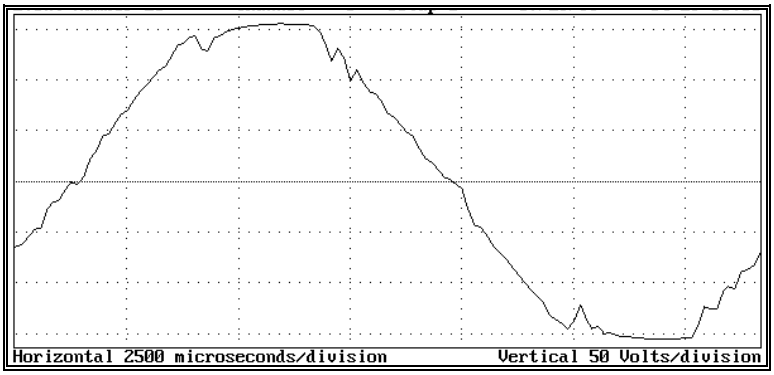
I_{SC}/I_L Ratio

- Load on backup generator (low I_{SC})
  - Significant voltage distortion: 5.7% THD_V



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Total Demand Distortion

- Current harmonic limits do not use common harmonics definitions
  - TDD (Total Demand Distortion)
    - Not THD (Total Harmonic Distortion)
  - Individual harmonics in % of I_L
    - Not in % of I_1 (fundamental)
- Harmonics meters measure THD and % of I_1

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Total Demand Distortion

- TDD and THD definitions are similar
  - Only difference is the denominator

$$THD_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + \ldots}}{I_1}$$

$$TDD_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + \ldots}}{I_L}$$

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Total Demand Distortion

- Important to distinguish between TDD and THD (and % of I_L and % of I_1)
- Prevents user from being unfairly penalized during periods of light load
  - Harmonics could appear higher as a percent of a smaller I_1 value

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Total Demand Distortion

- Application advice
  - Post-processing of data necessary to properly assess IEEE 519 current harmonic limits
  - Try to ensure all harmonic loads AND all linear loads running during measurements
    - Closer match of THD and TDD, easier to assess limits
  - Real world: Compare THD and % of I_1 measurements to limits, see if there is a problem
    - Rarely need to convert to TDD and % of I_L
    - If THD and % of I_1 measurements meet limits, then TDD and % of I_L values will also meet limits
    - Only convert to TDD and % of I_L when necessary

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Harmonic Limit Enforcement

- Harmonic current limits (for individual customers) are not actively enforced
  - Investigated only if voltage is distorted
- Common to measure harmonic currents in excess of limits, without problems
- Problems will often be noticed in excessive voltage distortion first

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Harmonic Limit Enforcement

- New customer may seem to cause harmonics problems
  - In reality, the additional harmonic current is the "straw that broke the camel's back"
  - Other existing customers also to blame
- System changes (customer or utility) can cause harmonic levels to rise
  - Power factor correction capacitors
    - Harmonic resonance

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Conclusion

- Limits assessed at the PCC
- PCC is the point where another customer can be served
  - Regardless of metering location
  - Regardless of equipment (transformer) ownership
- I_{SC}/I_L ratio must be known to determine which harmonic current limits apply

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Conclusion

- TDD versus THD
  - TDD: Harmonics expressed as % of I_L
  - THD: Harmonics expressed as % of I_1
- IEEE 519 harmonic current limits written in terms of TDD, and % of I_L
  - Prevents users from being unfairly penalized during periods of light load

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Conclusion

- Not always practical or necessary to:
  - Measure at the true PCC
  - Convert THD and % of I_1 values to TDD and % of I_L
- Useful to know what we would want to do in a perfect world
- Use engineering judgment to know when you have to sweat the details

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Future of IEEE 519

- More concise document
  - Some content moved to subsequent application guide
- PCC clarified
  - Same concept as mentioned in this paper
- New voltage range
  - 1.0 kV and below
    - 8% THD_V
    - 5% individual voltage harmonics

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Future of IEEE 519

- Will provide measurement guidance
  - 200 msec measurement window
    - 12 cycles at 60 Hz
  - Aggregation of harmonic measurements
    - Way to reduce impact of momentary events
      - Instead of unclear wording of previous version
    - Very short time harmonic measurements
      - 15 consecutive 12-cycle measurements (3 seconds)
    - Short time harmonic measurements
      - 200 consecutive "very short time" measurements (10 minutes)

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Future of IEEE 519

- Statistical evaluation of harmonic limits
  - Very short time (3 second) measurements
    - 99th percentile over 24 hour period
      - Voltage: Less than 1.5 times limits
      - Current: Less than 2.0 times limits
  - Short time (10 minute) measurements
    - 95th and 99th percentiles over 1 week period
      - Voltage: 95th percentile less than limits
      - Current: 99th percentile less than 1.5 times limits
      - Current: 95th percentile less than limits

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Future of IEEE 519

- Interharmonics
  - Below 120 Hz, based on voltage flicker limits

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Eaton's Power Quality Experience Center and Lab

Tell me and I will forget. Show me and I will remember. Involve me and I will understand.
-Confucius

The End