
# Facility Harmonics

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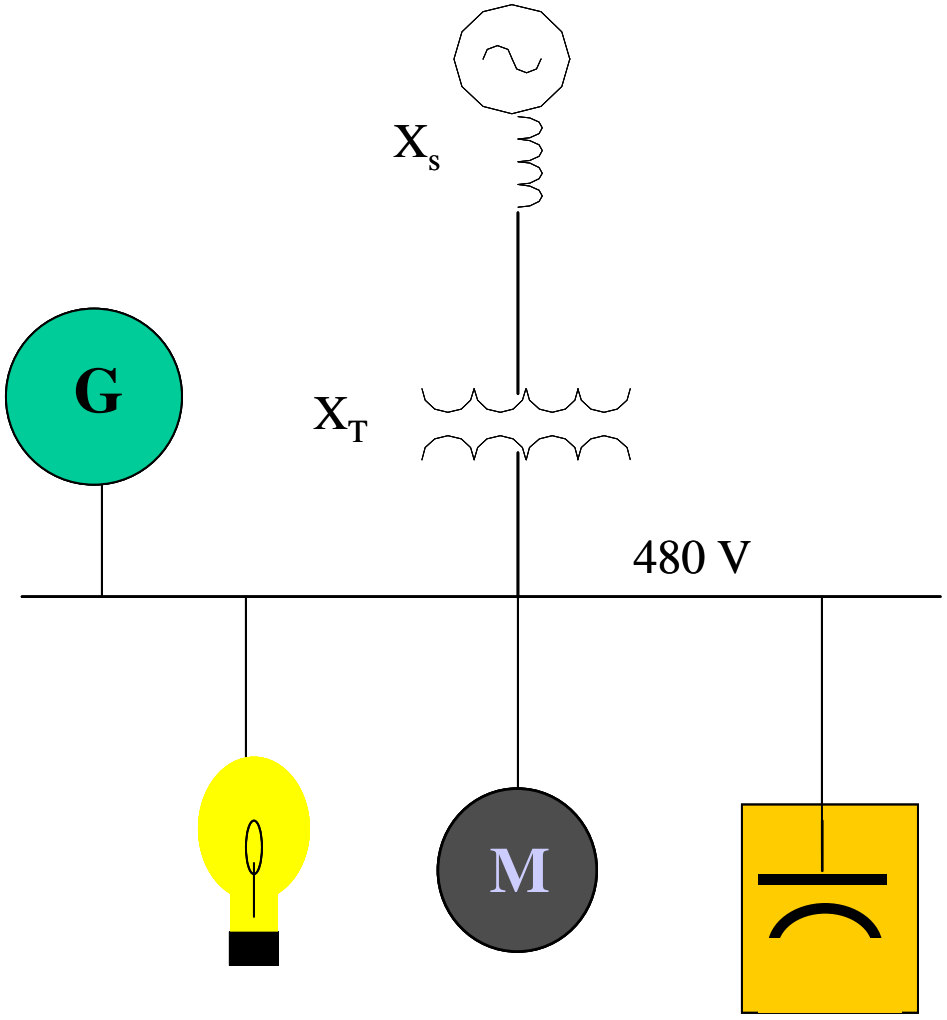
# Purpose and Learning Objectives

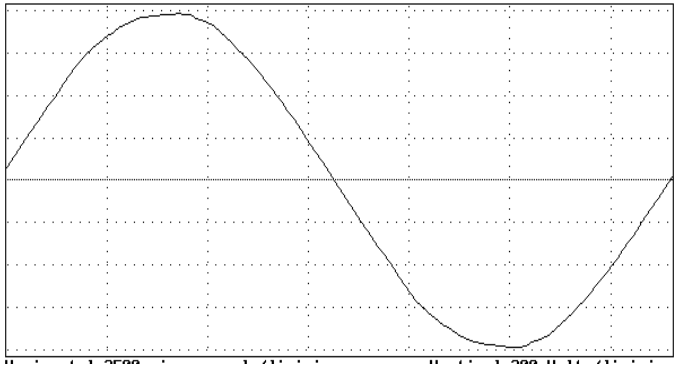
- Purpose of this class is to:
  - Help understand what Harmonics are and what causes them. Focus will be on the Variable Frequency Drive as a “harmonic contributor”
  - Learn about the IEEE recommendations for measuring and calculating Harmonics
  - Help you realize the potential damage Harmonics can present if not addressed
  - Learn about the tools used to analyze and mitigate Harmonics
- At the end of this presentation, you will be able to:
  - Recognize that Harmonics can be harmful to a facility and to understand the various tools available for measuring, analyzing, and mitigating Harmonics within IEEE-519 compliance.

# Topics

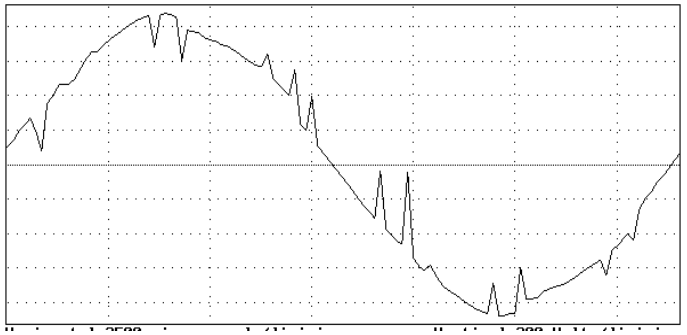
1. What are Harmonics?
2. IEEE-519 Recommendations
3. Who Cares?
4. Tools to analyze and mitigate

# A Long, Long Time Ago….
# The World was Linear



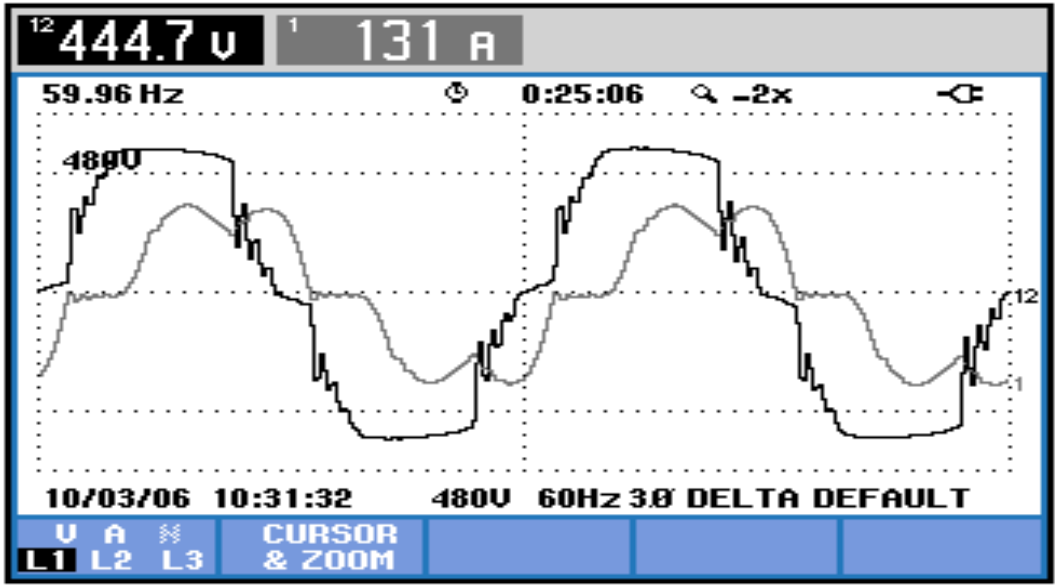



# Today . . . Increasingly Non-linear



# What Are Harmonics?

Harmonics are generated by non-linear loads (switching power supply's and VFD's for example) and result in a distorted AC sine wave which can cause many detrimental issues in an electrical distribution system

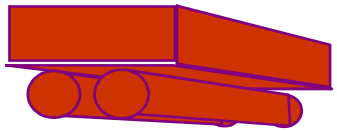


# What Are Harmonics?

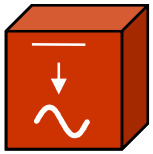
- Most often harmonics occur when a device is converting AC power to DC power
- The diodes on the front end of a VFD, UPS, electronic charger, CFL or LED lamp, or lighting ballast are constantly switching in order to convert the incoming AC power into DC power
- The constant switching of the diodes causes these devices to be a non-linear load

# Harmonics Sources

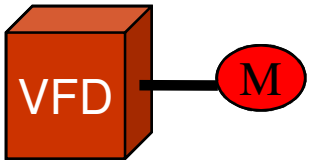
Unlike passive linear loads of yesterday, modern electronic power conversion equipment introduces harmonic currents and voltages into the utility supply. Harmonics can be thought of as power which do no useful work but requires extra generation and distribution capacity. Some examples include:



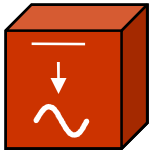
Lighting ballast, CFL, LED



UPS systems

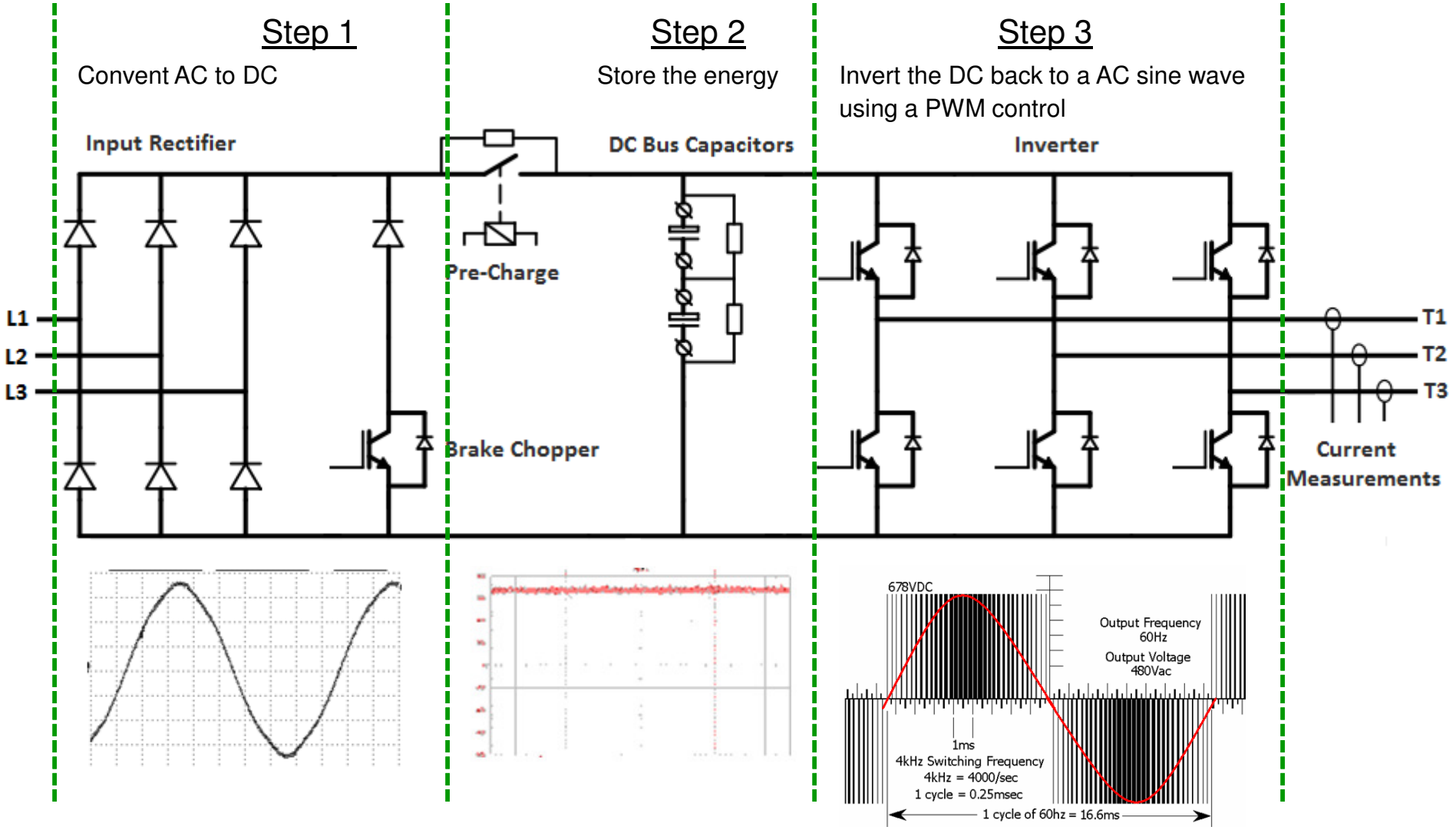



AC and DC drives (converter section)

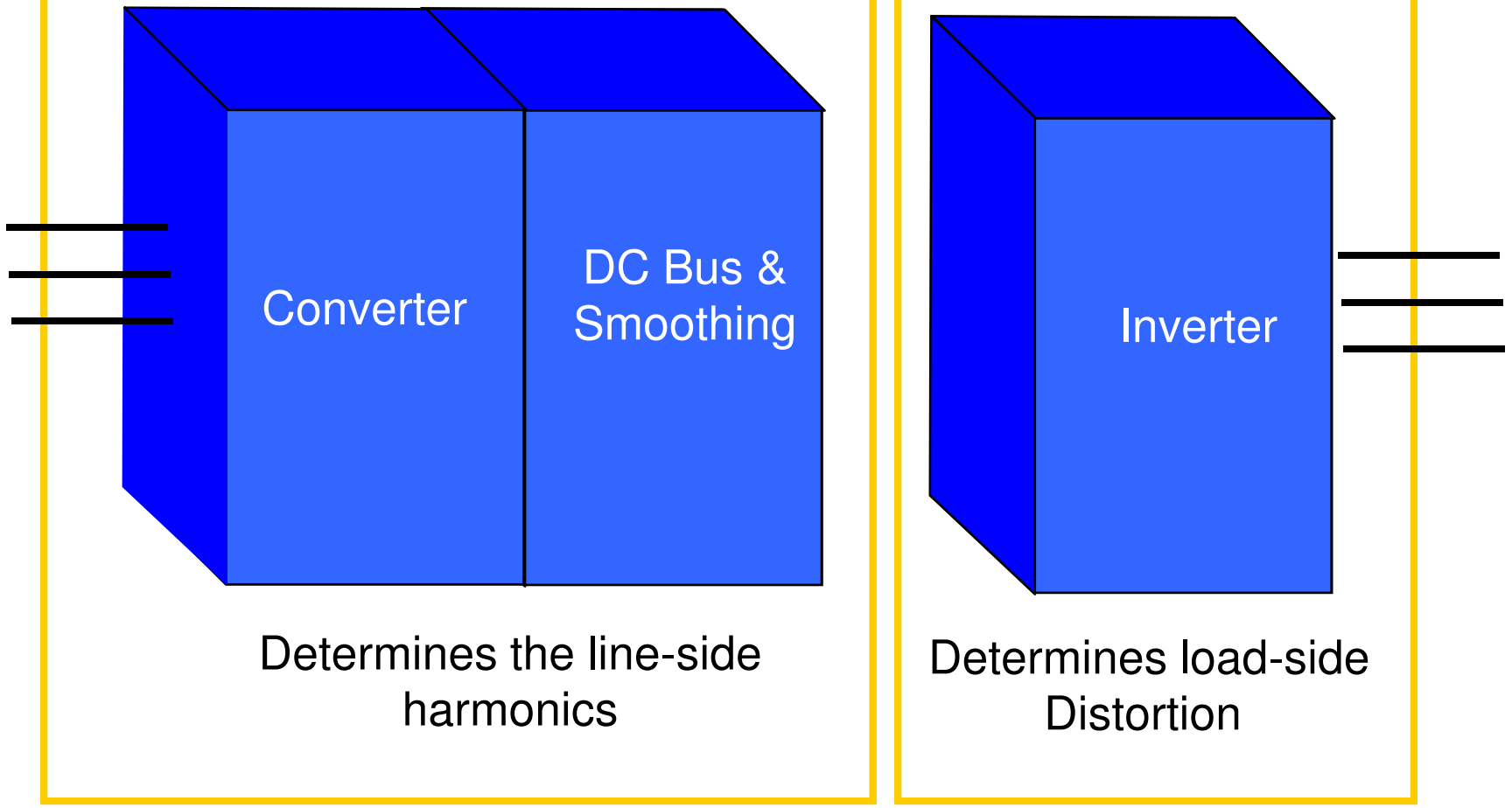


DC power supplies/converters

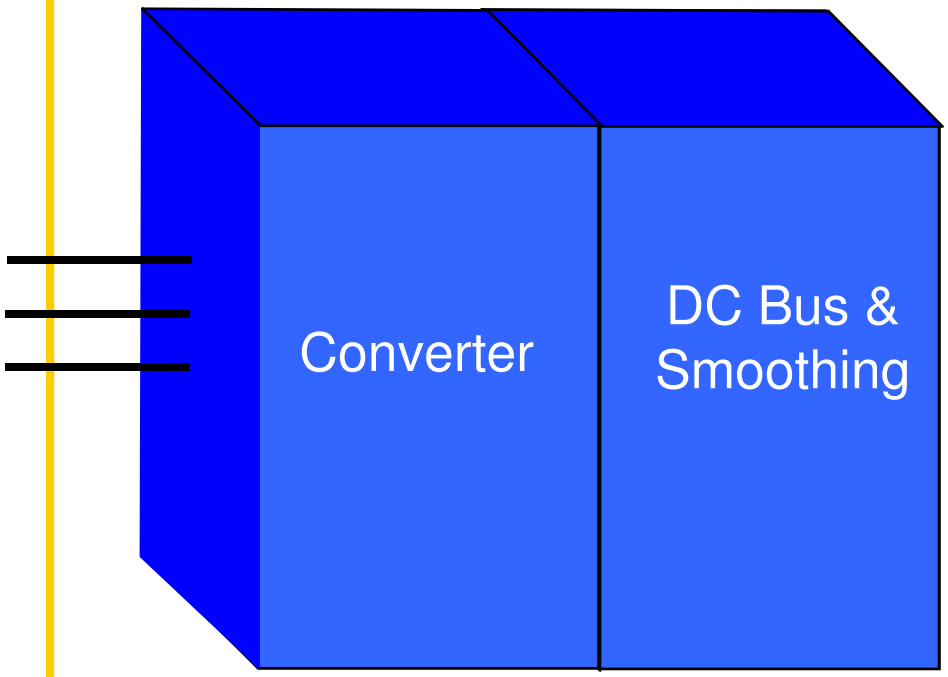
# VF Drive Block Diagram



# VF Drives and Harmonics



# VF Drives and Harmonics




Determines the line-side harmonics

Line-side harmonics can have far-reaching effects on the power system:

- Distribution transformers
- Standby generators
- Communications equipment
- Switchgear and relays
- Computers, computer systems
- Diagnostic equipment

# IEEE* 519 - 2014
(*Institute of Electrical and Electronics Engineers)

## The Situation

- Utility is responsible for providing “clean” voltage to its customers.
- Customer is responsible for not causing excessive current harmonics downstream

## The Recommendation

- IEEE 519 - 2014 provides a recommendation for customer generated harmonic limits

# IEEE 519- 2014 Recommendations

The Institute of Electrical and Electronics Engineers (IEEE) has set recommendations for applying limits to the level of harmonic distortion that a utility customer may inject into the power system. The recommendations pertain to percent harmonic current and voltage distortion at the point of common coupling (PCC), which is clearly defined as the point where the utility connects to multiple customers.

**IEEE-519 2014, Page 6, Table 1:**

**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.

Users produce harmonic currents that flow through the system owner's or operator's system, which lead to voltage harmonics in the voltages supplied to other users.

## IEEE 519, Table 2 - Current Distortion Limits (120 V [illegible])

Not THD

**Harmonic Current Distortion Limits ($I_h$ and TDD) in % of $I_L$ (≤ 69kV)**

| $I_{SC}/I_L$ | <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** |

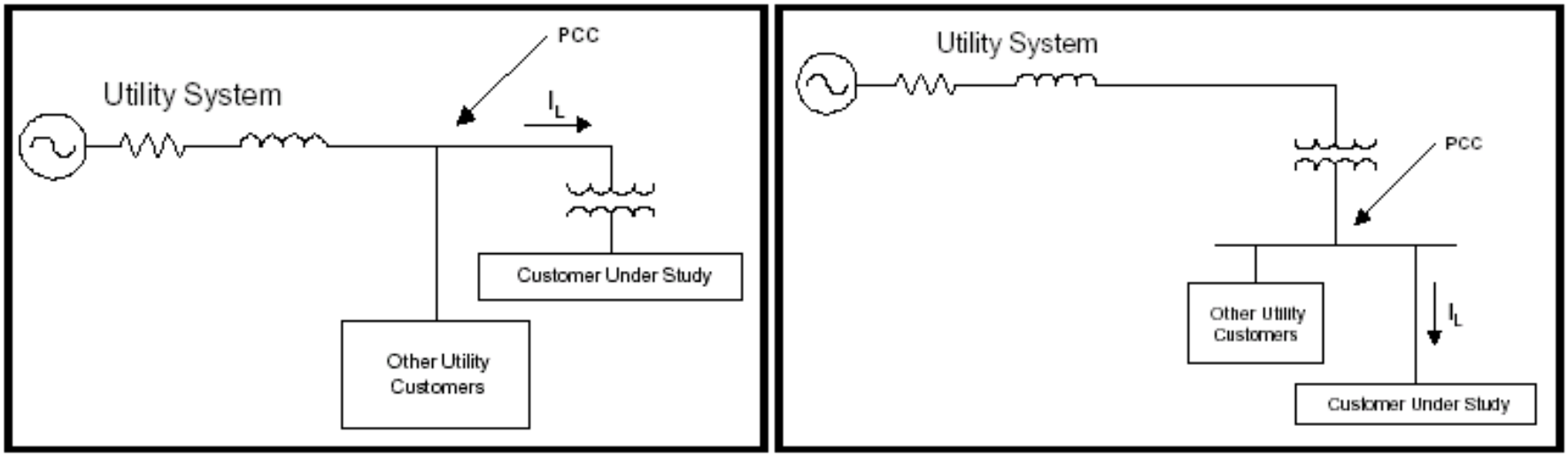
- Current distortion limits are dependent on the "stiffness" of the source ($I_{sc}/I_L$)
  - A stiffer source has lower impedance ⁂ more distortion allowed
  - A softer source (i.e. generator) has higher impedance ⁂ less distortion allowed
- Current distortion limits are typically much more difficult to reach than Voltage distortion limits
- Ratio of linear loads to non-linear loads can affect TDD and THD.
- Source: IEEE 519 – 2014, page 7, Table 2`

# Point of Common Coupling

- PCC is where harmonic limits are applied
- PCC is well-defined by IEEE 519-2014 as:
  - "….the point in the power system closest to the user where the system owner or operator could offer service to another user" (IEEE 519-2014, page 2)
- Very misunderstood and misapplied part of IEEE 519-2014
- Not intended to be applied within a user's system

# Point of Common Coupling - Examples

PCC is where another customer can be served by the utility

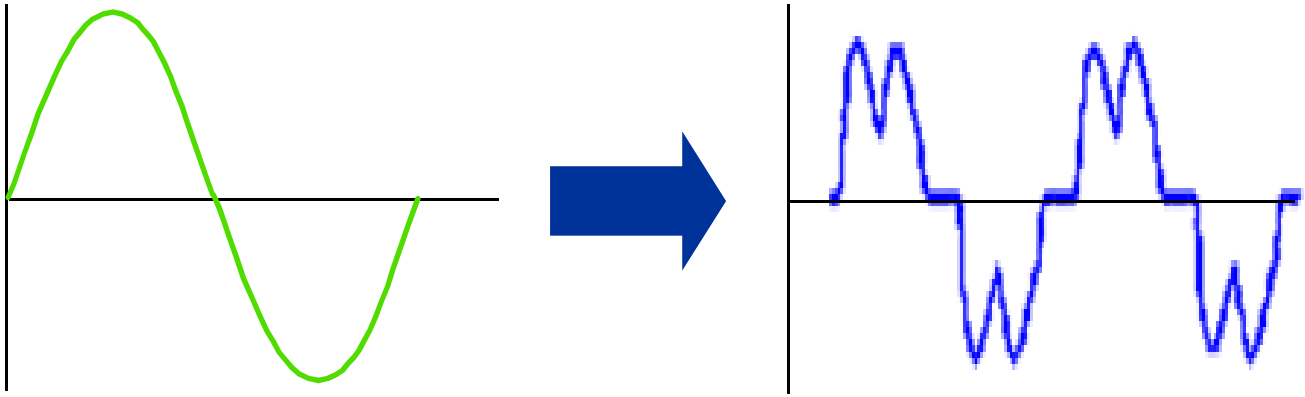


# Who Cares About Harmonics?

- Utilities
- Users
- Maintenance and facility engineers

# Utilities

The power company typically supplies a reasonably smooth sinusoidal waveform:



...but nonlinear devices distort voltage and current waveforms resulting in poor power quality on the distribution grid with further implications

# Utilities

- Harmonics can be thought of as power which does no useful work but requires extra generation and distribution capacity
- With the increased number of motors controlled by VFD's and other nonlinear power electronics, utilities are delivering a higher percentage of "harmonic power" without a comparable increase in revenue
- Some utilities have introduced billable charges for excessive customer generated harmonic distortion

# Users

- Control capital expenses
- Needs to be a good citizen in the electrical community via IEEE 519 compliance
- Seek increased uptime and profits
- Want to protect electrical assets
- Work to add value to facilities
- Desire reduced energy expenses
- Oftentimes Users “don’t know what they don’t know”

# Maintenance and Facility Engineers

Harmonics can have far-reaching effects on the power system:

| System | Concern |
|---|---|
| Distribution transformers | Overheating and efficiency loss, leads to Over-sizing and more increased losses |
| Standby generator | Distortion dramatically reduces capacity, Synch issues with zero crossings for relays |
| Communications equipment | Downtime and loss of productivity |
| Computers and computer systems | Nuisance tripping and downtime |
| Diagnostic equipment | Nuisance tripping and erroneous results |
| Utility | Charges for harmonic pollution |

# Why One Size Doesn't Fit All

- IEEE 519 is a system recommendation not a product specification or standard
- The same VFD, UPS, or power converter in two different installations will have completely different harmonic profiles
- Linear vs. Non-Linear load profiles vary throughout the daily duty cycle affecting harmonic distortion content.
- Duty Cycle of the facility will have different harmonic content results.

# How to Stomp Out Harmonics

There are several alternatives for the attenuation and mitigation of harmonics, some of which offer distinctive advantages over others. Among the most popular methods are:

- Increase percentage of linear load on system
- Additional inductive reactance
- Passive filters
- Phase-shifted sources
- 12-, 18-, 24-pulse converters
- Active filters
- Active Front End

# Harmonic Mitigation

**18 Pulse**
**3-5% TDD**

- Autotransformer
- 3 Bridge Rectifiers
- Ultra Low Harmonic
- Very Common

**Passive Filter**
**5-8% TDD**

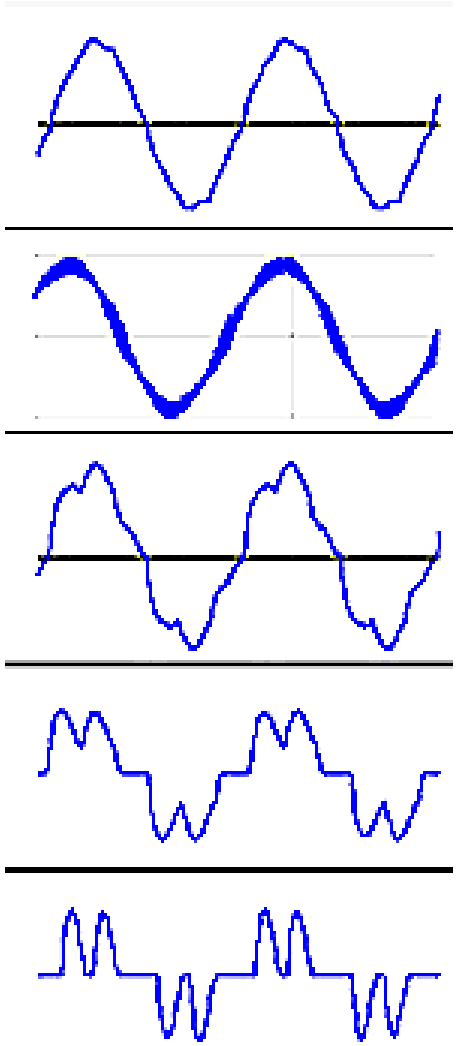
- Standard Drive
- Added LCL Filter
- Low Harmonic
- Very Common

**12 Pulse**
**12-18% TDD**

- Autotransformer
- 2 Bride Rectifiers
- Low Harmonic
- Less Common

**6 Pulse**
**30-35% TDD**

- Standard Drive
- 3% Line Reactor Or 5% DC Link Choke
- Very Common



# Key Take-Away

- There are a variety of harmonic mitigation techniques available for each unique application
- Establishing the optimum level of harmonic dilution leads to the most cost effective mitigation solution

# What Will It Take?

- Begin with a facility analysis
- Then interpret IEEE 519 as it applies to your facility  (TDD, THD, etc)
- Select the most cost effective harmonic mitigation technique
- When further study is required, a system analysis service can recommend cost effective harmonic mitigation solutions based on a facility single line diagram.

# IEEE 519 Interpretation

- As part of your system analysis, our application engineers will interpret the results with respect to current IEEE-519 recommendations
- “Because of the nature of the recommendations, some conservatism is present that may not be necessary in all cases” Translation? Don’t spend more than you need.

# Think you might have a harmonic issue?

- Don’t tackle it alone
- Use Eaton’s Harmonics Calculator
- Utilize Eaton’s local and product engineers to help analyze and interpret your system
- Eaton Engineering Services is available to perform on-site harmonic studies and field analysis.
  - Perform initial harmonic study
  - Recommend mitigation techniques and solutions
  - Perform post-mitigation harmonic study

# Get Started Today

## Download the Free Eaton Harmonics Calculator

http://electricalsector.eaton.com/forms/HarmonicsCalculator

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Harmonics Estimator

for Variable Frequency Drive Systems

# Thank you for your time…

# Questions?

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