A Technology Review of Harmonics in Todays Power Systems

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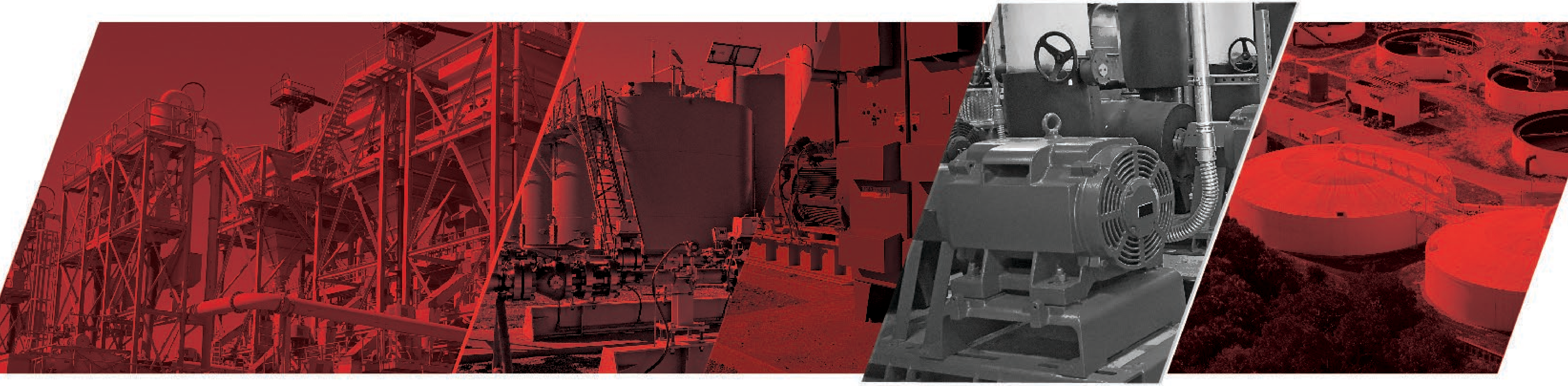

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Agenda

1. Causes & Effects of harmonic distortion
2. System compliance standards and best practices
3. Today's Harmonic Mitigating Technologies
4. Meeting Harmonic Limits on a Utility or Generator Feed
5. Summary
6. About TCI

Causes of Harmonic Current and Voltage Distortion

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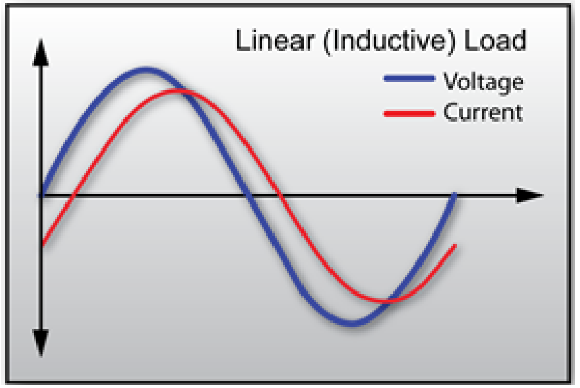
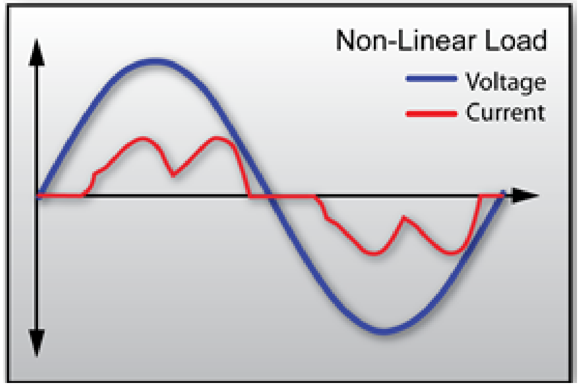
Harmonic Currents Drawn by Non-Linear Loads

Voltage is delivered in sinusoidal form at 60 Hz.



Linear Load: sinusoidal 60 Hz voltage ⇨ sinusoidal 60 Hz current only



Electrical systems are designed to operate with mostly sinusoidal currents

Non-Linear Load: sinusoidal 60 Hz voltage ⇨ multiple frequencies of current

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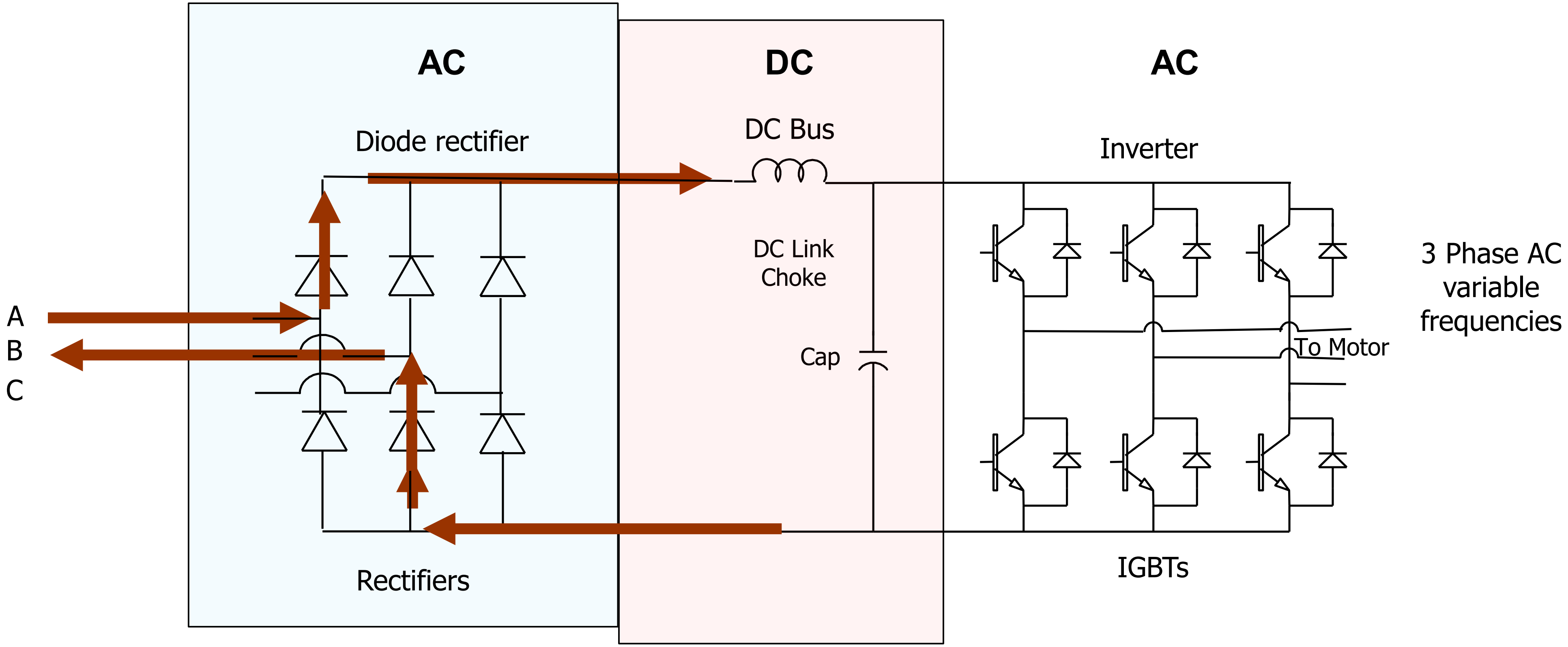
VFD Rectifier Operation



VFDs are typically the largest contributor of harmonics on The grid.

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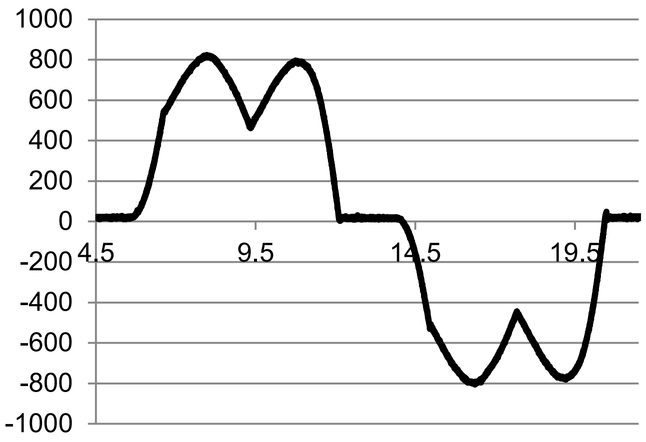
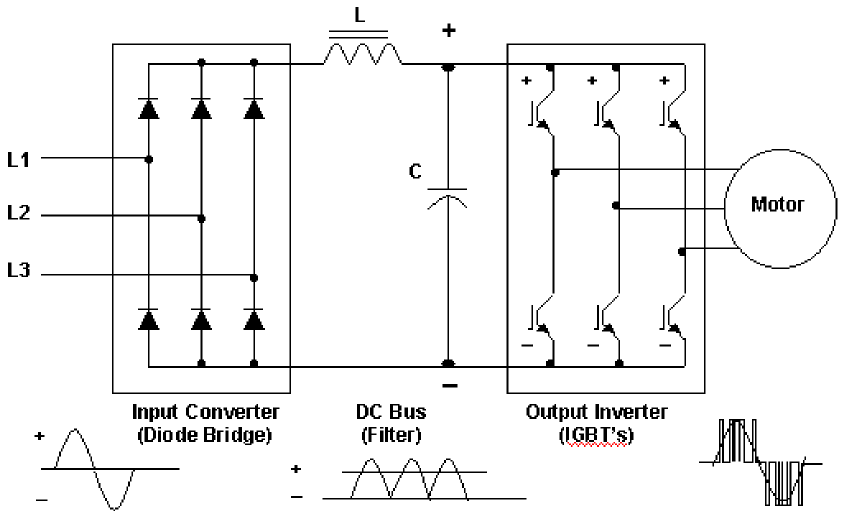
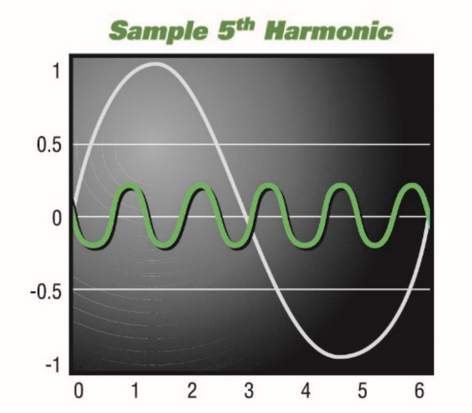
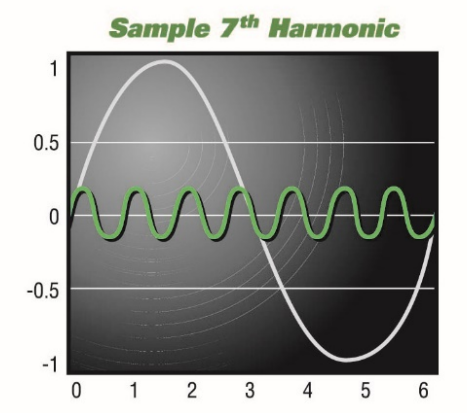
6 Pulse VFD Current





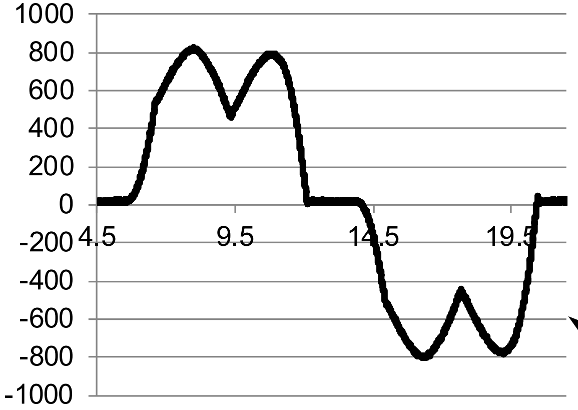




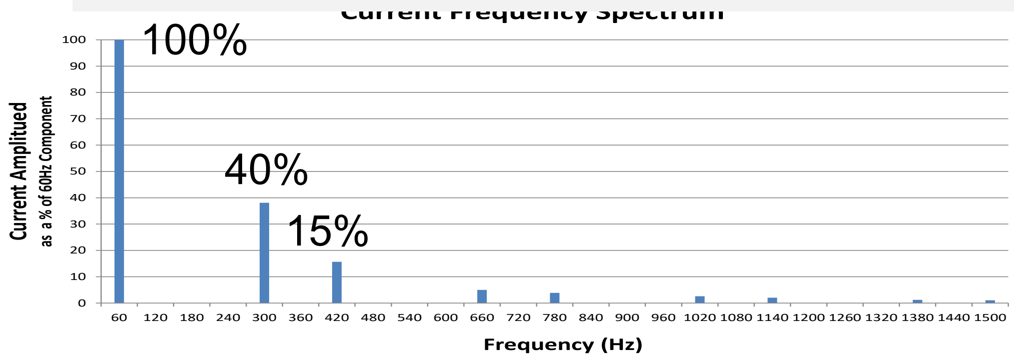
Harmonic Number	Frequency
5th	300Hz
7th	420Hz
11th	660Hz
13th	780Hz
17th	1020Hz
19th	1140Hz
23rd	1380Hz
25th	1500Hz

6 Pulse VFD Current Harmonics

VFD Input Current Waveform



VFD Input Current Spectrum



$$I_{rms} = \sqrt{I_1^2 + I_2^2 + I_3^2 + \ldots + I_n^2}$$

Fundamental 60Hz Current (I1)

harmonic Current (Ih)

<u>45% THD Example</u>

I1 = 100 A

Ih = 45 A

%THD = 45 %

Irms = 110 A

<u>Total Harmonic Distortion</u>

$$\%THD = \frac{Ih\ (A)}{I1\ (A)}$$

$$\%\ THD = \frac{\text{Harmonic Current (Ih)}}{\text{Fundamental Current (I1)}}$$

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Effects of Harmonic Distortion

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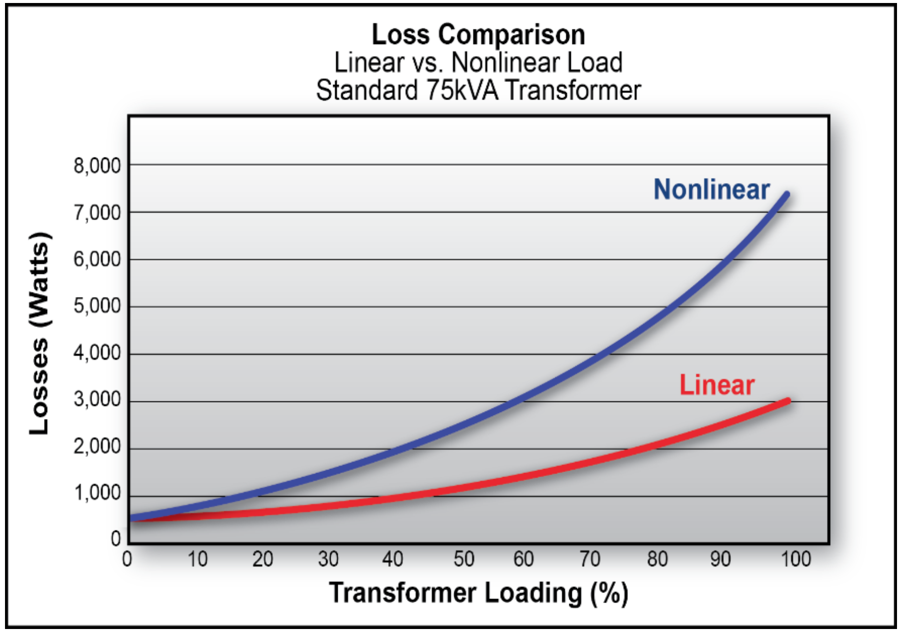
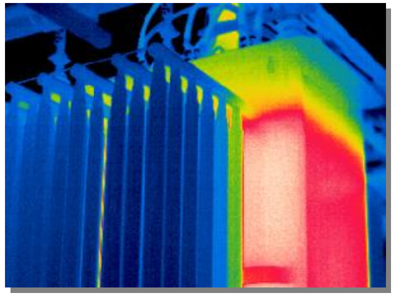
Common Effects of Harmonics
Higher Losses & Temperature



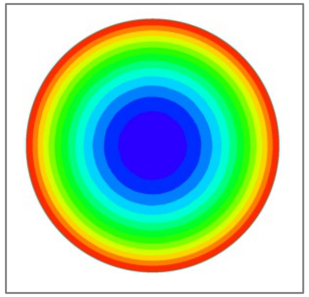
Transformers Fail



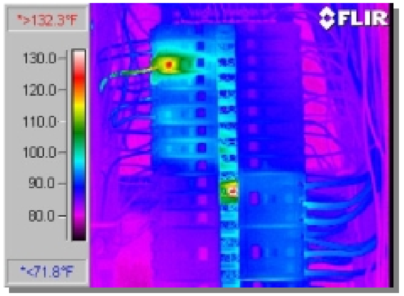
De-rate transformer to 52% to limit temperature with VFD loads

Source: Using methods in IEEE-C57.110 Recommended Practice for Establishing Liquid Filled and Dry Type Power and Distribution Transformer Capability When Supplying Nonsinusoidal Load

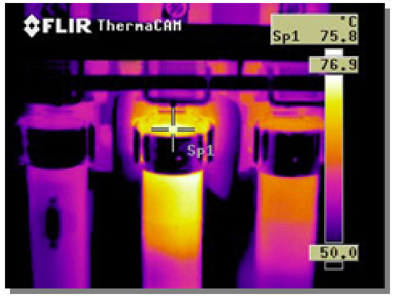
Skin effect on cables



Circuit Breakers Trip



Fuses Blow



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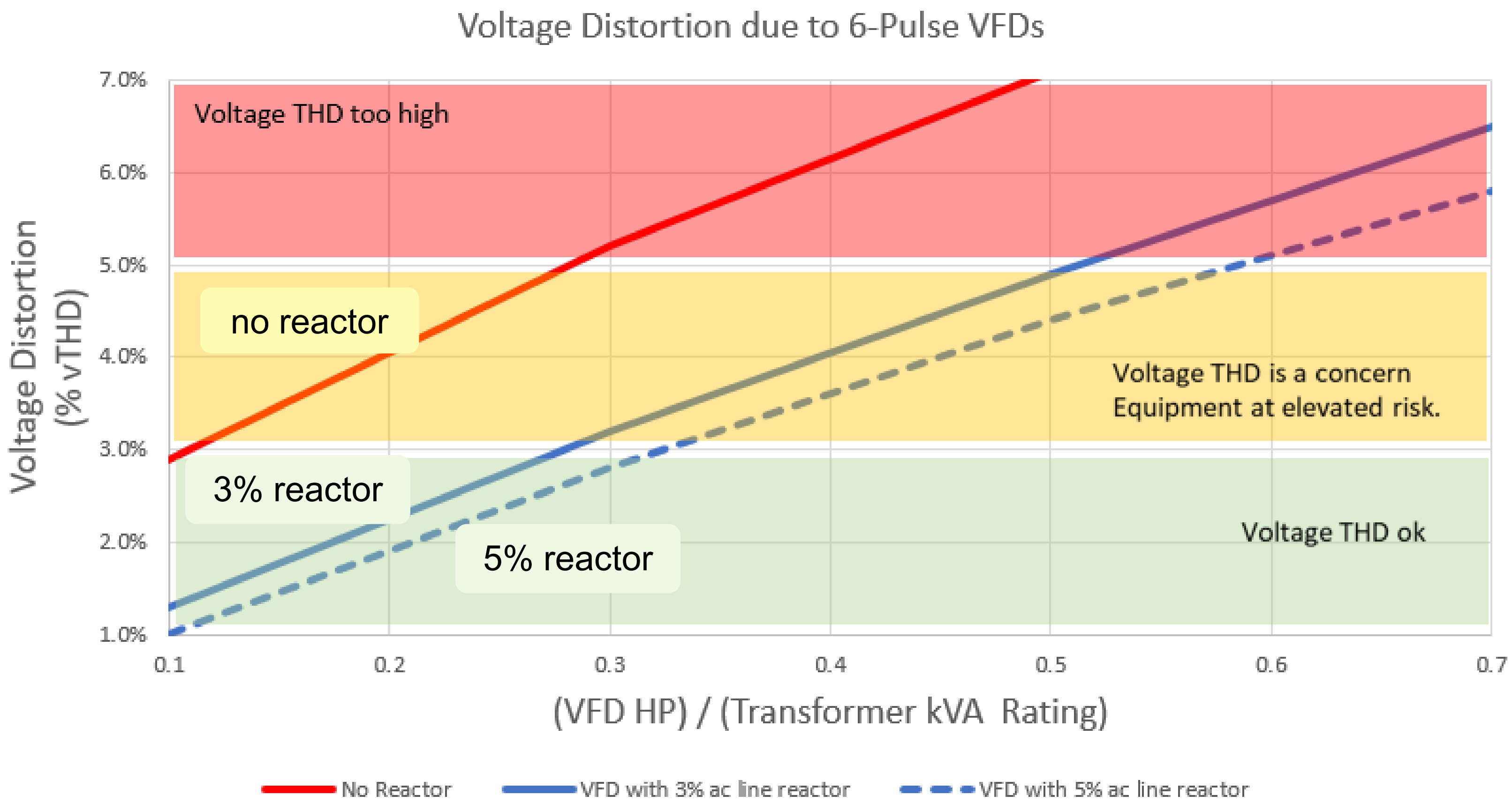
Common Effects of Harmonics
Voltage Distortion



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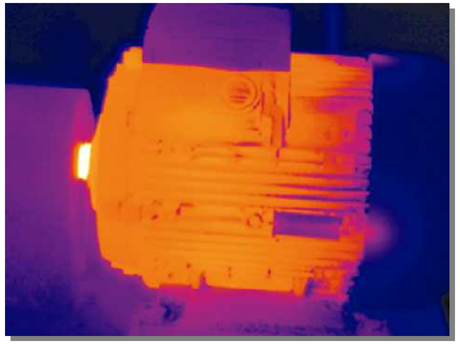
Common Effects of Harmonics



Across The Line
Motors Fail

Caps Blow

Generators Trip

General Equipment Reliability

- PLC I/O can change state
- Loss of lighting ballasts
- SCADA issues
- Welding problems

Harmonics Increase Business Costs

- **Increased maintenance**

  Excessive heat burdens electrical infrastructure, from transformers, cables, bussing, to across the line motors.
- **Interruption of production causing downtime**
- **Replacement Costs of equipment failing prematurely**
- **Reduced system capacity**

  Requires costly equipment upgrades to support expansion

Today almost every business is affected by harmonics, but what guidelines are there for harmonics – how much is too much?

System Compliance Standards and Best Practices

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IEEE-519 2014 Standard Overview

IEEE-519 2014

IEEE Std. 519™-2014 is a recommended set of guidelines for harmonic control in electric power systems.

Defines responsibilities of utilities and power users to maintain power quality at the Point of Common Coupling (PCC).

- protects the user and utility equipment from the negative impact of harmonics.

The separate individual responsibilities are:

- User – limit harmonic currents at the PCC to prescribed levels
- Utility – limit voltage distortion at the PCC to prescribed levels by maintaining system impedance as necessary

Example Utility Power Quality Policy

Southern Company
Power Quality
Policy

November 11, 2015

SOUTHERN COMPANY

Alabama Power
Georgia Power
Gulf Power
Mississippi Power

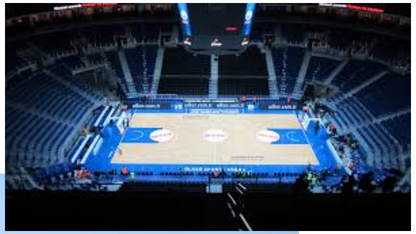
General

Control of Harmonics is the joint responsibility of the User and the Owner as per IEEE 519 - 2014[3]. In order to properly manage ESS Harmonics, the User must communicate to the Owner any change, addition, and/or expansion proposed, or made to an existing User's facility.

Voltage distortion is generally caused by harmonic current flowing through the System impedance. This Policy places responsibility for the limits of Total Harmonic Distortion and voltage Individual Harmonic Distortion levels upon both the Owner and the User. This Policy places responsibility for the limits of Total Demand Distortion and current Individual Harmonic Distortion upon the User. It is the responsibility of the User to ensure the User’s facility operates in adherence with this Policy.

Considerable effort should be spent, and a Study conducted, if appropriate, in the planning and design phase of User and Owner facilities to limit the level of voltage and current harmonics. In any event, unique problems can arise after the User facility is in operation. To this end, the Owner may periodically verify ongoing adherence through the use of field measurements taken at the Point of Common Coupling or other suitable location as specified by the Owner.

Some Industries with Engineering Specifications that Limit Harmonics



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IEEE-519 2014 Current Limits for Energy Users

IEEE 519 TDD limits are based on loading (Isc/IL)

Table 2—Current distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{SC}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
$< 20^c$	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

available short circuit current (Isc)

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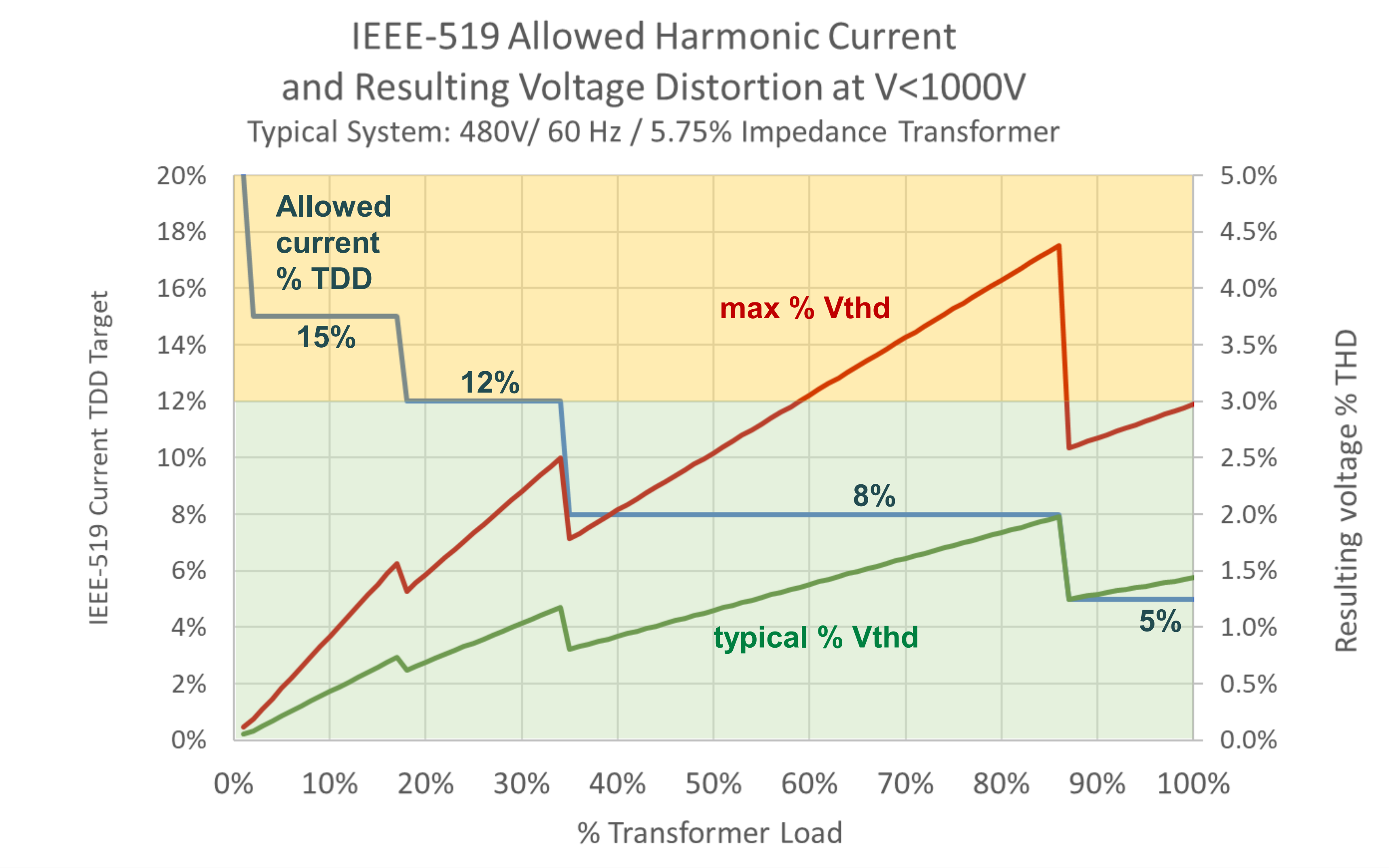
demand current (IL)



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Existing Harmonic Mitigating Technologies

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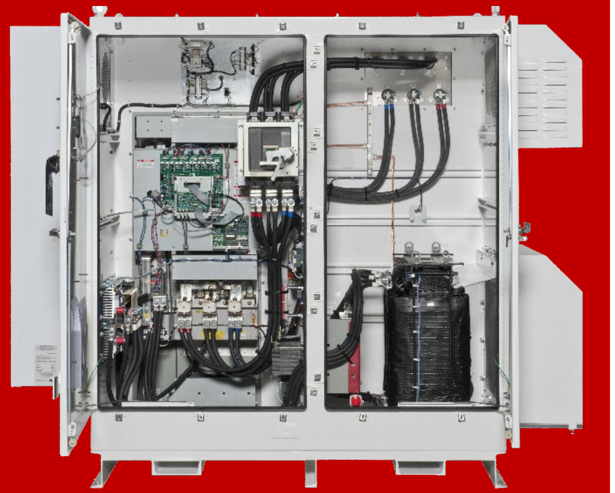
Harmonic Solutions

6 Pulse VFD +

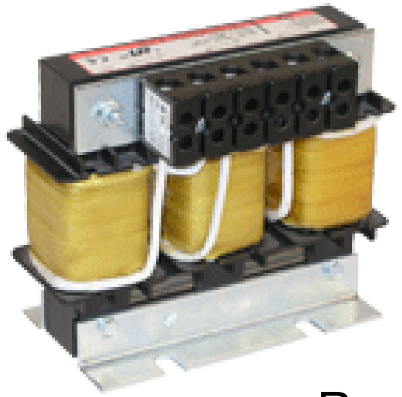
- Line Reactor – 28% to 40% ITHD
- Passive Filter – 5% ITHD
- Active Filter – 5% ITHD



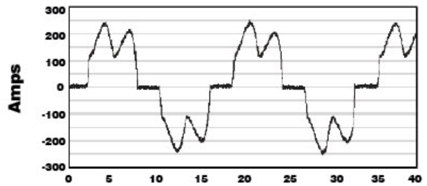
VFD Built in Options

- 12 Pulse – 10%-12% ITHD
- 18 Pulse – 5%-10% ITHD
- Active Front End – 5%-7% ITHD

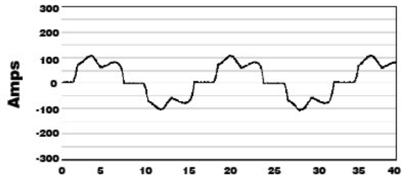
Line Reactors



Before



After



Reactors

- First line of defense for harmonic mitigation
- transient blocker

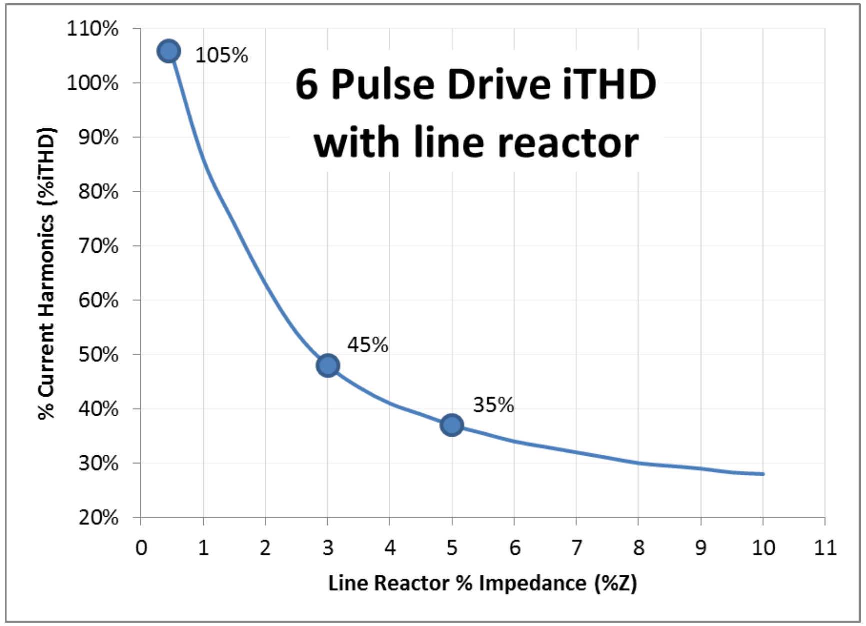
Impedance Choices

- 3%, 5%, 10%

Minimal Voltage Drop

Impedance %	Voltage Drop
3%	0.0%
5%	1.2%

Harmonic Reduction



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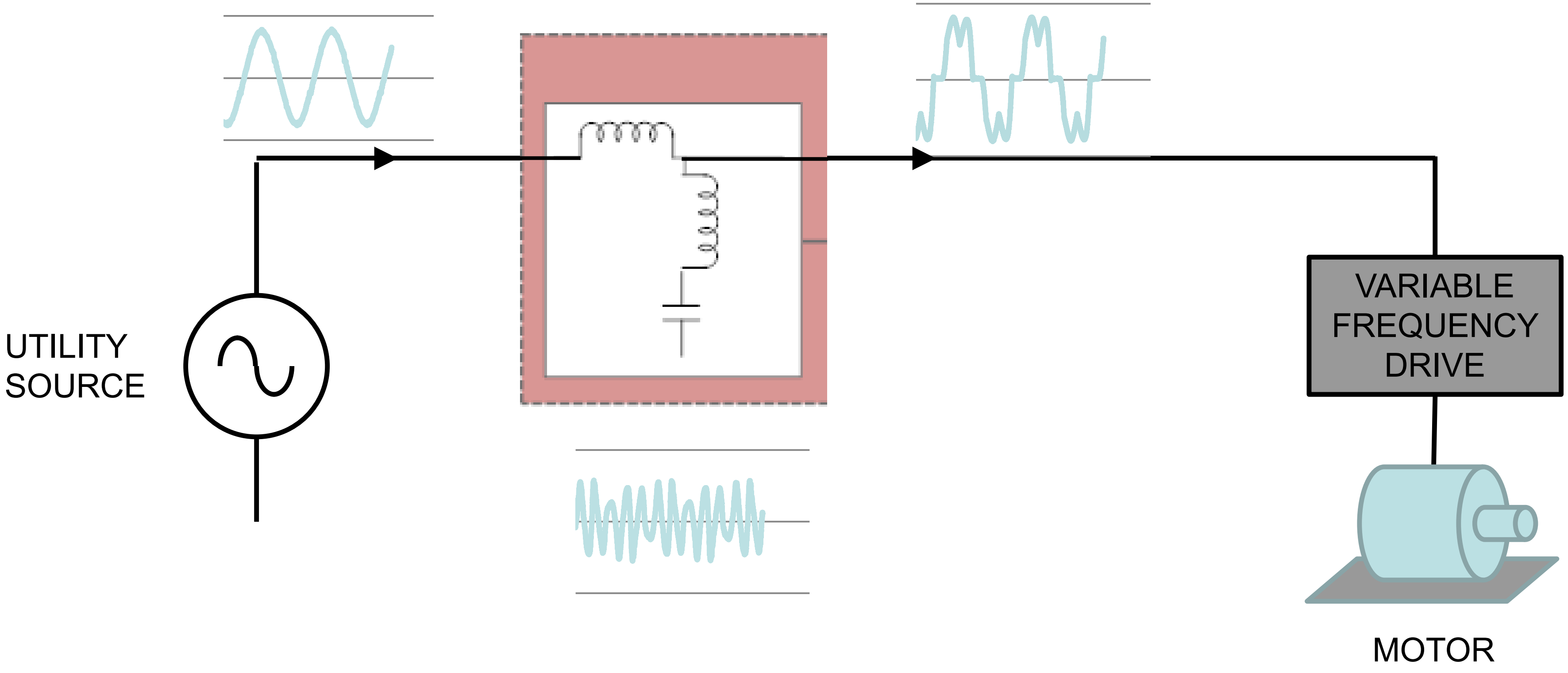
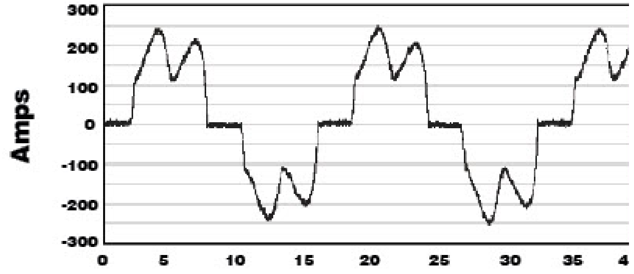
Passive Harmonic Filter

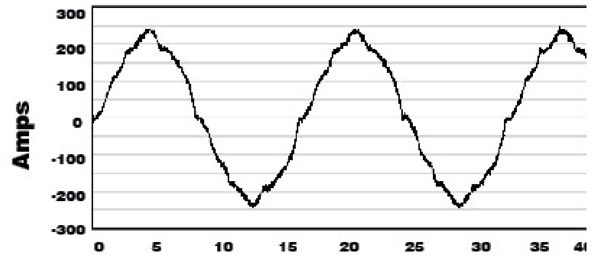


Passive Harmonic Filter

Without a Filter

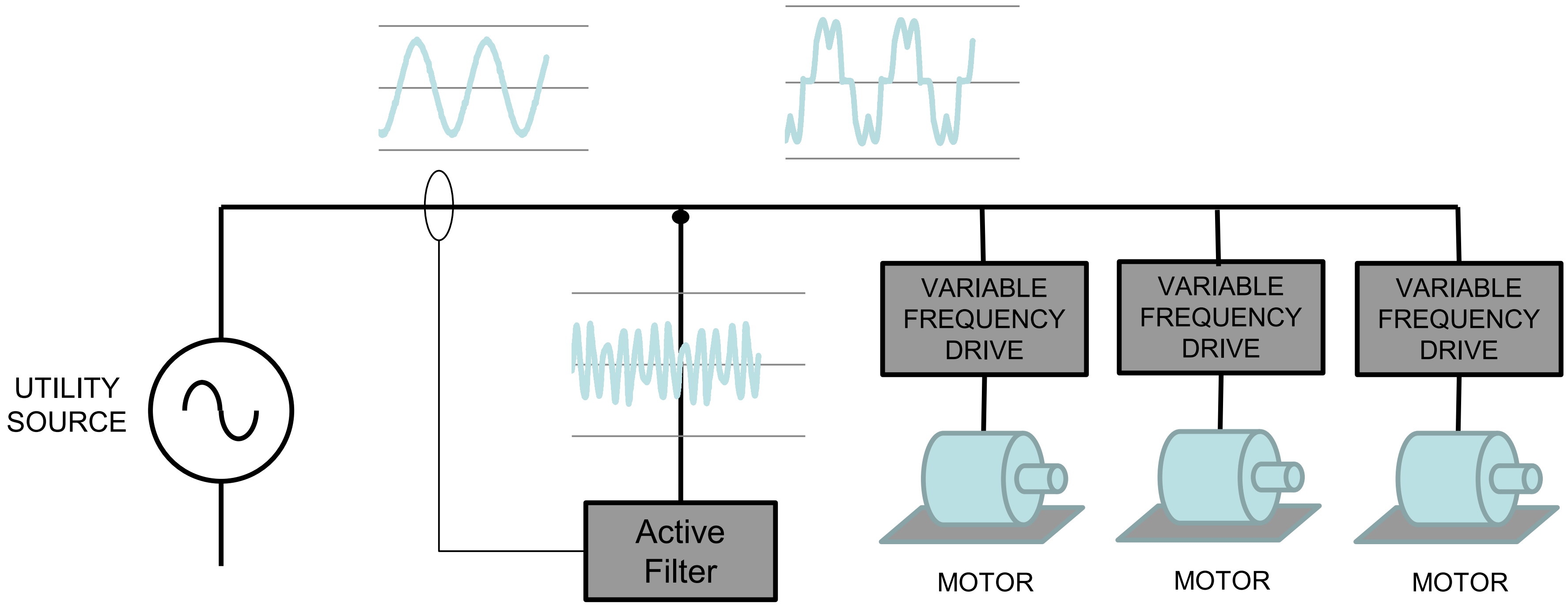


With a Filter



- ❑ Harmonic reduction to 5% ITHD.
- ❑ Broadband filter with a 5th tuned harmonic circuit
- ❑ Use when need to meet IEEE-519 specification and other harmonic problems
- ❑ Use built in contactor to protect against leading power factor
- ❑ Built in series inductor to protect from resonance issues
- ❑ Can be used with Standard Six Pulse VFD.
- ❑ Filter Caps may need to be managed…. PF / Generator

Active Harmonic Filter

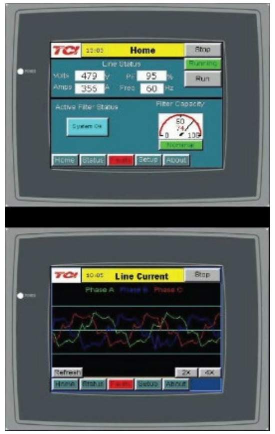


Active Harmonic Filter

- ❑ Harmonic reduction to 5% TDD
- ❑ Shunt active device – not in critical power path
- ❑ System applied on standard 6 pulse VFDs at VFD, MCC or switchboard
- ❑ Very cost effective for multiple or redundant drives
- ❑ Monitors bus, injects counter current to cancel out harmonic currents
- ❑ Provides Power Factor Correction
- ❑ Corrective Current / ratings – New 700A Frame

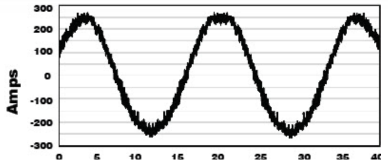
  50, 100, 150, 200, 250, 300, 350, 400, 500, 600, 700

  Higher ratings via paralleling
- ❑ HMI – Modbus; Ethernet; DeviceNet; BACNet

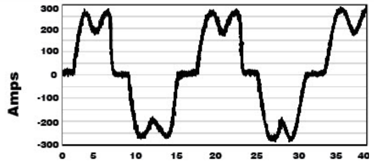


Active Harmonic Filter Locations

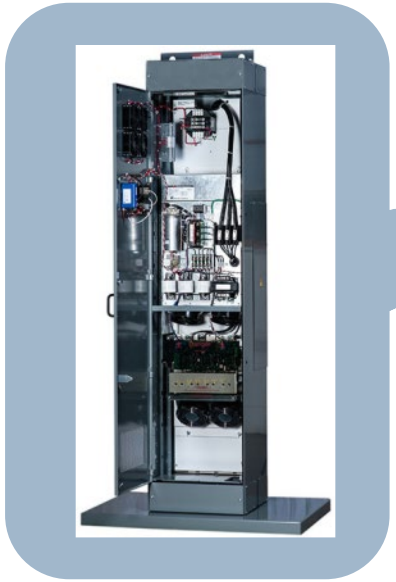
With Active Filter

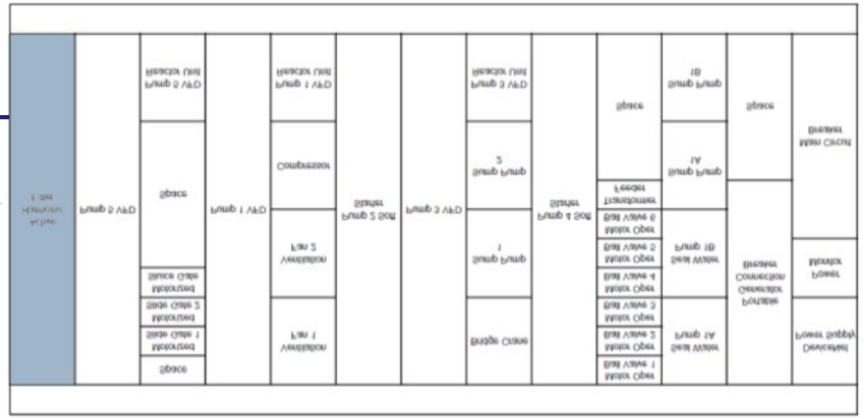


Without Active Filter



CTs





Typical MCC

The CTs monitor the harmonic distortion on the Bus. The active filter injects the appropriate correction based on loading at the time to eliminate the distortion.

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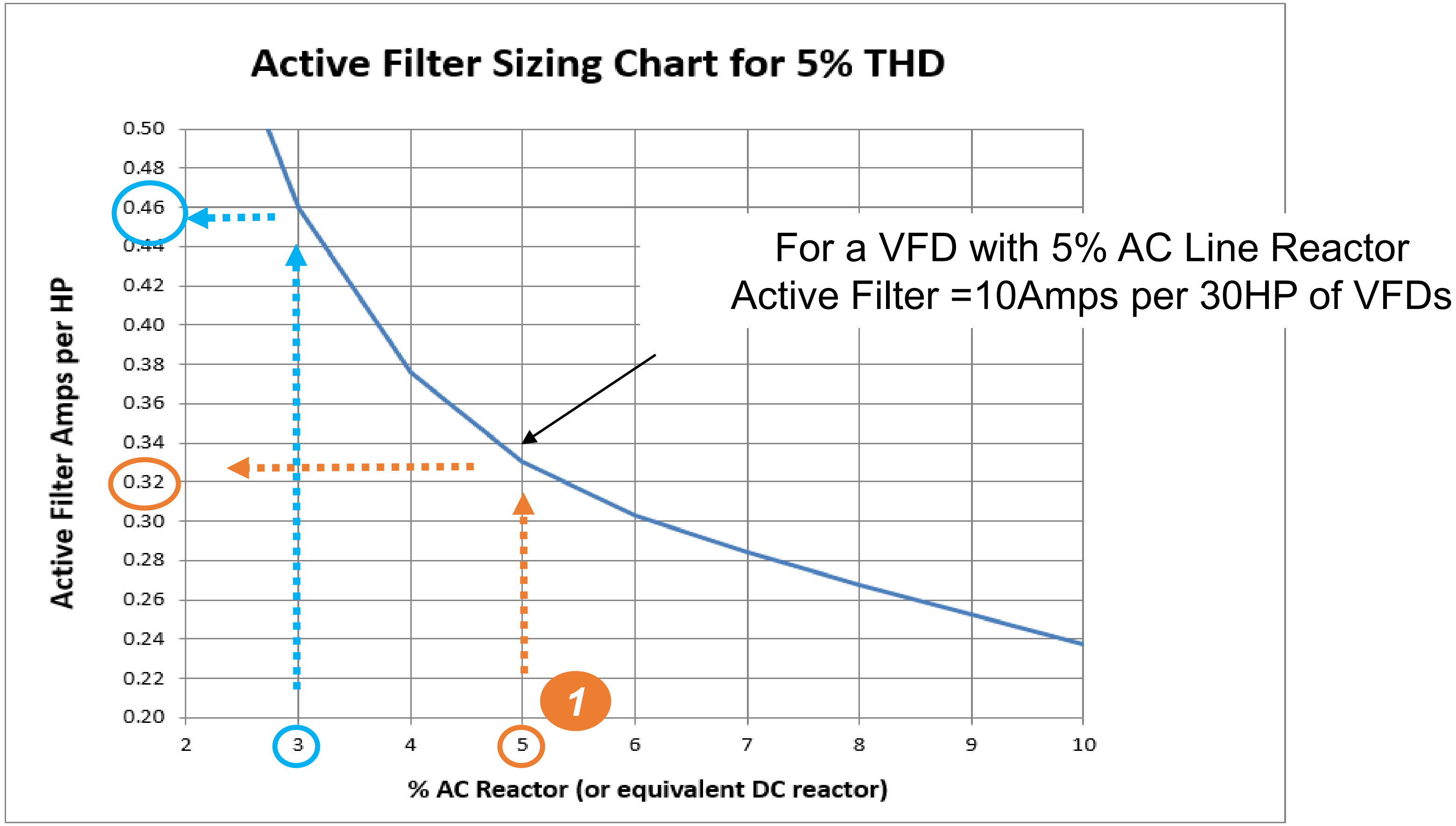
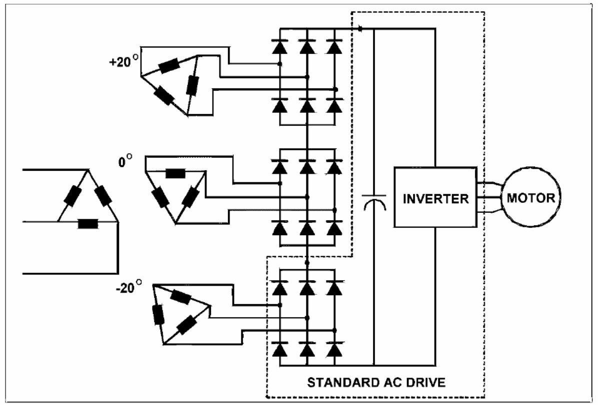
Simple Active Filter Sizing using Amps / VFD HP ratio



VFD Built In Options for Lower Harmonics

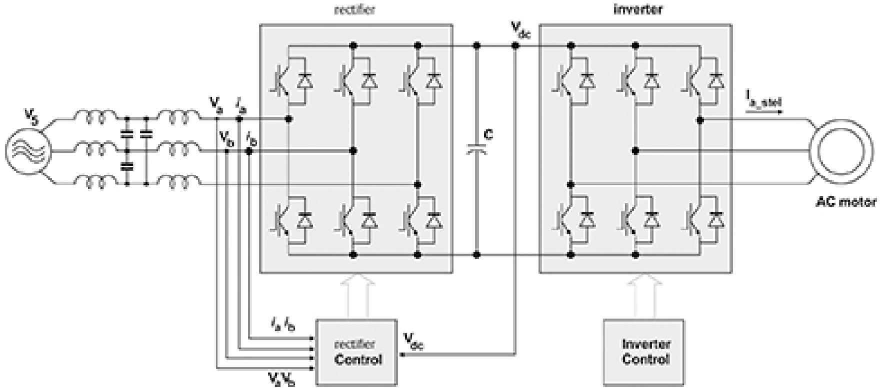
18-Pulse VFD's

- Older Technology / Legacy
- Inefficient – Watts Losses / PF
- Long Lead times / Custom
- Large Footprint
- More Expensive
- Harder To Install
- 5% ITHD When Balanced



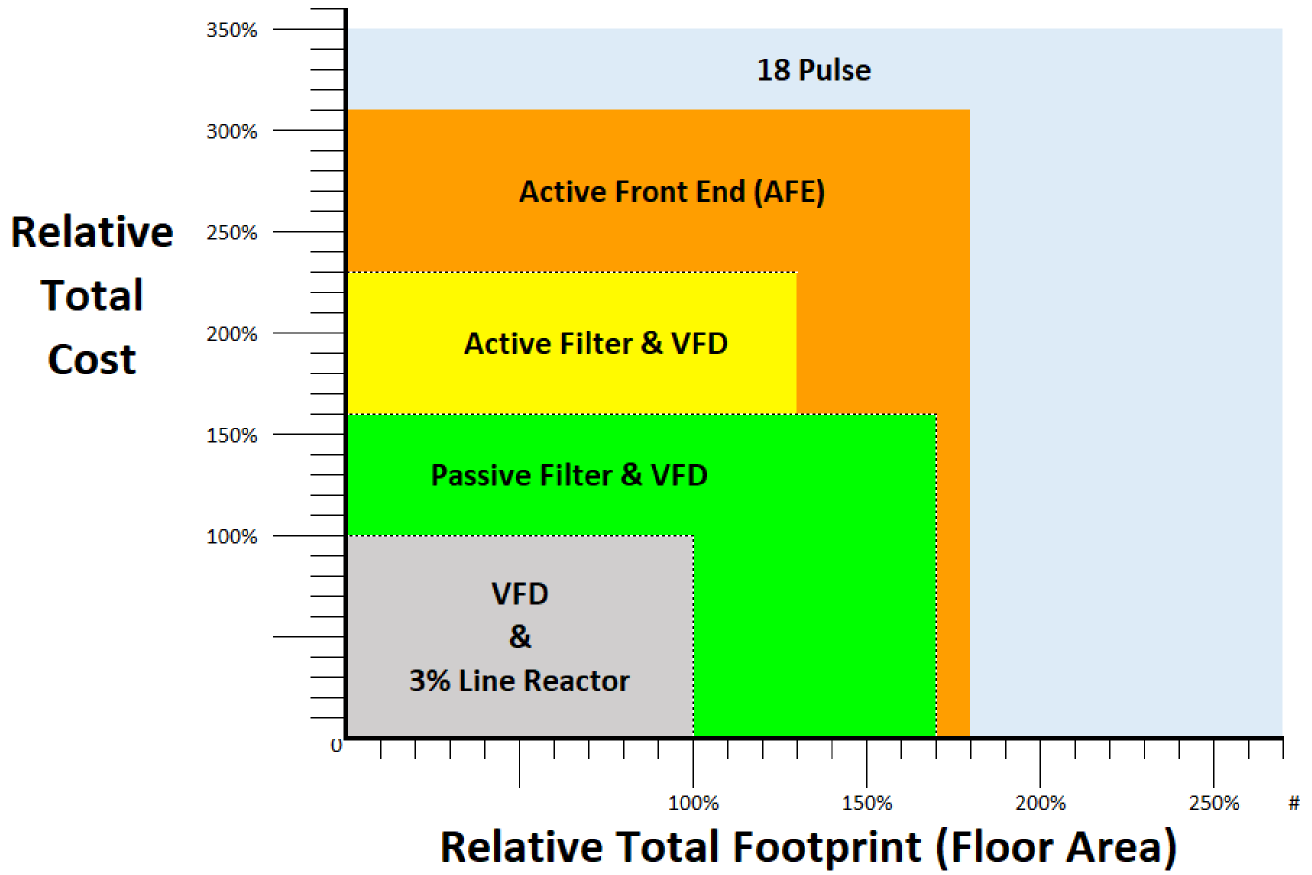
Active Front End VFD's

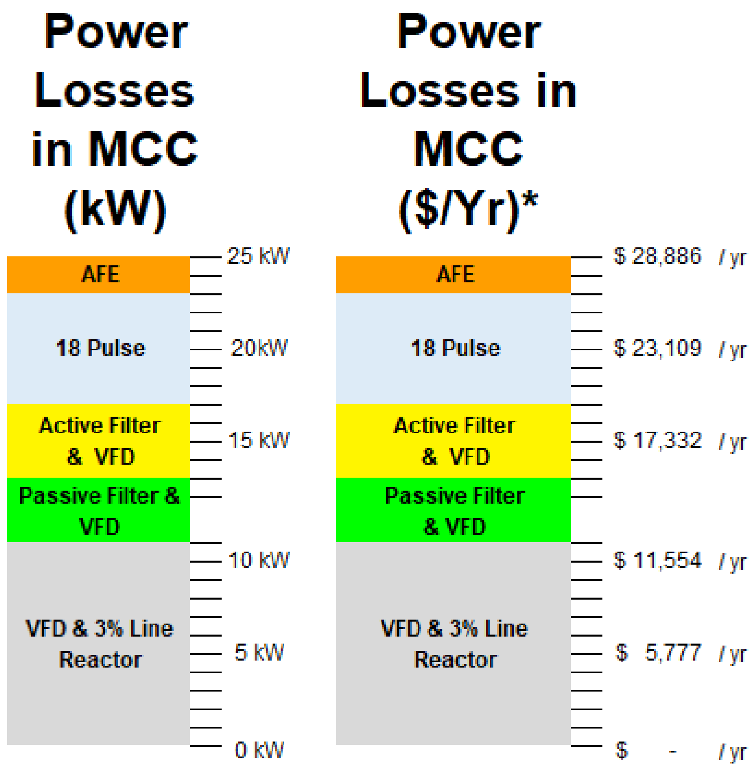
- Newer Technology
- 5% ITHD
- Smaller than 18 pulse
- Less efficient and larger than active or passive filters
- More parts in series with critical power path



Comparison of 5% THD Filtering Solutions
Cost – Floor Area – Losses

Example: 3 x 200HP VFDs in MCC sections





*The average electricity rate is 13.19 cents per kilowatt hour (kWh).

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Meeting Harmonic Limits on a Utility or Generator Feed

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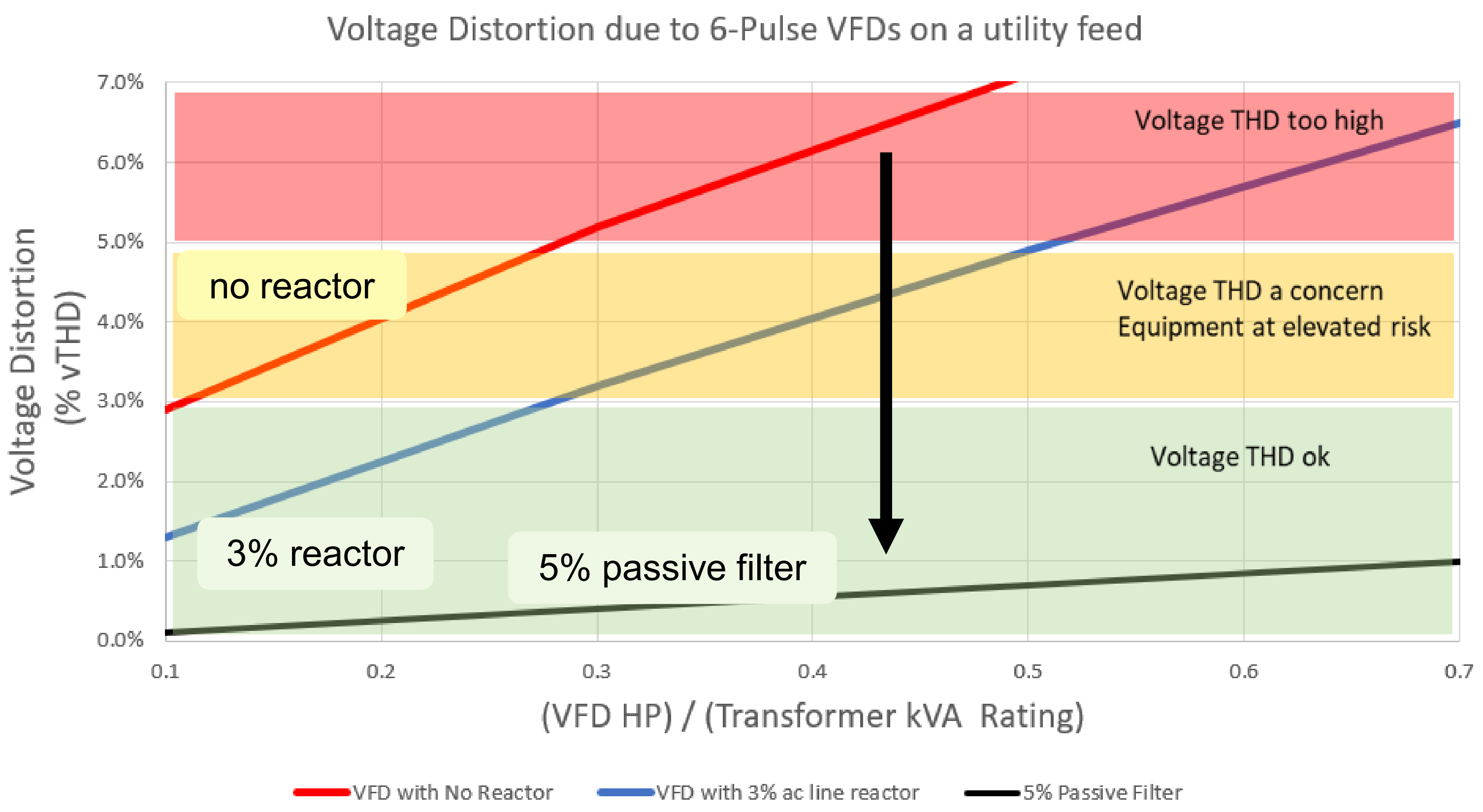
Best Practices to Limit Voltage Distortion
without IEEE-519 requirements



- Keeping VFD HP to < 25% of the transformer kVA
- Use ac line reactor to extend VFD ratings before applying harmonic filters

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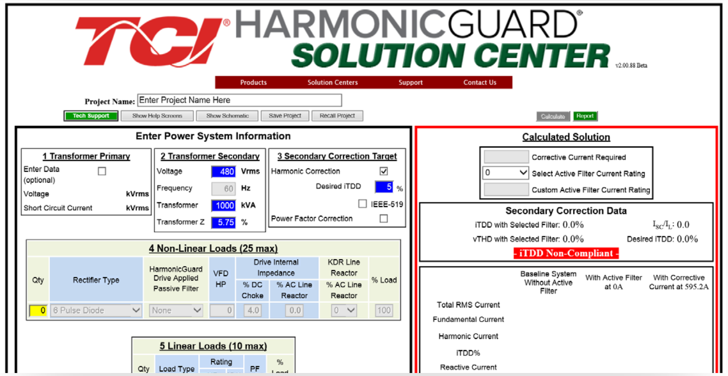
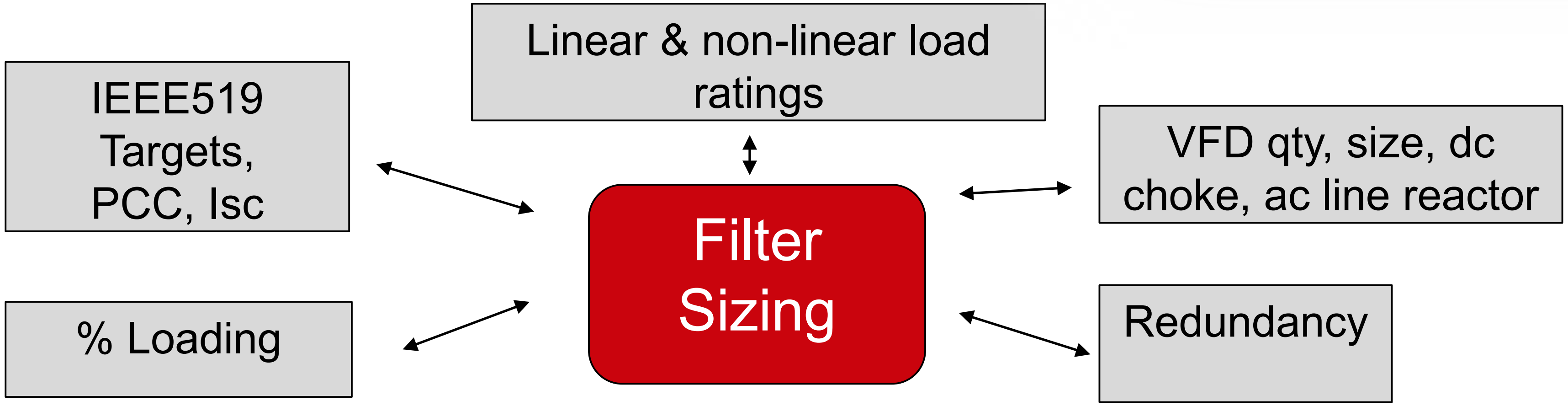
Performing IEEE-519 Harmonic Calculations

Harmonic Calculation Tools Available

- Use IEEE519 or specified limits
- Sizing of reactors, passive filters, active filters for 6-pulse drives and built-in VFD options to meet IEEE or best practice





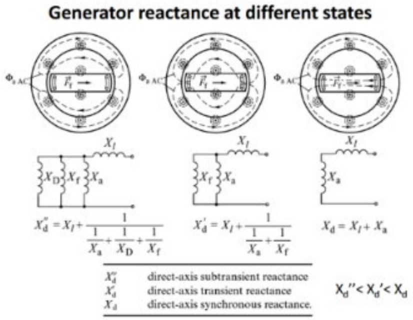
Power Quality Issues with Generators

Engine Generators for

- back up power for critical loads
- islanding for demand load reduction

Main Issues

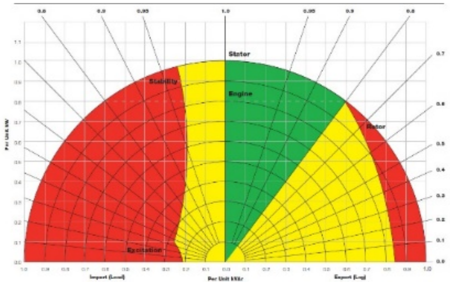
- More sensitive to harmonic current losses
- Create more voltage distortion than similar sized transformer
- Reduced power factor capability



higher voltage distortion

Harmonics also affect converter based generation

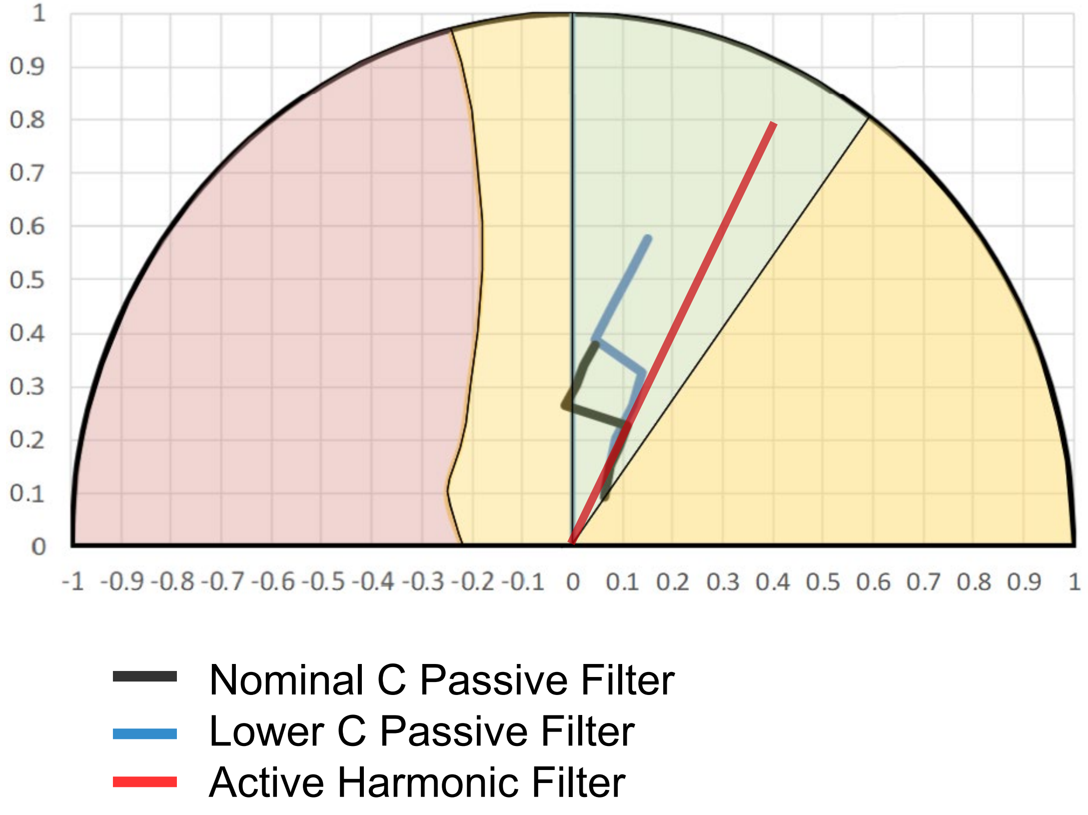
- Micro-turbines
- Renewable energy converters



power factor capability

Active and Passive Filters meet Generators Capability

Passive Filter Contactor Control



50% Loaded Generator

- 40% VFD with nominal C passive filter
- 10% ac motor

75% Loaded Generator

- 65% VFD with lower C passive filter
- 10% ac motor

100% Loaded Generator

- 90% VFD load
- 10% ac motor load
- Active Harmonic Filter

Passive filter contactor controlled for power factor and filtering performance

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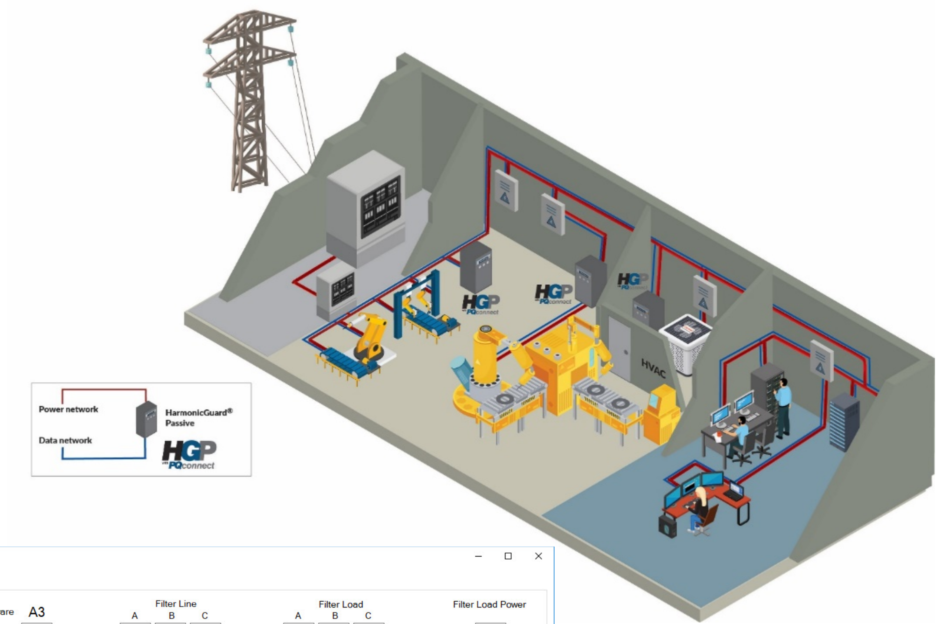
HGP & HGL with PQconnect Technology

HGP with PQconnect

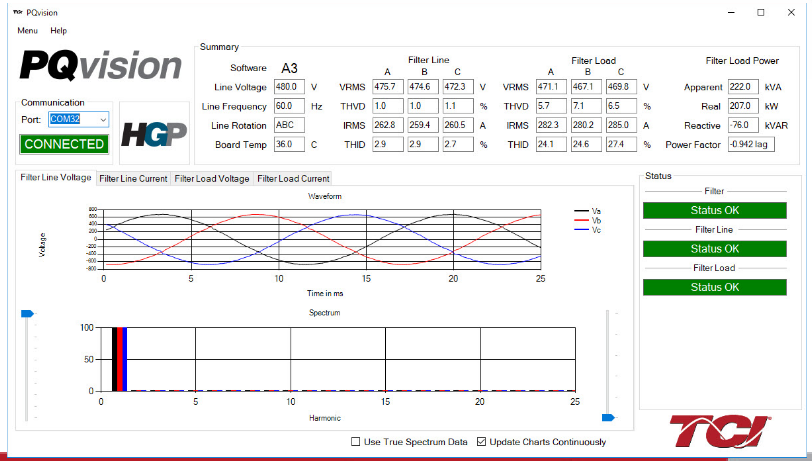
The HGP and HGL filter with PQconnect

- First intelligent passive filter to offer industry leading harmonic mitigation and allow remote monitoring and control
- Supports your facility power system monitoring with electrical data and information alerts
- IEEE-519 2014 compliant
- Serial and Bluetooth communications, Networkable
- Local control eliminates need for VFD field wiring
- Programmable generator compatibility



DATA MEASUREMENTS

- Filter status detection
- THID (total harmonic current distortion)
- THVD (total harmonic voltage distortion)
- V (voltage)
- I (current)
- PF (power factor)



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Harmonic Filtering Summary

Summary

- Electrical systems are continually compromised by the increase in non-linear loads causing harmonic distortion. Non-linear loads such as variable frequency drives (VFDs) are great for efficiency, but leave power quality polluted with harmonic distortion.
- IEEE-519 regulates the total harmonic current distortion (THID) applied to the line.
- The addition of a harmonic filter reduces the total harmonic current distortion (THID) to 5% and protects other equipment on the bus by reducing voltage distortion.
- Each type of filtering has different functions, features and benefits. There is not a one-size fits all solution to filtering.
- Depending on your system requirements/regulations, motor size, generator needs and linear/non-linear load ratings, filtering options are available that will fit your needs.

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About TCI, LLC

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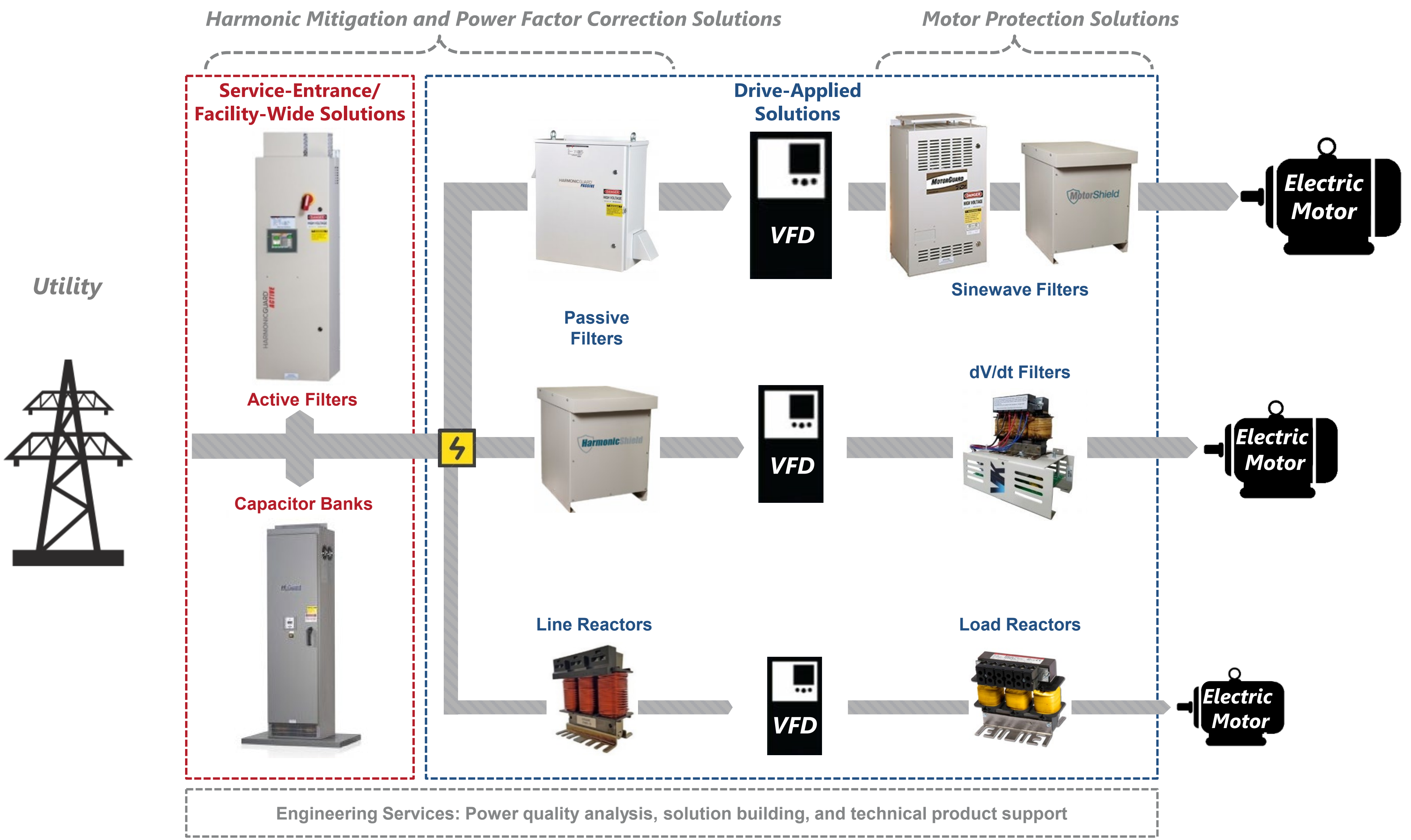
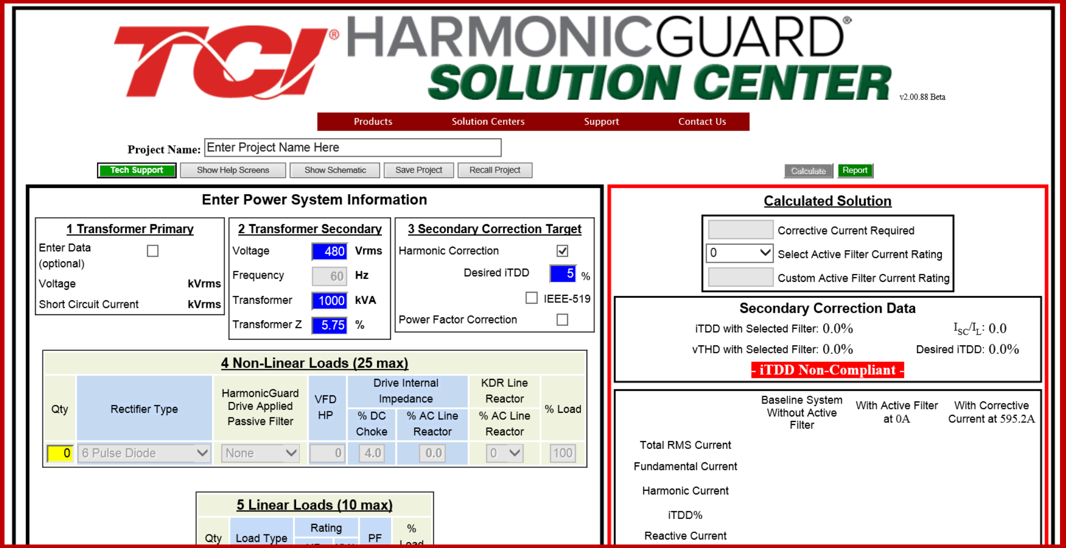
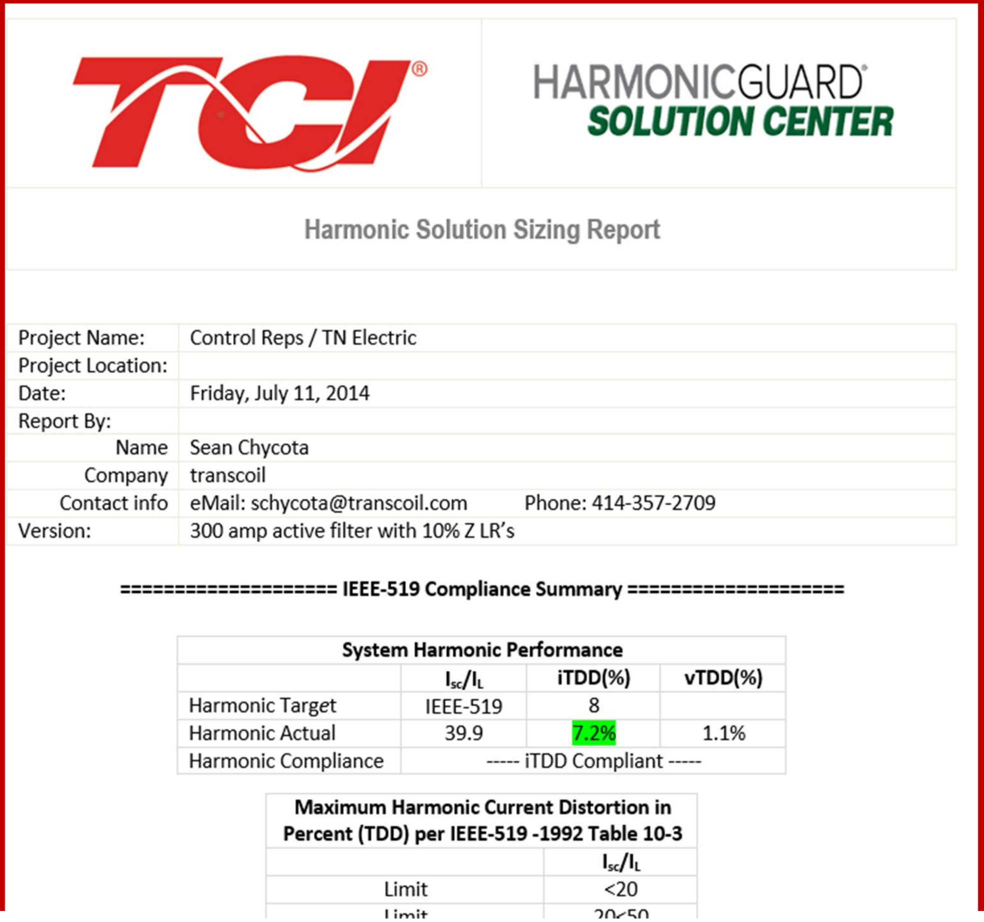
TCI's Range of Power Quality Solutions



Only North American Manufacturer to Offer Both Active and Passive Filters ⇨ Allows for Hybrid Solutions

New On Line Harmonic Calculator





HARMONICGUARD® SOLUTION CENTER

Harmonic Solution Sizing Report

Project Name:	Control Reps / TN Electric
Project Location:	
Date:	Friday, July 11, 2014
Report By:	
Name	Sean Chycota
Company	transcoil
Contact info	eMail: schycota@transcoil.com Phone: 414-357-2709
Version:	300 amp active filter with 10% Z LR's

=================== IEEE-519 Compliance Summary ===================

System Harmonic Performance			
	I_{sc}/I_L	iTDD(%)	vTDD(%)
Harmonic Target	IEEE-519	8	
Harmonic Actual	39.9	7.2%	1.1%
Harmonic Compliance	----- iTDD Compliant -----		

Maximum Harmonic Current Distortion in Percent (TDD) per IEEE-519 -1992 Table 10-3	
	I_{sc}/I_L
Limit	<20
Limit	20<50

- IEEE519 Compliance Report
- Sizing of Active Filters
- Design Most Cost Effective Harmonic Solution
- Free online tool-open to public use

Thank you

Advancing Power Quality