Setting the Standard for Automation™

Harmonics, IEEE519 and Harmonic Solutions

Thomas J Schaefer

Rockwell Automation/Allen Bradley

Standards

Certification

Education & Training

Publishing

Conferences & Exhibits

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- 30 years experience in controls and automation
  - Water/Wastewater
  - Pulp and Paper
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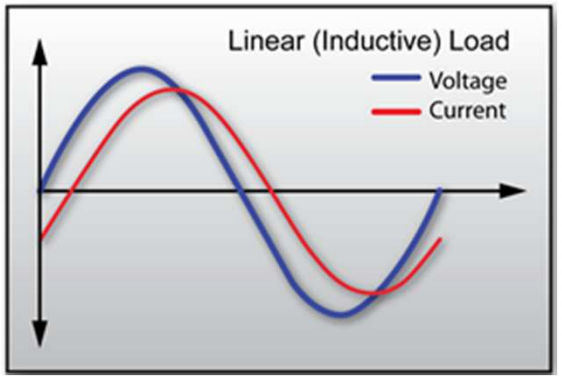
Allen-Bradley

Agenda

- Bio
- Harmonics Basics – Linear/Non-Linear Loads
- Affect of VFD's
- Harmonics left unchecked
- IEEE and *ISC/IL*
- Harmonic Considerations
- Specification Considerations

Utility Power to a Facility

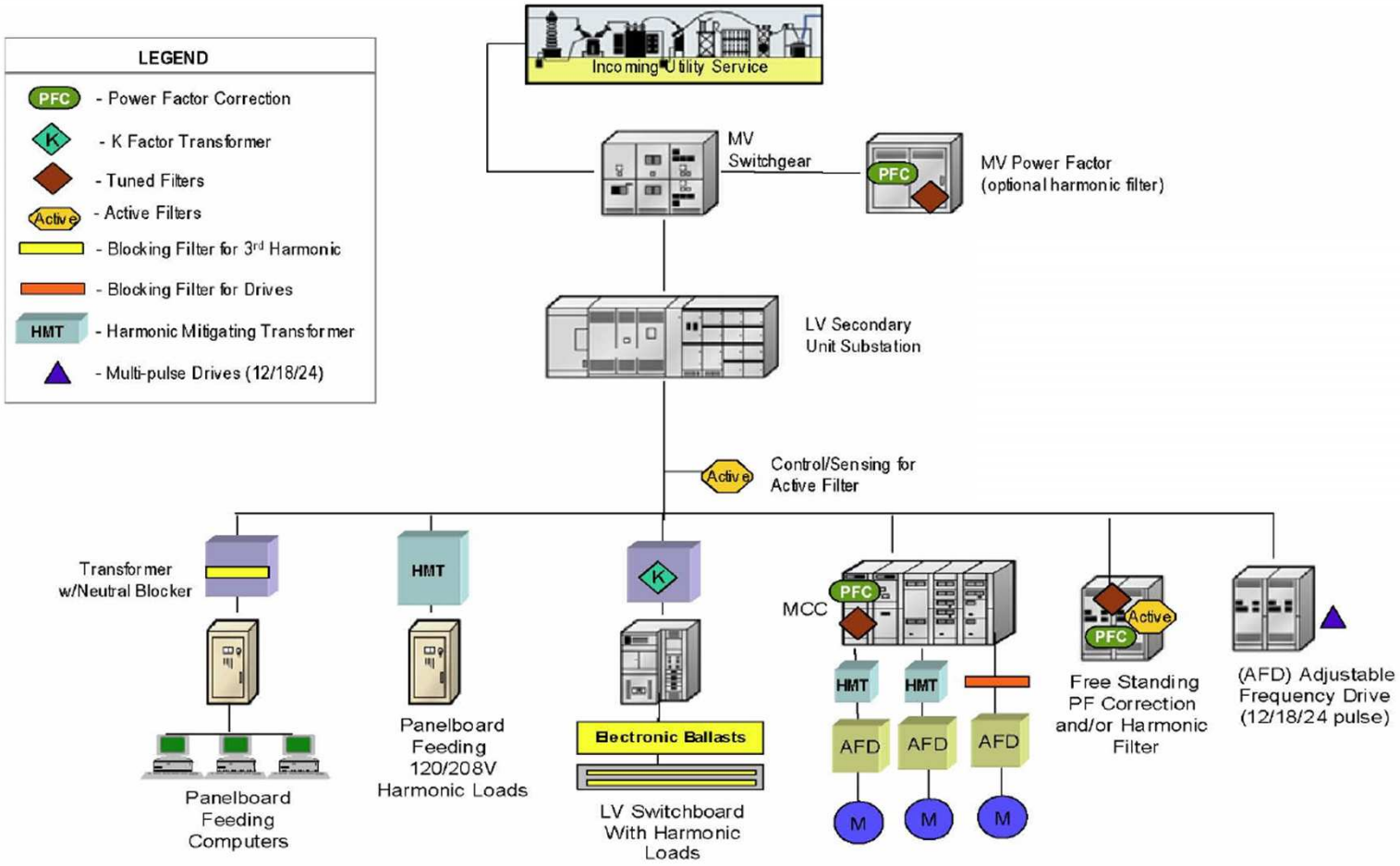
Coal Plant



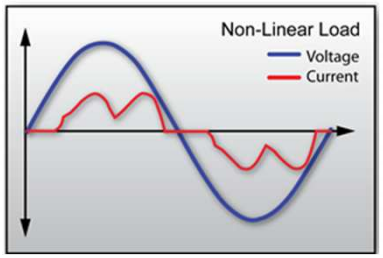
WW Plant

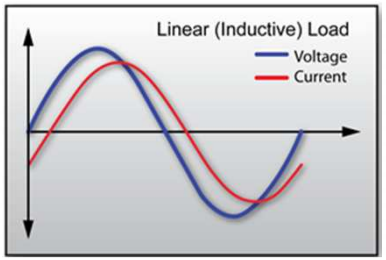
Power from the utility is delivered to a wastewater plant in sinusoidal form, at a frequency of 60 Hz. All electrical equipment in the plant is designed to run off of this waveform at this frequency.

Typical Power Distribution System

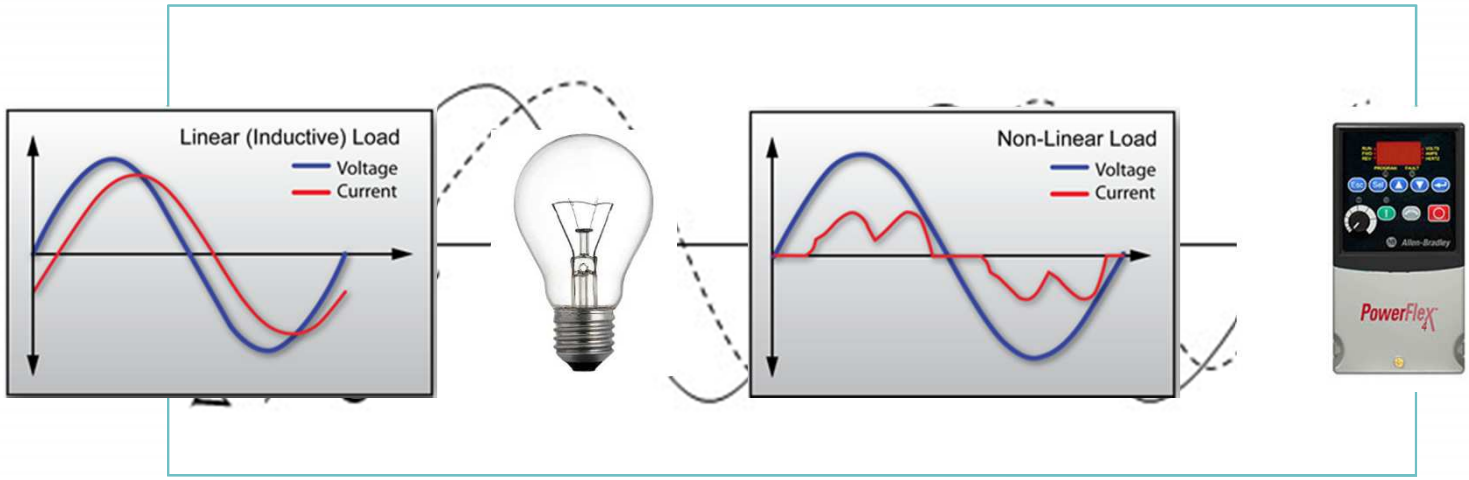


Linear v. Non-Linear Loads





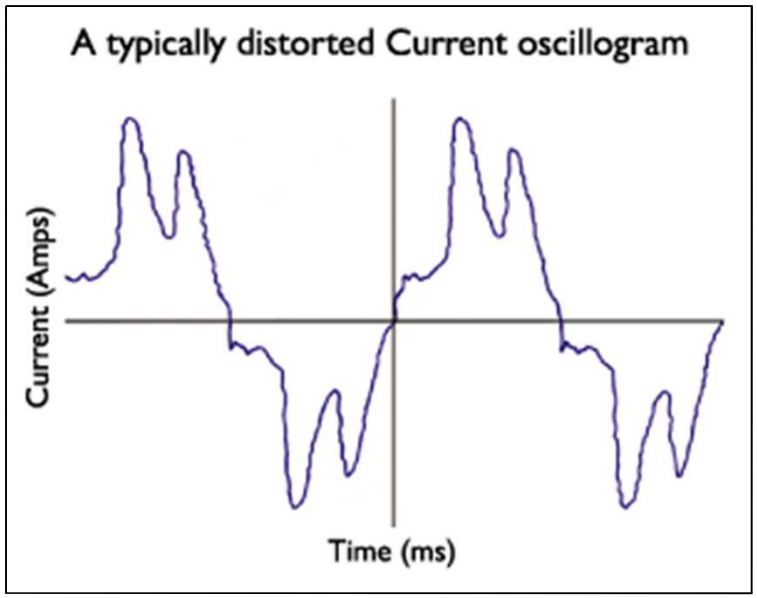
Harmonics and Non-Linear Loads



A linear load is one where voltage (a sine wave) is applied across a constant resistance resulting in current (another sine wave). In AC power distribution systems, non-linear loads create harmonics by drawing current in abrupt short pulses, rather than in a smooth sinusoidal manner.

Non-linear loads are caused by Switching Power Supplies such as Computers, AC & DC variable Speed Drives, UPS and lighting loads.

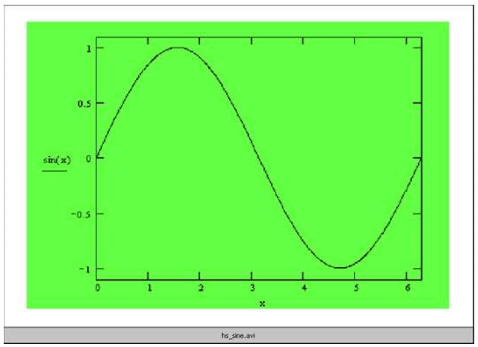
Variable Frequency Drives

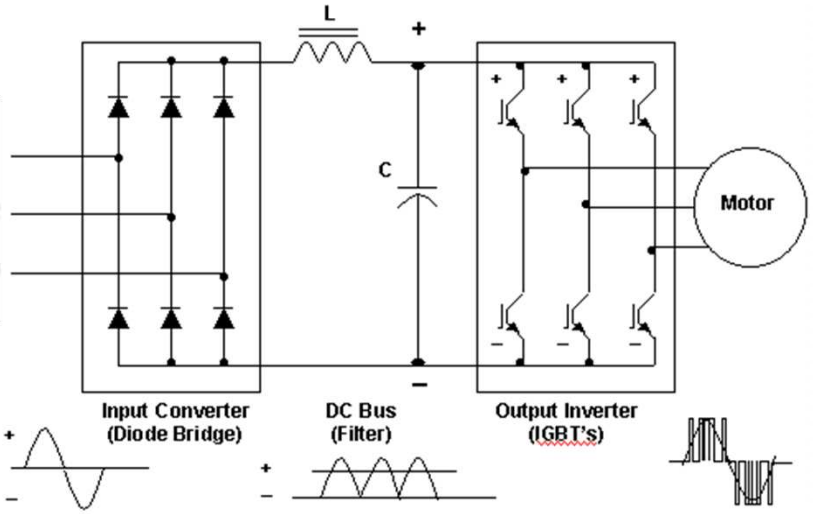


When non-linear loads such as variable frequency drives (VFDs) are introduced into electrical distribution systems they cause harmonics. A rectifier located at the input stage of the drive converts the AC supply voltage into a DC voltage for the DC Bus. The action of the rectifier distorts the input current which is then no longer sinusoidal.

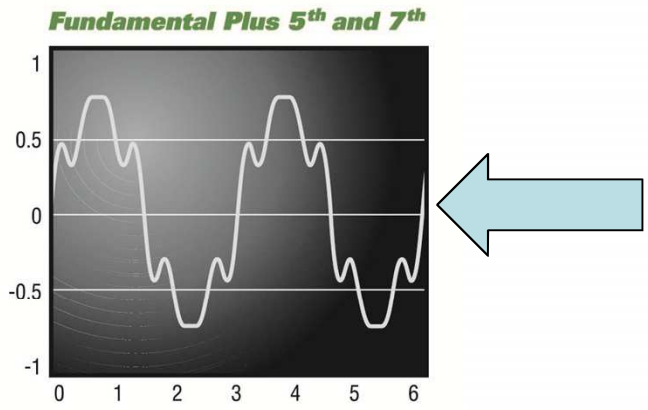
VFDs are typically the largest contributor of harmonics back on to the grid.

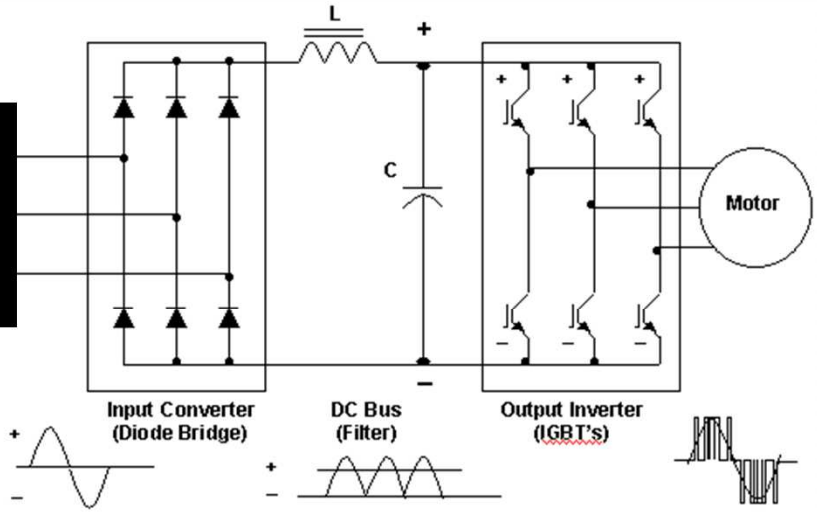
6 Pulse VFD

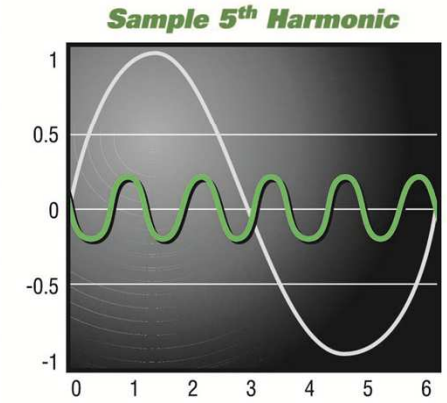


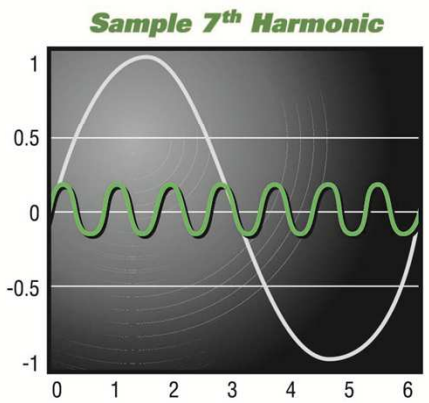

L
+
C
–
Motor
Input Converter
(Diode Bridge)
DC Bus
(Filter)
Output Inverter
(IGBT's)

6 Pulse VFD









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

Variable Frequency Drives

Typical Motor Applications

- HVAC, Oil and Gas, Water/Wastewater, Industrial, Manufacturing, Food Processing, Pharmaceutical, Elevator/Escalator and Pulp and Paper

Benefits

- Reduces mechanical stress on equipment
- Lower electrical power costs (fan and pump loads) for each 1 hertz in reduction amps consumed is reduced by three.
- More precise machine control with constant torque loads
- Better process yields
- Higher overall plant productivity

Major Drawback

- These devices create harmonics back on to the utility grid.

The problem is getting worse – VFD's are Everywhere!

In a wastewater plant or hospital VFD's or switch mode power supplies are powering almost every piece of equipment with a motor…..

HSI

TROJAN UV

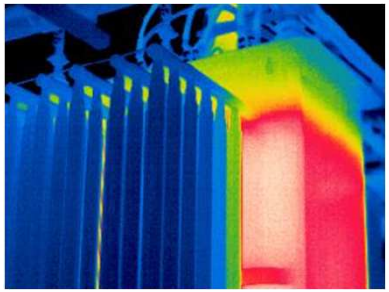
AQUA-AEROBIC SYSTEMS, INC.

APG

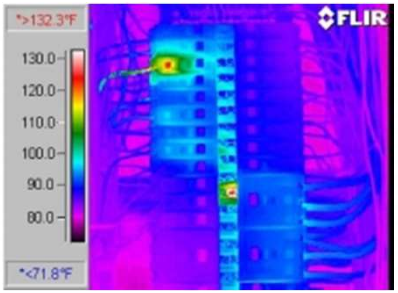
Neuros

THERMAL PROCESS SYSTEMS

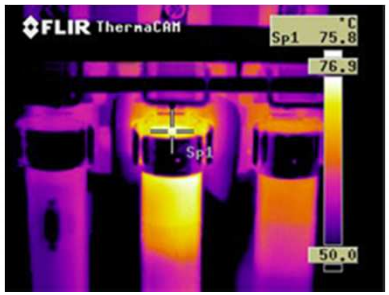
Symptoms of Harmonics



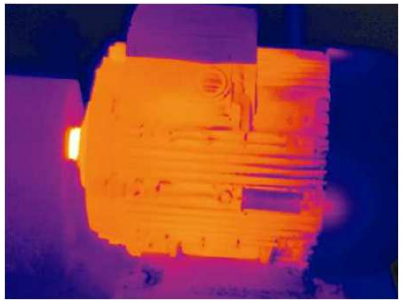
Transformers Fail



Circuit Breakers Trip



Fuses Blow



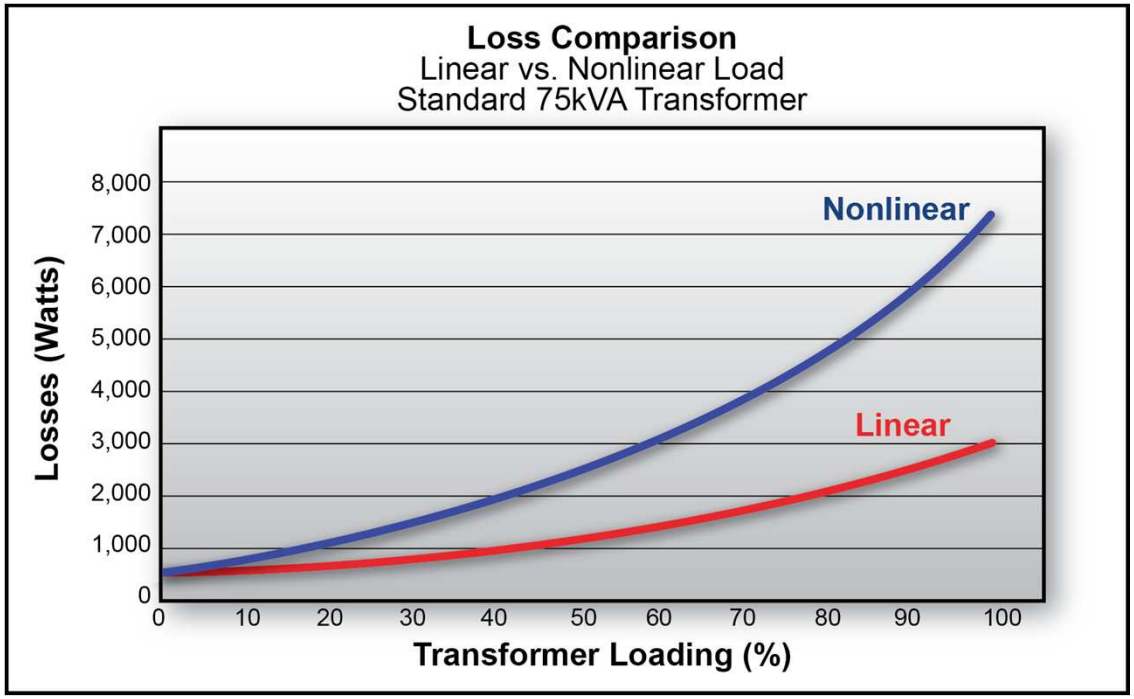
Motors Fail

Generators Trip

Caps Blow

Common Effects of Harmonics

- Resonance
- Circuit breaker tripping
- Fuse meltdown
- Capacitor bank failure
- PLC I/O can change state
- Loss of lighting ballasts
- SCADA issues
- VFD problems
- Skin effect on cables
- Welding problems
- Motor failure
- Transformer failure



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

- The growth of non-linear loads has led to the creation of IEEE-519 to control the amount of harmonics allowable on the Utility Electrical System.
- IEEE 519-1992 defines harmonic limits within a power distribution system to assure proper equipment operation through its “Standard Practices and Requirements for Harmonic Control in Electrical Power Systems.”
- It is currently the only recognized industry standard in North America for setting harmonic limits (voltage and current).
- Designed to limit utility harmonics as well as customer harmonic contribution to the utility grid.

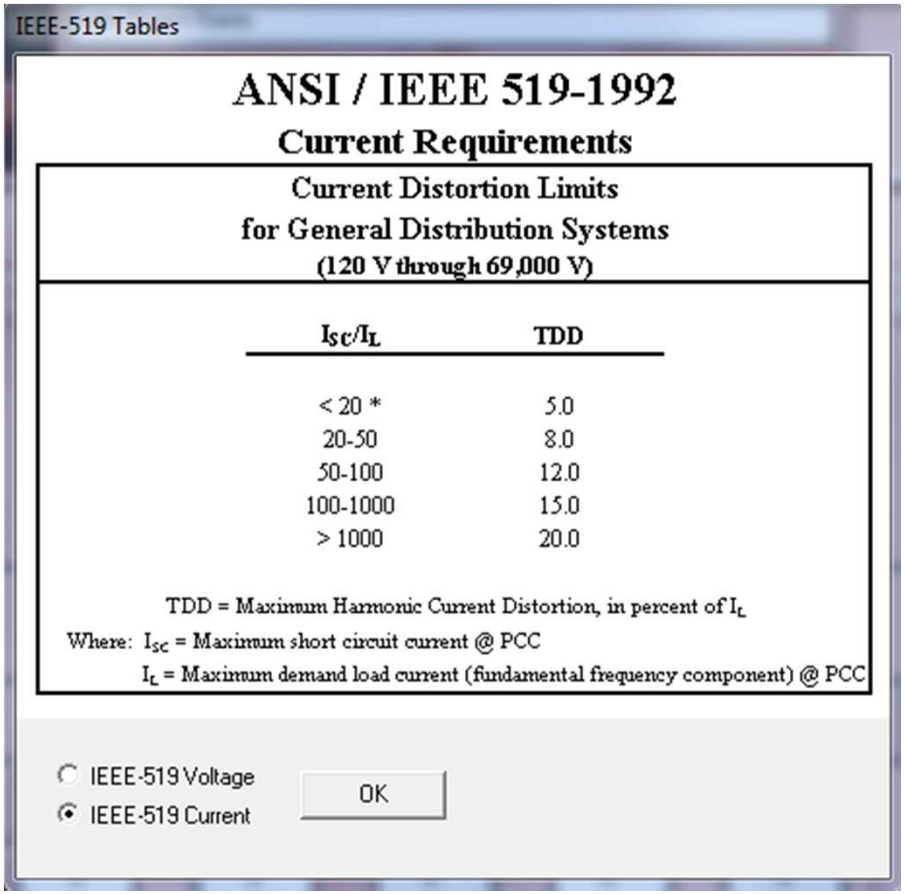
Many utilities use this spec to govern their customers’ harmonic “output”…

Is IEEE-519 Enforceable?

PACIFICORP
PACIFIC POWER UTAH POWER
Engineering Handbook

In nearly all cases harmonic distortion is produced by a customer's equipment injecting electrical noise into the power system. This can degrade PacifiCorp's service to other customers. For help in avoiding this problem please refer to Sections 9-12. Reducing electrical noise will allow PacifiCorp to provide quality electrical service to all its customers as partially specified in Section 8. ***PacifiCorp requires that a customer's facility must stay within all limits described in Sections 5, 6 and 7 as measured at the point of common coupling****, see 4.5.* ***The customer shall take necessary action at the customer's sole expense, for the customer's facility to stay within these limits. Disregard of such limits can result in termination of electrical service*** or other remedial action as provided by state regulatory authority.

IEEE-519 Current Requirements


IEEE-519 Tables

ANSI / IEEE 519-1992

Current Requirements

Current Distortion Limits
for General Distribution Systems
(120 V through 69,000 V)

I_{SC}/I_L	TDD
< 20 *	5.0
20-50	8.0
50-100	12.0
100-1000	15.0
> 1000	20.0

TDD = Maximum Harmonic Current Distortion, in percent of I_L

Where: I_{SC} = Maximum short circuit current @ PCC

I_L = Maximum demand load current (fundamental frequency component) @ PCC

IEEE-519 Voltage
IEEE-519 Current
OK

The short circuit to load ratio determines allowable harmonic distortion. When a transformer is fully loaded the short circuit to load will be <20. Maximum allowable distortion is 5%.

What is ISC/IL ?

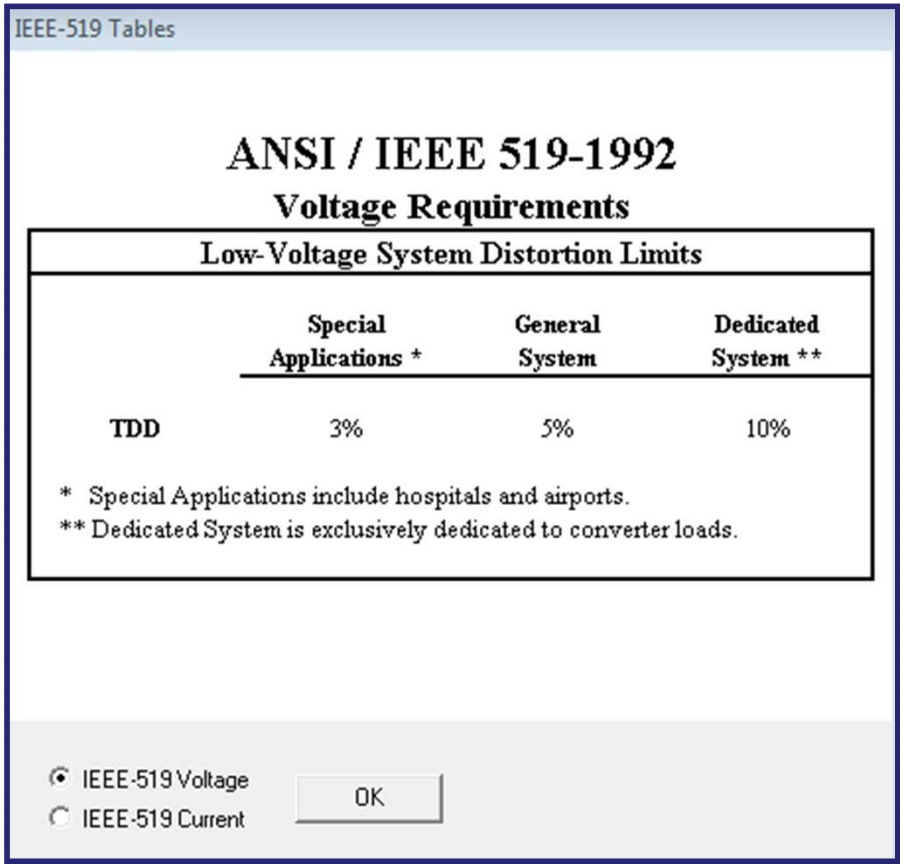
The size and strength of your system:

Blue dye represents VFD load.

Clear water represents linear load

Vessel size represents transformer/ syste

IEEE-519 Voltage Requirements


IEEE-519 Tables

ANSI / IEEE 519-1992

Voltage Requirements

Low-Voltage System Distortion Limits

	Special Applications *	General System	Dedicated System **
TDD	3%	5%	10%

* Special Applications include hospitals and airports.

** Dedicated System is exclusively dedicated to converter loads.

IEEE-519 Voltage

IEEE-519 Current

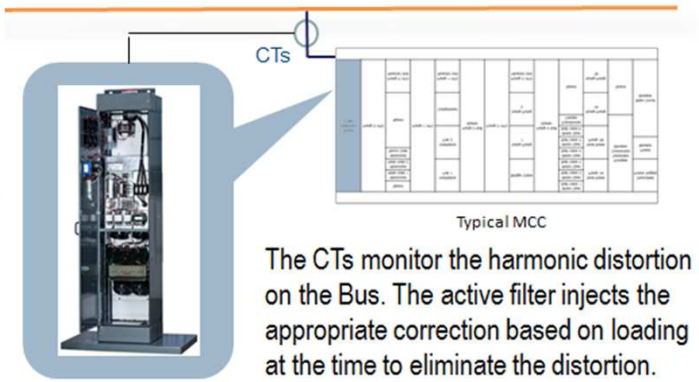
OK

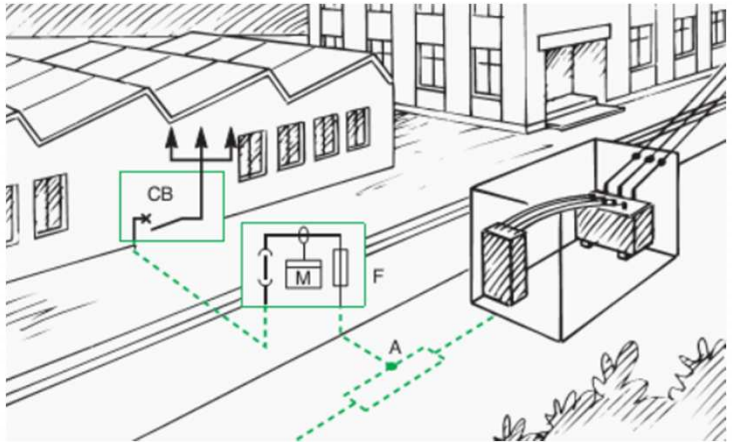
5% voltage distortion is allowable for general applications. Hospitals, airports, and government buildings fall under "special" and require 3% maximum voltage @ the PCC.

Commonly Asked Questions

- **What is IEEE-519?**
  - Measurement at the Point of Common Coupling (PCC) of current and voltage distortion
  - Measurement of a complete distribution system….not individual components
  - Determines the allowable limits of harmonics back onto the power grid
- **Point of Common Coupling**
  - The PCC is generally defined as the utility/customer connection point. It is this point at which the current distortion limits apply.
  - It is also the point where non-linear loads intersect with linear loads and is used to measure TDD.

Commonly Asked Questions





Harmonics generated in this facility would effect other customers

❑ What is Total Harmonic Distortion (THD)?

-THD is a measurement of the total harmonic distortion of a periodic distorted signal. Typical point of measurement would be at a main breaker on an MCC.

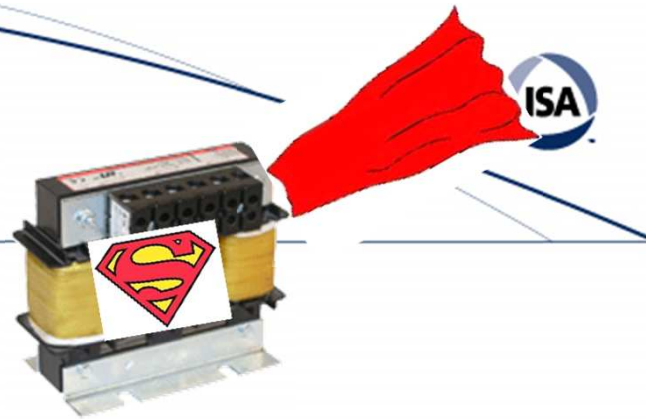
❑ What is Total Demand Distortion (TDD) ?

-TDD is a calculated harmonic current distortion against the full load (demand) level of the electrical system. This would be measured at the PCC and is the sum of all loads.

Harmonic Solutions

6 Pulse Drive +	Built in Solution
Line Reactor / DC Choke	12 Pulse
Passive Filter	18 Pulse
Active Filter	Active Front End

AC Line Reactors

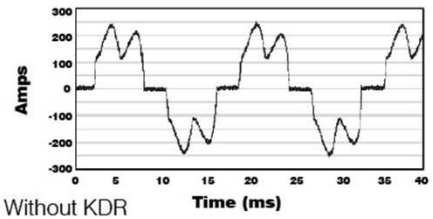


Dual Purpose: harmonic mitigation, transient blocker.

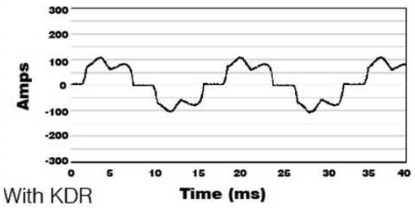
Impedance – slows the rate of change in AC waveform.

Impedance Choices – 3%, 5%, 10%

Prolongs the life of drive components.



Without KDR



With KDR

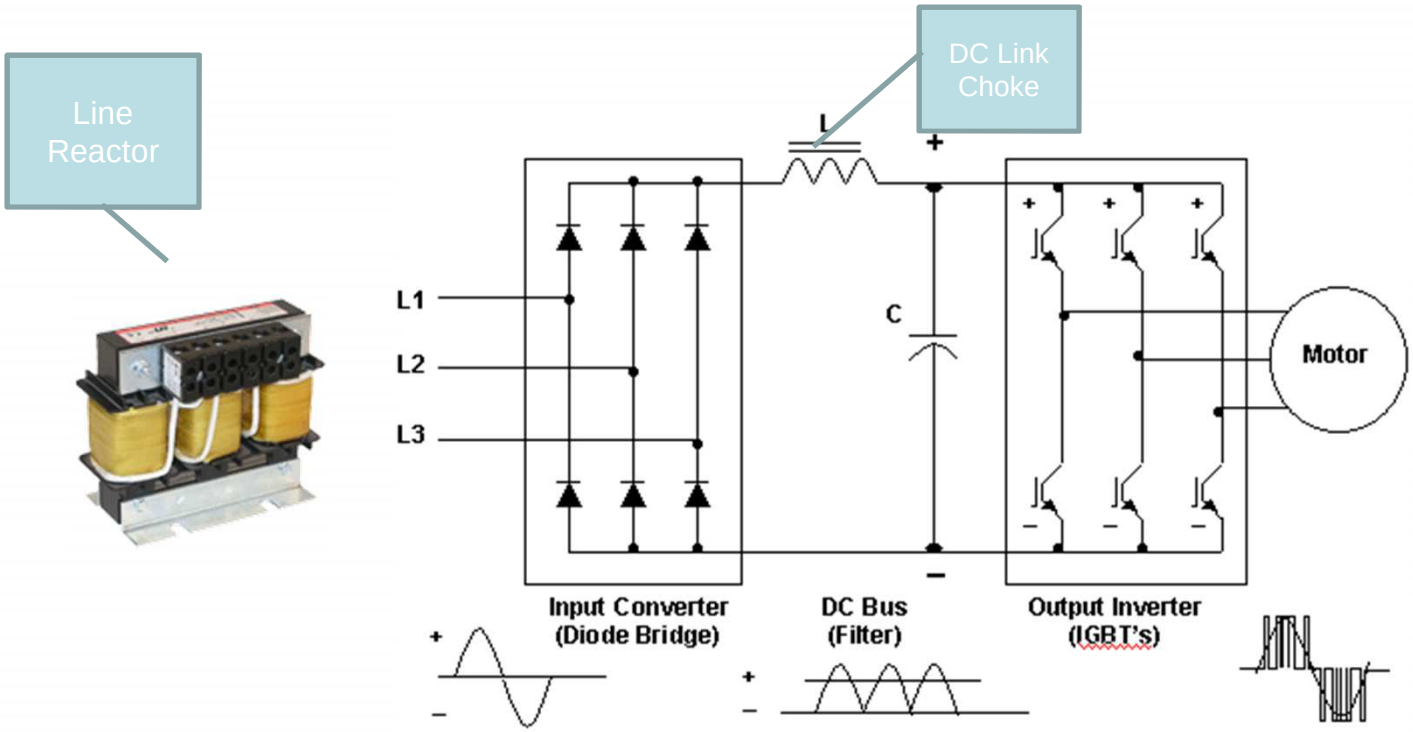
Harmonic Reduction

Z%	THD%
0.5	105%
1	86%
1.5	75%
2	63%
2.5	54%
3	48%
3.5	44%
4	41%
4.5	39%
5	37%
5.5	36%
6	34%
6.5	33%
7	32%
7.5	31%
8	30%
8.5	30%
9	29%
9.5	28%
10	28%

Voltage Drop

Impedance %	Voltage Drop
1%	0.005%
2%	0.02%
3%	0.04%
4%	0.08%
5%	0.12%
6%	0.18%
7%	0.24%
8%	0.32%
9%	0.40%
10%	0.50%

Line Reactors And DC Link Chokes



Very similar but location is everything! DC choke smooth's DC bus ripple, reduces harmonics but does not protect the diode bridge! About half the impedance value of an AC reactor unless located on the + & - of the DC bus.

Protecting VFD Components

Transformer Recommendations

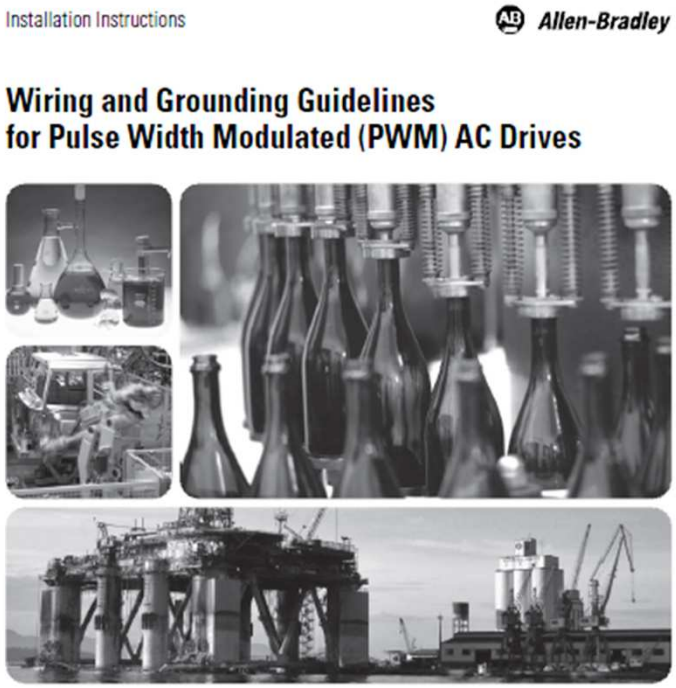


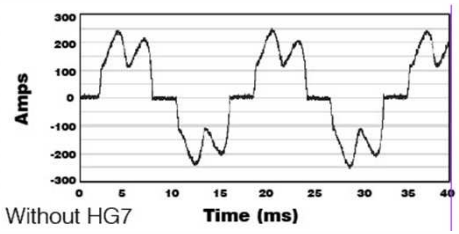
Table 2.C AC Line Impedance Recommendations for PowerFlex 4 Drives

	Drive Catalog Number[1]	Volts	kW (HP)	Max Supply kVA	3% Line Reactor Open Style 1321-	Reactor Inductance (mH)	Reactor Current Rating (Amps)
PowerFlex 4	22AB1P5	240	0.2 (0.25)	15	3R2-A	12	2
	22AB2P3	240	0.4 (0.5)	25	3R4-B	6.5	4
	22AB4P5	240	0.75 (1.0)	50	3R8-B	3	8
	22AB8P0	240	1.5 (2.0)	100	3R8-A	1.5	8
	22AB012	240	2.2 (3.0)	125	3R12-A	1.25	12
	22AB017	240	3.7 (5.0)	150	3R18-A	0.8	18
	22AD1P4	480	0.4 (0.5)	15	3R2-B	20	2
	22AD2P3	480	0.75 (1.0)	30	3R4-C	9	4
	22AD4P0	480	1.5 (2.0)	50	3R4-B	6.5	4
	22AD6P0	480	2.2 (3.0)	75	3R8-C	5	8
	22AD8P7	480	3.7 (5.0)	100	3R8-B	3	8

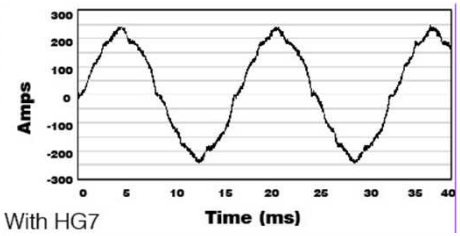
(1) Shaded rows identify drive ratings without built-in inductors

Rockwell publishes max supply kVA recommended without addition line inductance…..rarely is this used.

Passive Harmonic Filter



Without HG7



With HG7

- Harmonic reduction to 5-7% ITHD.
- Broadband filter with a 5th harmonic trap
- Use when need to meet IEEE-519 specification 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.

HG7 Standard Nema 1 Packaging

KDR Series Line Reactor

L1, L2, L3 Input
T1, T2, T3 Output to VFD

Circuit Protection

KTR Tuning Reactor

Input Connected to output terminals of Reactor
Output Connected to Isolation Contactor

Isolation Contactor

Input from KTR Reactor
Output to Capacitor

Capacitors

Disconnected when Isolation Contactor in Open State or VFD in Off Condition

CPT

Supplies 120V to Coil of
Isolation Contactor thru N/O VFD Aux Contact

Passive Harmonic Filter Locations

Active Harmonic Filter

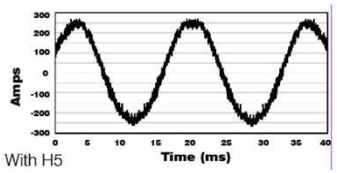
- System applied on standard 6 pulse VFDs
- Harmonic reduction – 5% TDD
- Load, bus or PCC applied solution, use with multiple VFDs
- Monitors bus, injects counter current to cancel out harmonic currents
- Provides Power Factor Correction

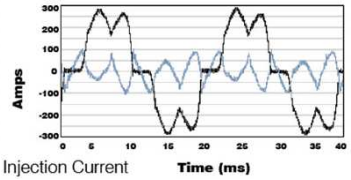
Active Harmonic Filter Sizes

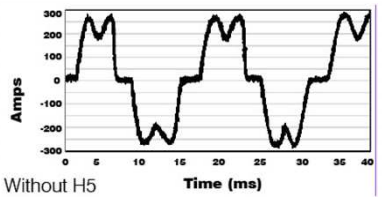
Rated In Corrective Amps

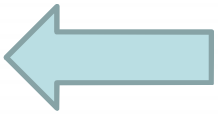
- 50 Amp
- 100 Amp
- 225 Amp
- 300 Amp
- Larger sizes available

Active Harmonic Filter Locations







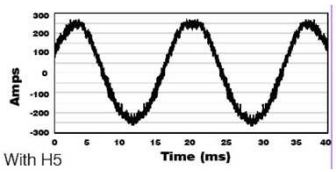


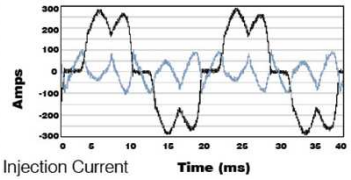
CTs

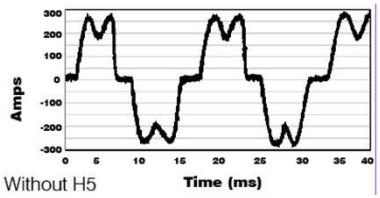
CTs mounted upstream or downstream of the active filter sense harmonic distortion from the load

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.

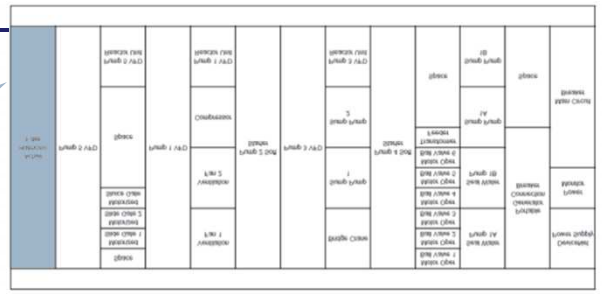
Active Harmonic Filter Locations







CTs

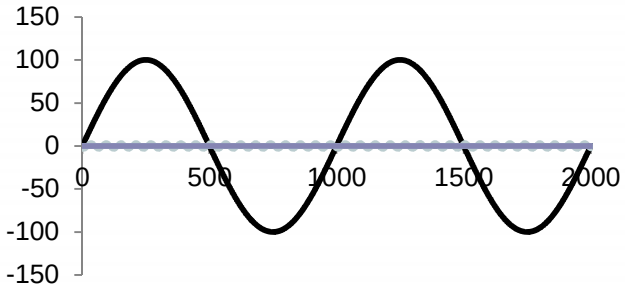


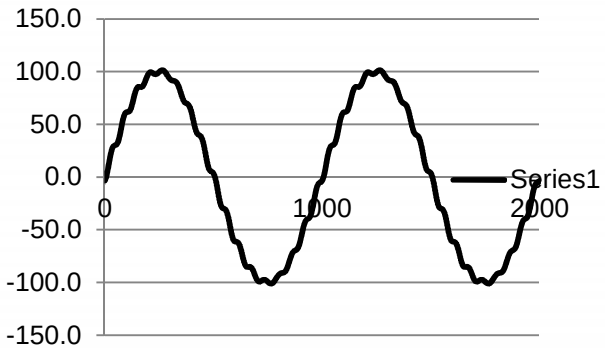
Typical MCC

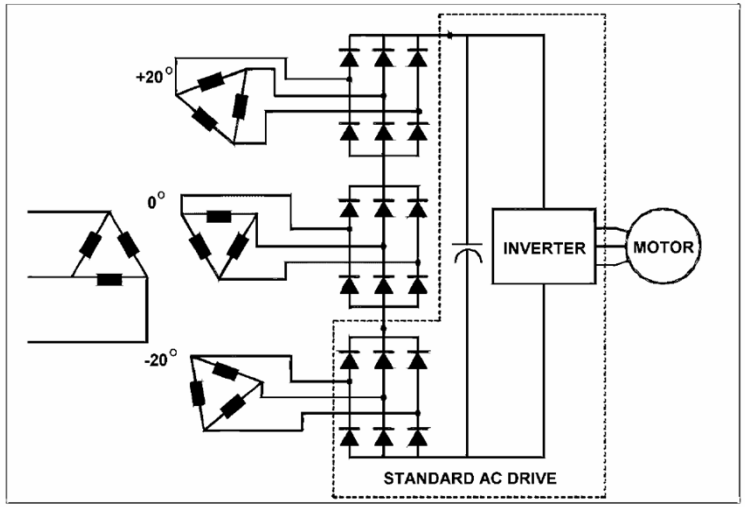
CTs mounted upstream or downstream of the active filter sense harmonic distortion from the load

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.

18 Pulse - WW's Go To Solution







5% Solution out of the box. No calculations.

Phase shifting transformer and more diodes limit harmonics.

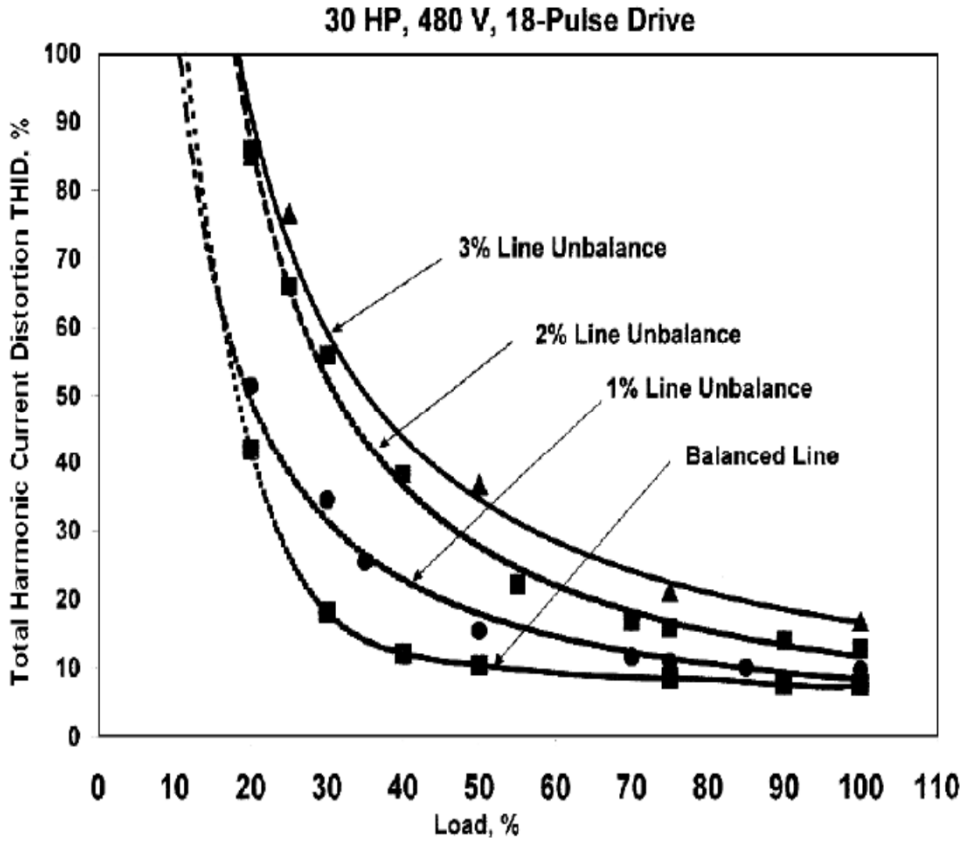
18 Pulse - Solution

Limitations

- Line unbalance reduces harmonic filter performance
- Large Physical Size
- Custom - Long Lead Time for Manufacture & Repair
- Cost
- Limited HP Range
- Less efficient than 6 pulse

Dimensions

60 to 75	96	40	2324 X 889 X 635 (91.5 X 35 X 25)
100 to 150	180	40	2324 X 889 X 635 (91.5 X 35 X 25)
150 to 200	325	40	2324 X 1524 X 787 (91.5 X 60 X 31)[4]



Active Filters v 18 Pulse VFD's

Based on application, active filters can be a very cost effective solution.

18 pulse drives are very expensive, large, heavy and less efficient than standard 6 pulse drives.

In applications with large HP VFD's, 18 pulse or 6 pulse VFD's with passive filters can be a better solution.

Product (enclosed)	Cost (estimated)	Watts Loss	Dimensions (inches rounded)	Weight (lbs)
100 HP 18 Pulse VFD	$17,000	4,776	94 x 36 x 24	1,703
100 HP 6 Pulse VFD	$6,500	1,720	24 x 12 x 12	100
100 AMP H5 Active Harmonic Filter	$17,000	4000	56 x 18 x 17	371

Multiple Drive Applications Comparison

Product (enclosed)	Qty	Total Cost	Total Watts Loss	Total Weight (lbs)
100 HP 18 Pulse VFD	3	$51,000	14,328	5,109
100 HP 6 Pulse VFD	3	$36,500	9160	671
100 AMP H5 Active Harmonic Filter	1			
Total Savings		**$14,500**	**5168***	**4,438****

*At 8 hours a day ($.08 kWh) operation, it costs $1207 a year extra to operate the 3- 100 HP 18 Pulse VFD.

**The large difference in weight (metals) impacts shipping costs, handling costs at facilities and disposal cost.

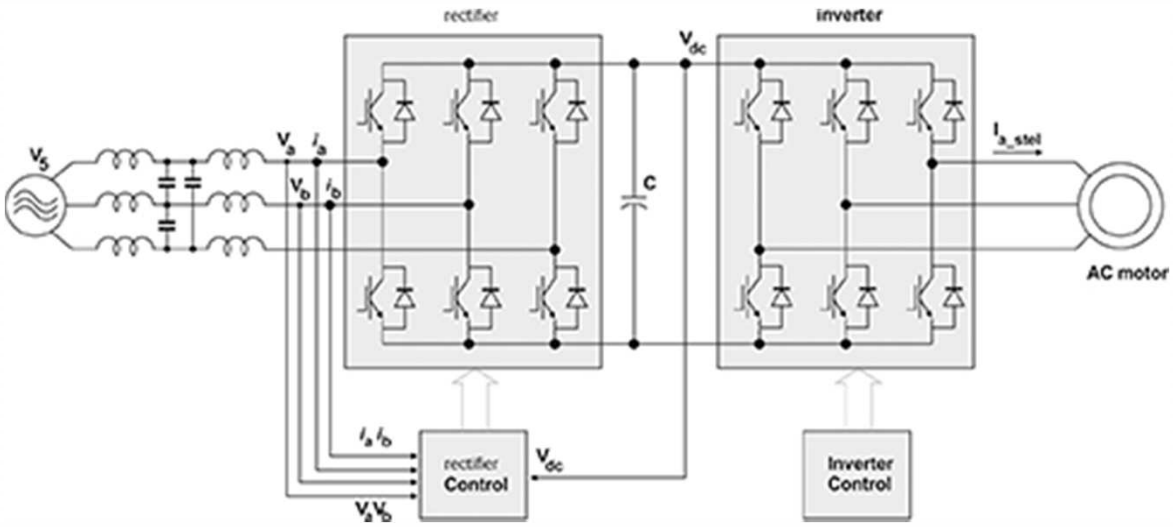
Active Front End Drives

5% Solution out of the box.
No calculations.

Like active filter but built right into drive – 2 in 1.

No major issues with loading or unbalance.

Larger and more expensive than 6 pulse.



AFE	100 HP – 83.9h x 16.9w x 25.4d - $19K
6-Pulse	100 HP – 26.2h x 12.3w x 13.64d - $8K

Which Solution is Best?

All solutions have their place.

Most can be combined to create the most cost effective solution

Consultant plan should be specific, no guess work come bid time.

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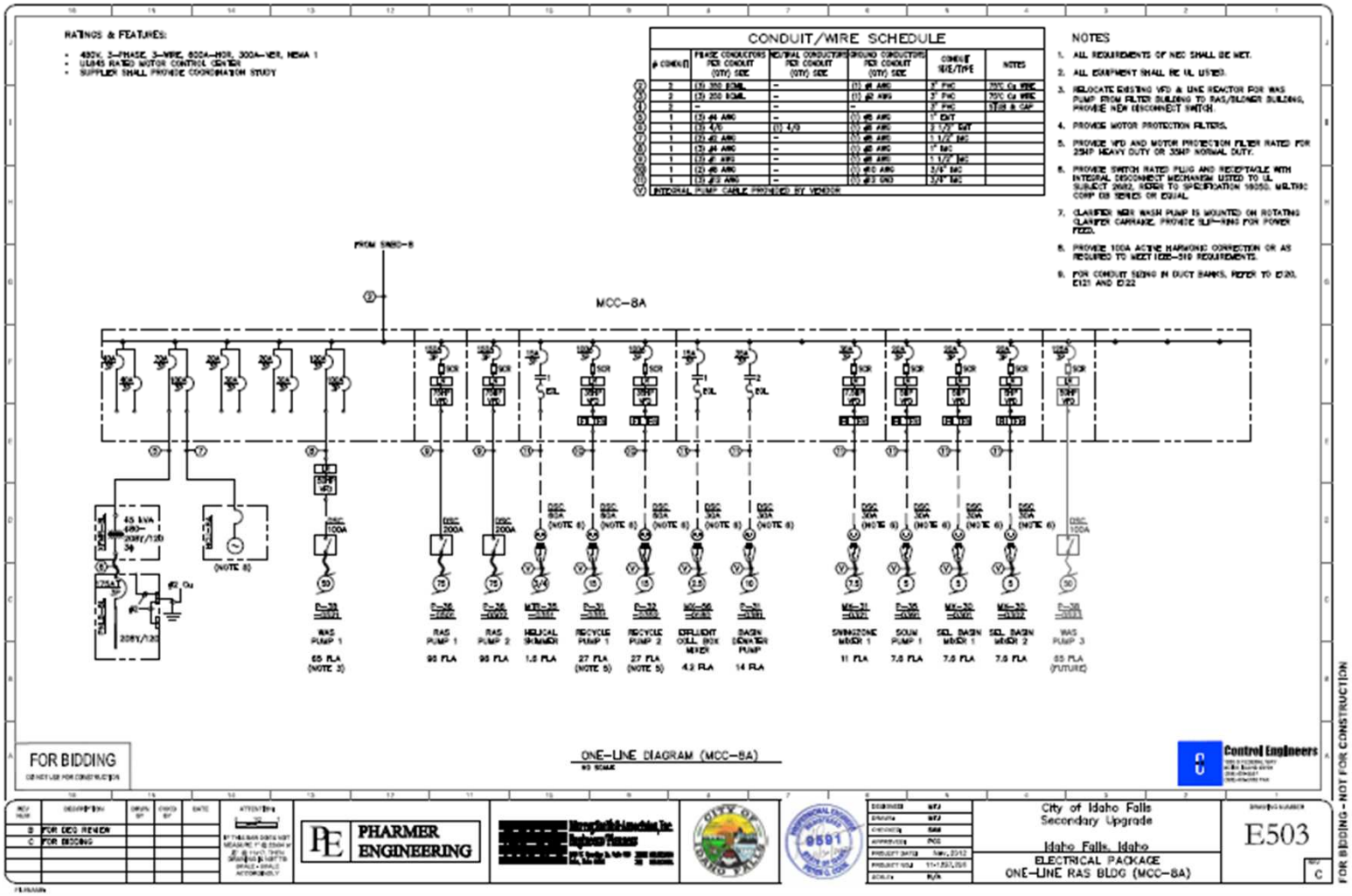
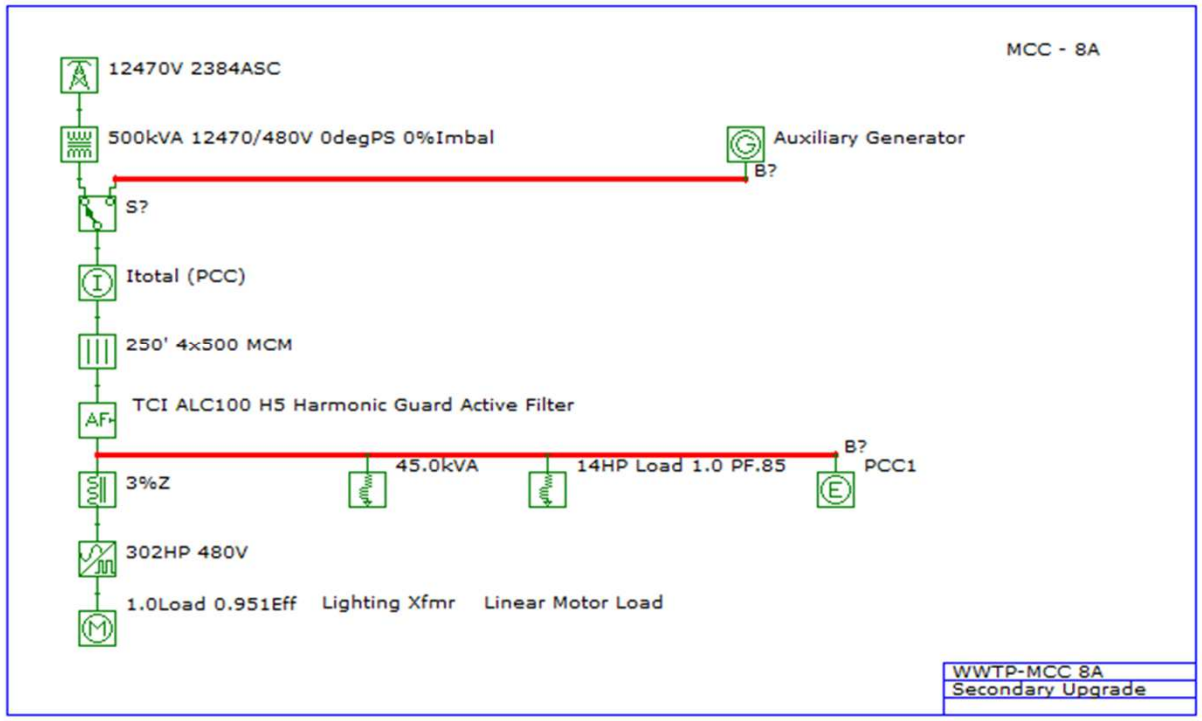
Sample of a 1-Line Plant Drawing



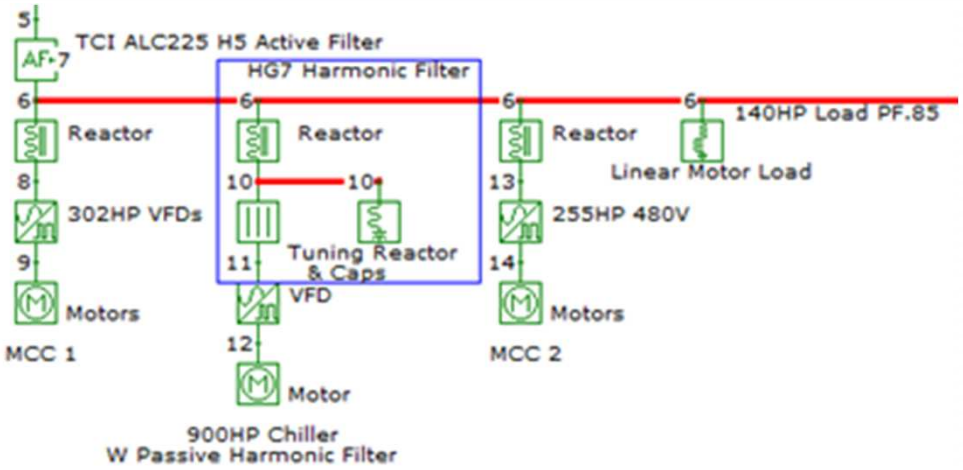
Typical Plant Harmonic Analysis



TDD – Total Demand Distortion is measured at the Point of Common Coupling (PCC)
Analysis done with TCI HAPro Software

Harmonic Filter Optimized Solution

Reactors, Active and Passive Filters Can be Used Together on a Common Bus



- Limit the use of passive filters to a third of the total non-linear load
- Improved power factor control over full load range
- Passive filter contactor can be eliminated to reduce cost
- Generator compatible

Appropriately integrating passive filters can reduce system solution costs by 10% or more

Key Take-Always From Today's Presentation

- What is the best solution?
- Importance of Line Reactors to Add Impedance
- Importance of knowing actual system loads
- Meeting IEEE-519
- Alternatives and Options

Setting the Standard for Automation™

Thank you

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