Reliable Advanced Power Quality

Harmonics in Modern Electrical Power Systems

Causes – Effects – Standards - Solutions

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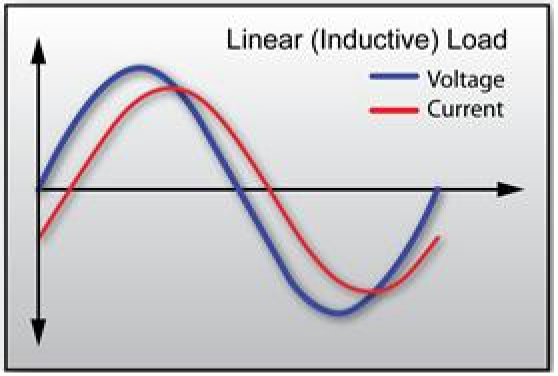
TCI, LLC

Causes – Effects – Standards - Solutions

Utility Power to a Facility

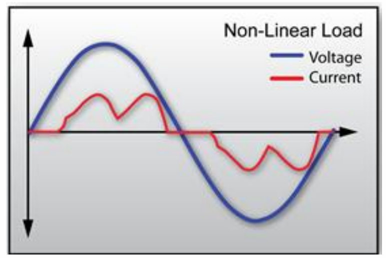
Coal Plant

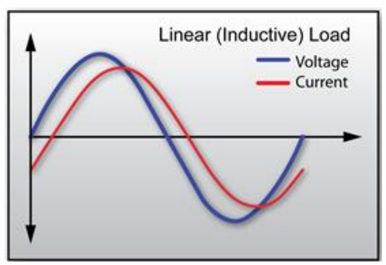


WW Plant

- Voltage from the utility is delivered in sinusoidal form, at a frequency of 60 Hz.
- All electrical equipment in the plant traditionally designed to operate at this frequency and draw sinusoidal currents.

Linear vs. Non-Linear Loads





Reliable Advanced Power Quality

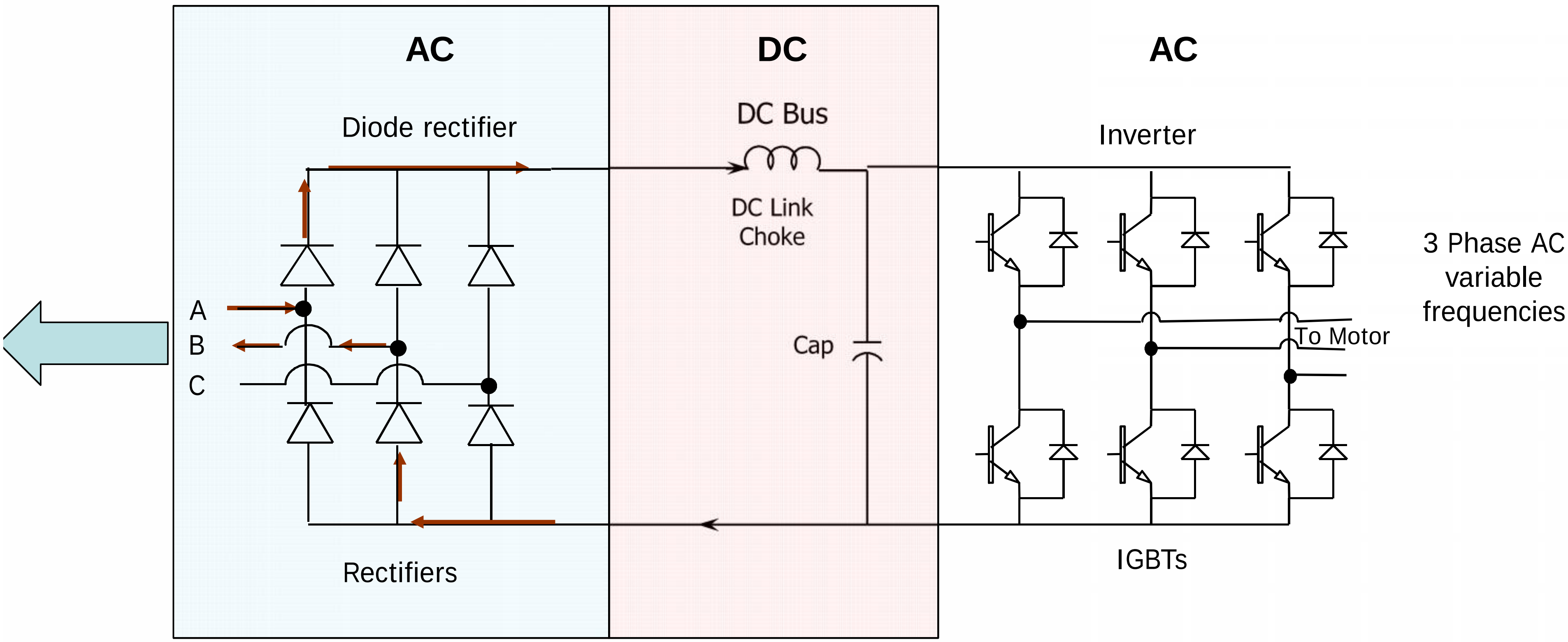
Variable Frequency Drives

- VFDs allow motor speed to be varied at full torque
- Enable precise process control
- Provide real energy savings
- High degree of penetration in past two decades

VFD’s are Everywhere!

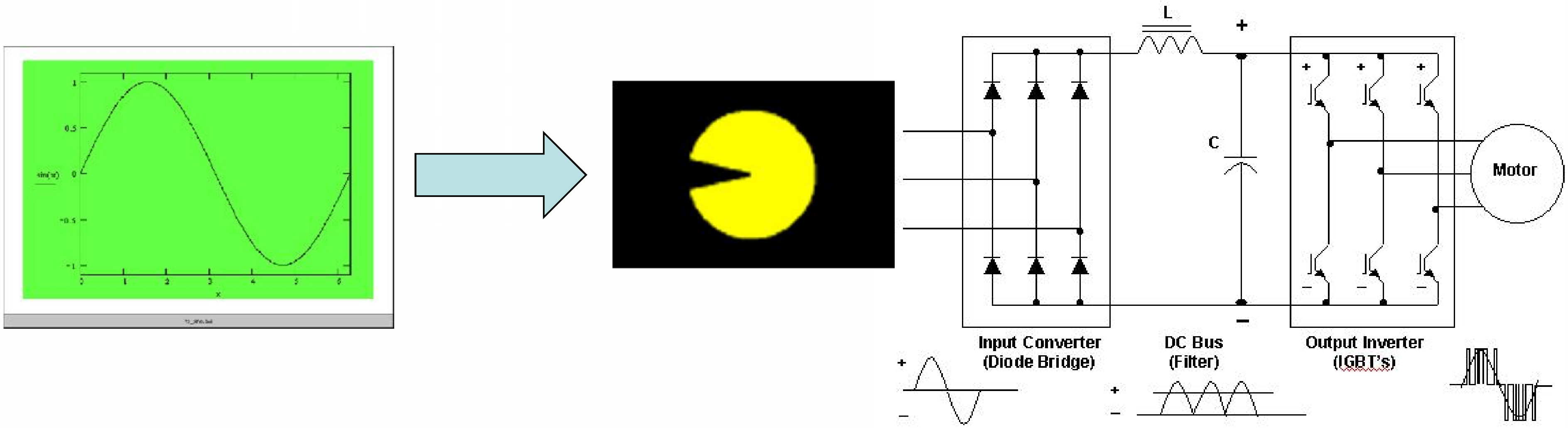
In a manufacturing plant, wastewater plant or hospital VFD’s or switch mode power supplies are powering almost every piece of equipment with a motor.

Harmonics /Front End Issue / System

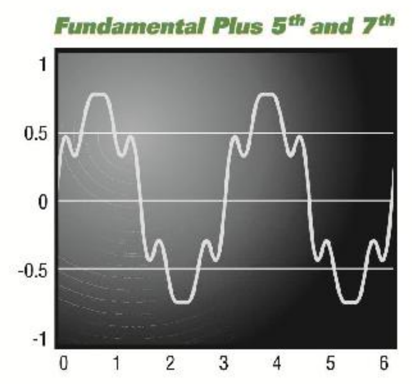


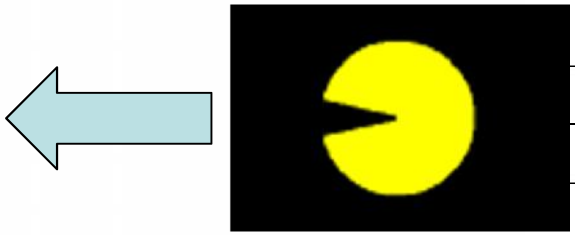
VFDs are typically the largest contributor of harmonics back on to the grid.

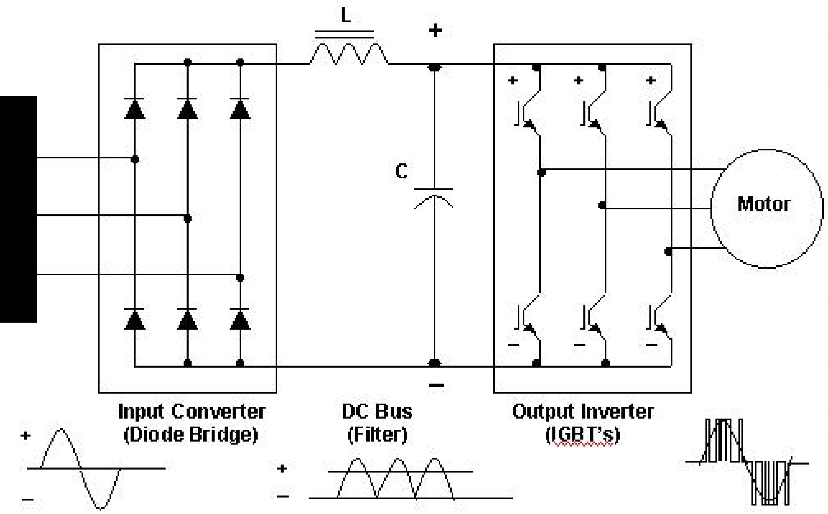
6 Pulse VFD

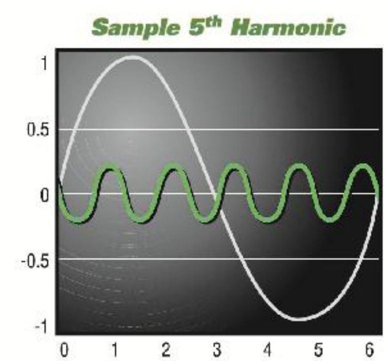

L
+
C
−
Motor
Input Converter
(Diode Bridge)
DC Bus
(Filter)
Output Inverter
(IGBT's)

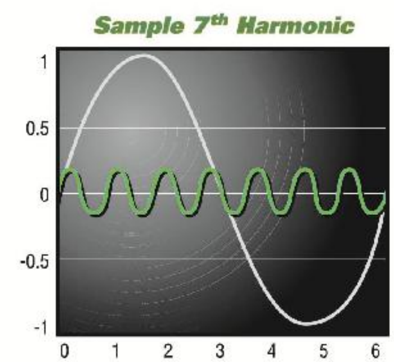
6 Pulse VFD









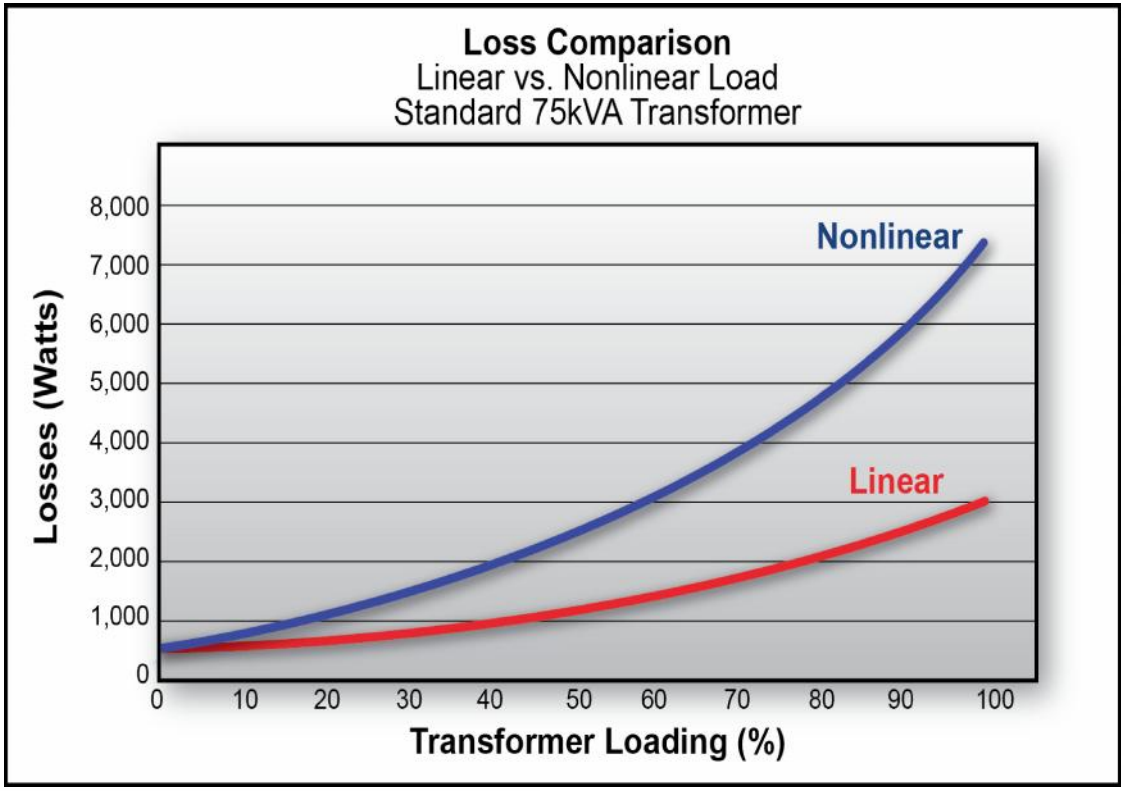


Harmonic Number	Frequency
5th	300Hz
7th	420Hz
11th	660Hz
13th	780Hz
17th	1020Hz
19th	1140Hz
23rd	1380Hz
25th	1500Hz

Causes – **Effects** – Standards - Solutions

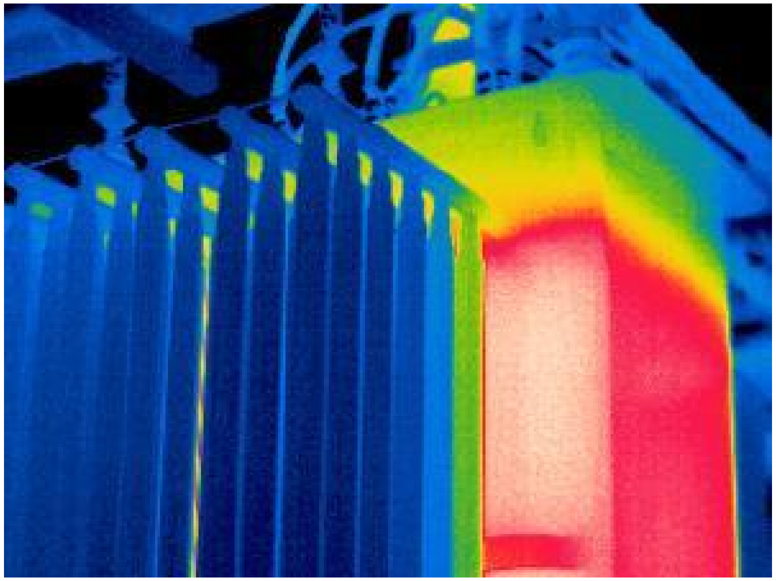
Common Effects of Harmonics

- 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



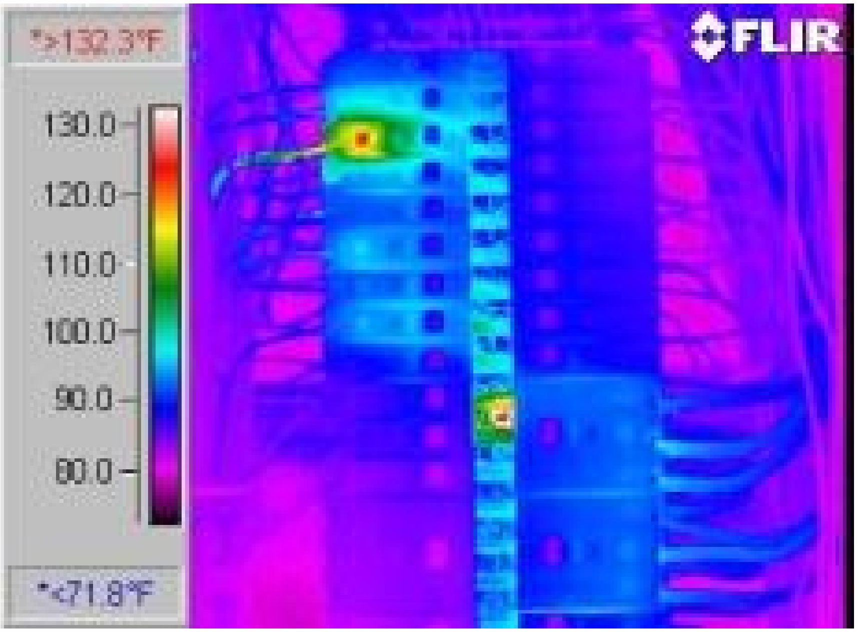
Overheating Distribution Transformers

- The increase in heat from harmonic currents can cause transformers to fail.
- Increased iron and copper losses or eddy currents due to stray flux losses cause excessive overheating.
- NEC states a 7-10 degree increase in heat can ½ the life of insulation



Tripping/Overheating of Breakers

- Harmonic currents can cause false circuit breaker tripping.
- Peak sensing circuit breakers often will trip even though the amperage value has not been exceeded.
- Harmonic current peak values can be many times higher than sinusoidal waveforms.

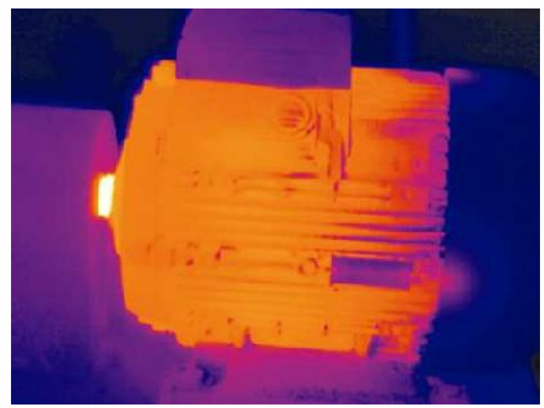


Cable Insulation Breakdown

- The added heat from harmonic currents can cause insulation breakdown on cables.
- Skin Effect Increases - Higher frequencies cause electrons to flow toward the outer sides of a conductor.
- This reduces the ability of the conductor to carry current by reducing the cross sectional diameter of the conductor.
- This reduces the ampere capacity rating of the conductor and adds more heat.

Motor thermal problems

- Higher frequency voltage components produce additional hysteresis and eddy current losses in the core of AC motors.
- These losses increase the operating temperature of the core and the winding surrounding the core.
- May cause undesirable torque pulsations



Generator Problems

Excessive harmonic distortion will cause multiple zero crossings of the current waveform, affecting the timing of the voltage regulator. This can cause the generator to shut down.

Power Factor Capacitor Problems

- Harmonic distortion has a direct affect on power factor. More harmonics = lower power factor.

- The heat losses generated by harmonics transpose into using and paying for more reactive power from your utility.

- Harmonic current can cause capacitors to fail.

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?

Causes – Effects – **Standards** - Solutions

Harmonics – How Do I Know/Plan?

- How much is too much – look at symptoms, power quality meter……
- What Guidelines Do I Follow?

  IEEE519 – National Standard
- End User - Your Utility can help / inform but they can also hold you accountable to IEEE519. Contract end user signs has a clause about meeting IEEE519.

  Know your electrical system
- OEM- spec may require you to meet IEEE519 for your piece of equipment.

- 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"…

Reliable / Advanced Power Quality

Commonly Asked Questions

- What is IEEE519?

  - Measurement at the Point of Common Coupling (PCC) of current and voltage distortion. Complete distribution system, not components. How much is allowed back onto the grid.

- What is the PCC?

  - The PCC is generally defined as the utility/customer connection point. It is this point at which the current distortion limits apply.

- 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.

Harmonics generated in this facility would effect other customers

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%.

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.

New IEEE-519 -2014 Edition

Defines the responsibilities for utilities and users to

- maintain the voltage THD within limits at the PCC,
- protect user and utility equipment from the negative impact of harmonics.

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.

Changes in IEEE-519 -2014

- Utility PCC Voltage THD Limits

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.

- New V<1kV level with high Vthd levels
- Elimination of Special, Typical and Dedicated System recommendations
- Moving away from being for internal facility buss info.

Other IEEE-519 -2014 Updates

- Eliminated multiple pulse rectifier relief from 1992 version
- No Change in the User Current THD Limits
  - based on Isc / IL ratio
- Measurement methods
  - Can use statistical measurement methods and increase current THD levels
- Much shorter document – elimination of background and educational matters.

Causes – Effects – Standards - Solutions

Harmonic Solutions

6 Pulse Drive +

Line Reactor / DC Choke

Passive Filter

Active Filter

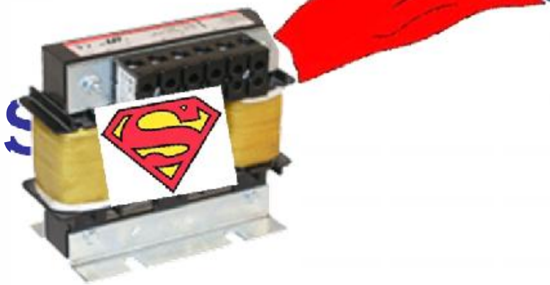
Built in Solution

12 Pulse

18 Pulse

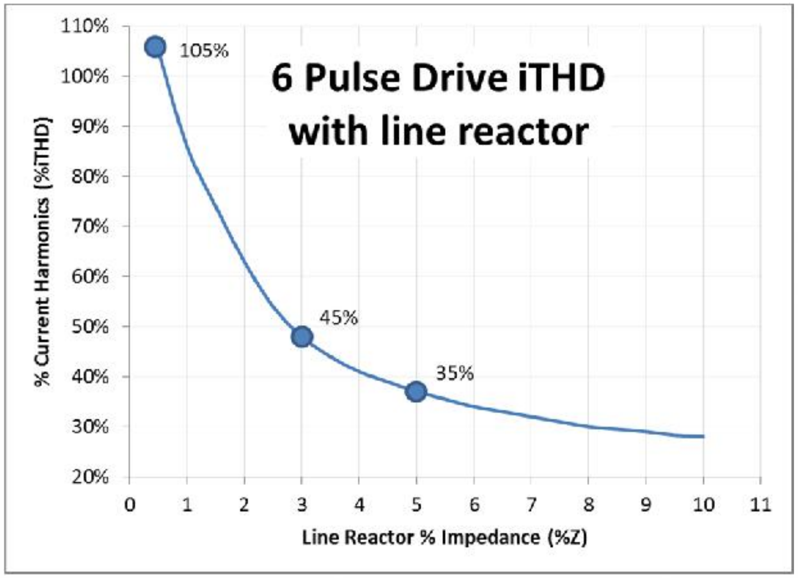
Active Front End

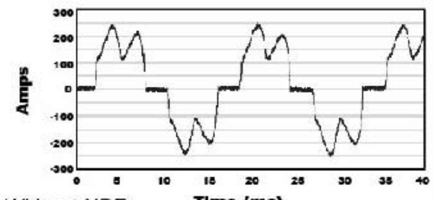
AC Line Reactors



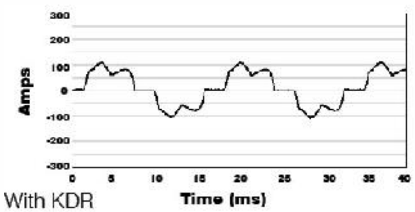
- Dual Purpose: harmonic mitigation, transient blocker.
- Impedance – slows the rate of change in AC waveform.
- Impedance Choices – 3%, 5%, 10%
- Prolongs the life of drive components.
- Series Passive device

Harmonic Reduction





Without KDR



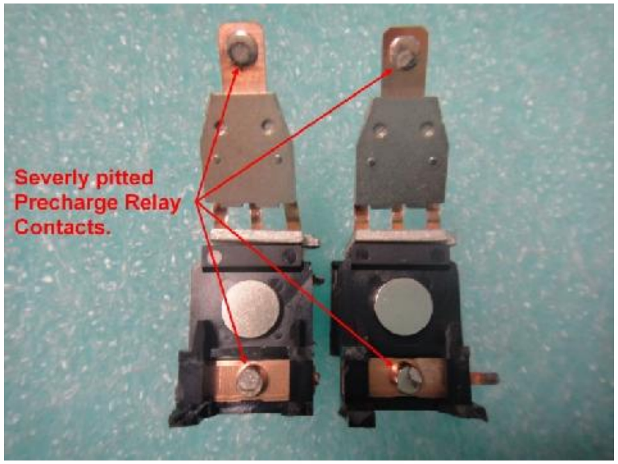
With KDR

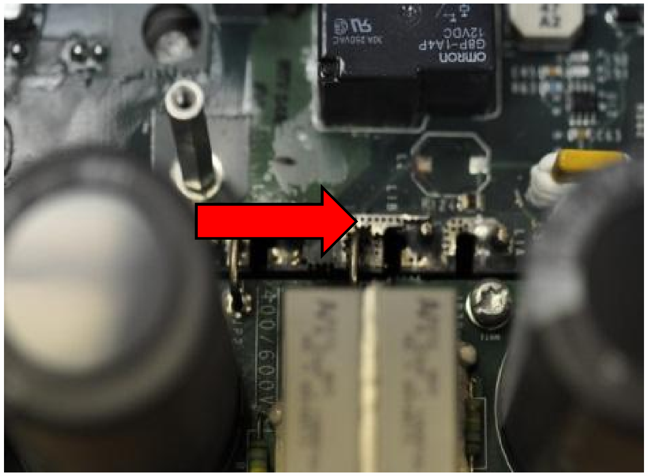
Voltage Drop

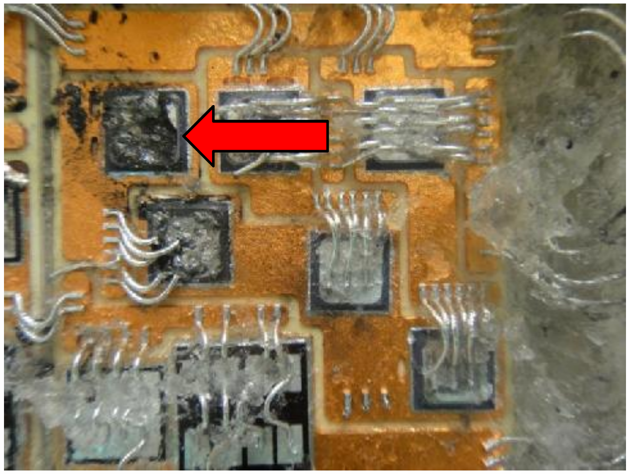
Impedance %	Voltage Drop
3%	0.0%
5%	1.2%
7%	2.4%
10%	3.7%

Transient Blocker

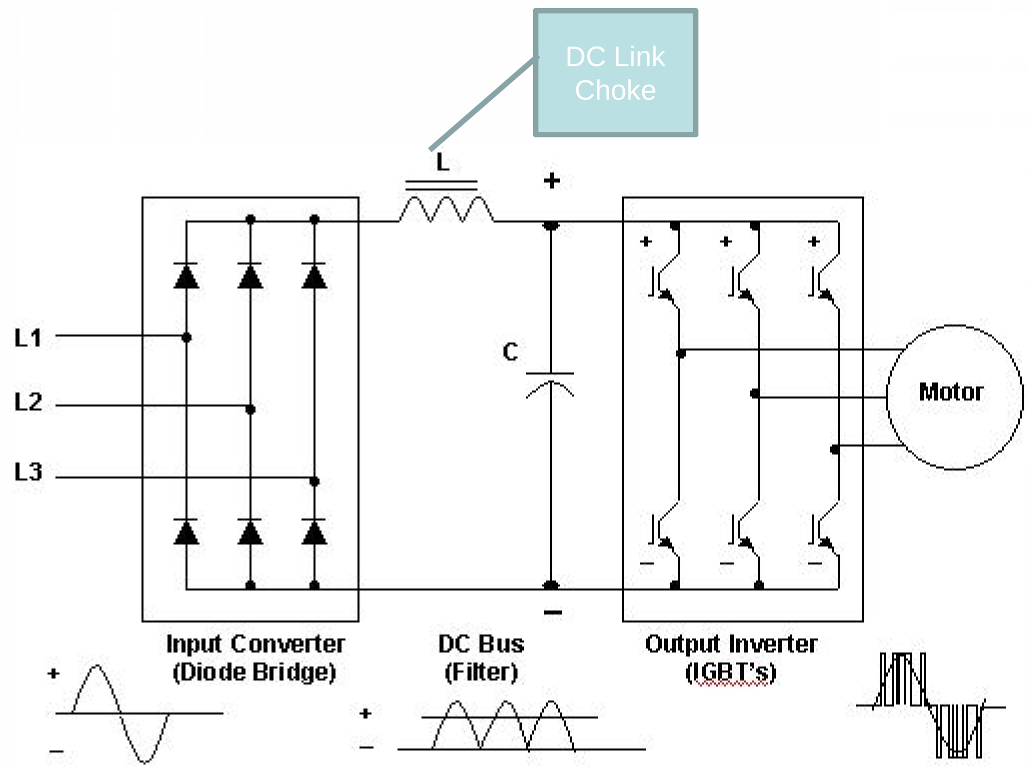
- **What Components are susceptible or likely to fail due to a current surge condition?**
  - Input Bridge Diodes
  - PCB Power Traces
  - Precharge Relay Contacts







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.

VFD Manufacturer recommendation

Installation Instructions   Allen-Bradley

Wiring and Grounding Guidelines for Pulse Width Modulated (PWM) AC Drives

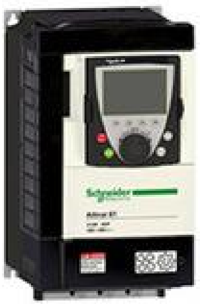
Table 2.C AC Line Impedance Recommendations for PowerFlex 4 Drives

	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

VFD Manufacturer recommendation

Installing the line reactor on ATV61H•••Y drives



The use of an AC line reactor (which must be ordered separately) is mandatory on these drives if a special transformer is not used (for example, 12-pulse).

CAUTION
CONTROLLER DAMAGE A 3–5% impedance input line reactor is required on all ATV61HC••Y drive installations. **Failure to follow these instructions can result in equipment damage.**

VFD Manufacturer recommendation

ABB

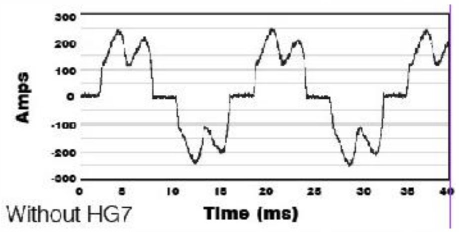
ABB Automation
Effective 5/27/09

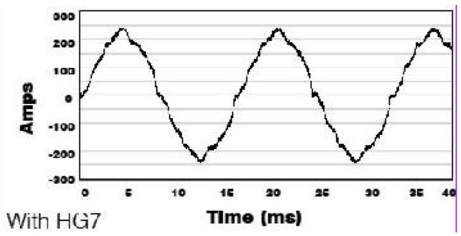
Sample Specification for
Variable Frequency Drives
For Centrifugal Pump & Fan Applications

SUBMITTALS

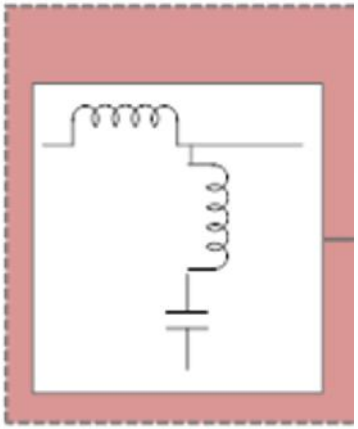
A. Submittals shall include the following information:
   1. Outline dimensions, conduit entry locations and weight.
   2. Customer connection and power wiring diagrams.
   3. Complete technical product description include a complete list of options provided. **Any portions of this specification not met must be clearly indicated or the supplier and contractor shall be liable to provide all additional components required to meet this specification.**
   4. Compliance to IEEE 519 – harmonic analysis for particular jobsite including total harmonic voltage distortion and total harmonic current distortion (TDD).
      a) The VFD manufacturer shall provide calculations; specific to this installation, showing total harmonic voltage distortion is less than 5%. Input filters shall be sized and provided as required by the VFD manufacturer to ensure compliance with IEEE standard 519. All VFD's shall include a minimum of 5% impedance reactors, **no exceptions**.

Passive Harmonic Filter

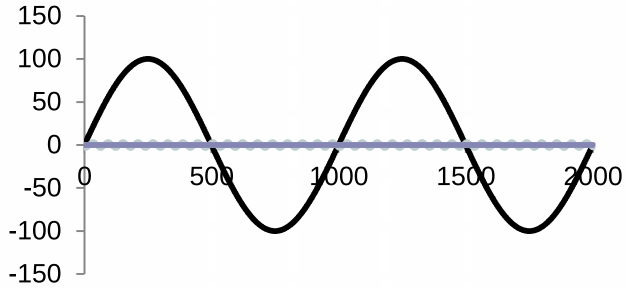


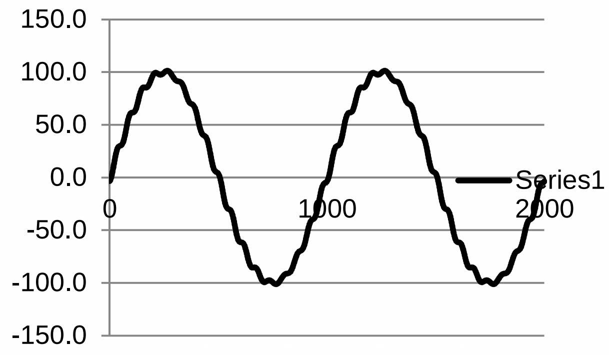


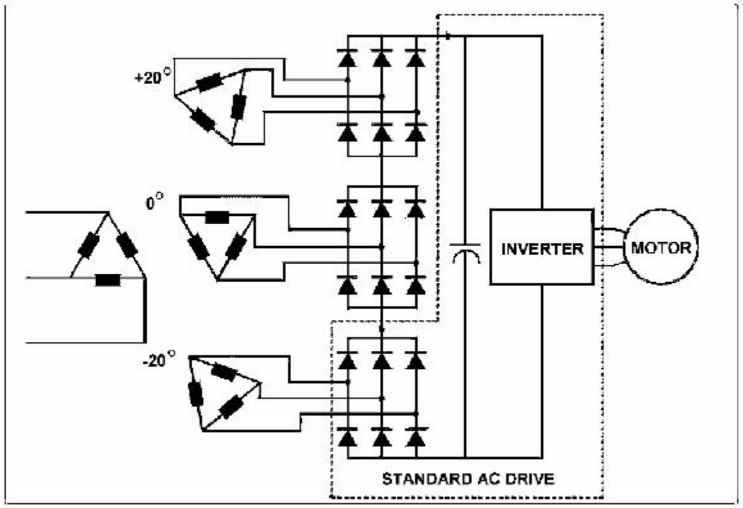
- Harmonic reduction to 5-7% ITHD.
- Broadband filter with a 5th harmonic trap
- Use when need to meet IEEE-519 specification and other harmonic problems
- Use built in contactor to protect against leading power factor
- Built in series inductor to protect from resonance issues
- Can be used with Standard Six Pulse VFD.
- Filter Caps may need to be managed….PF / Generator.
- Series/Shunt passive device



18 Pulse - legacy solution





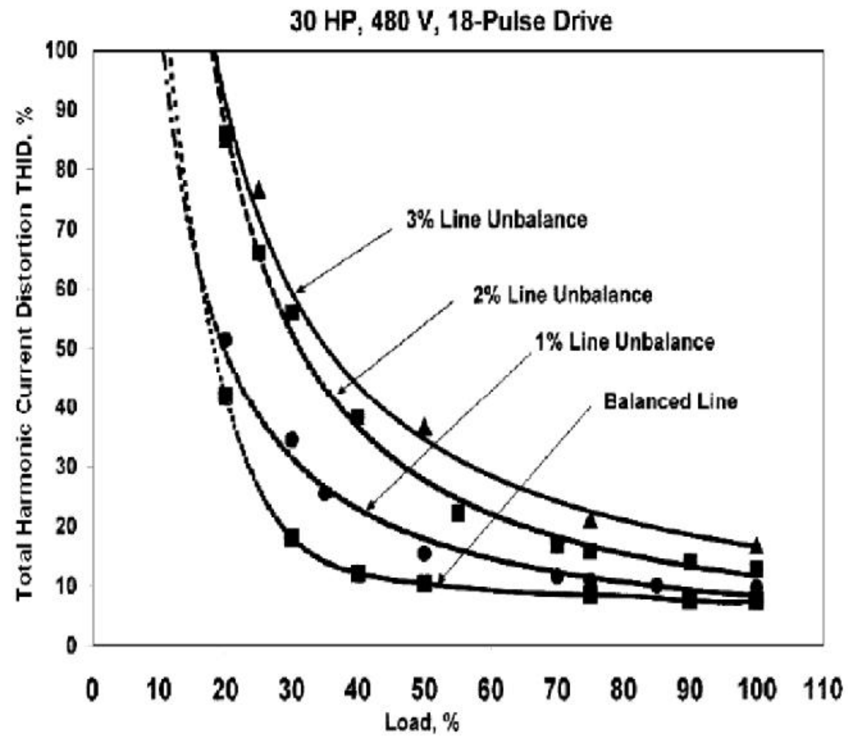


- 5% Solution out of the box.
  No calculations.
- Phase shifting transformer and more diodes limit harmonics.
- Series Passive device

Reliable / Advanced Power Quality

18 Pulse - legacy solution

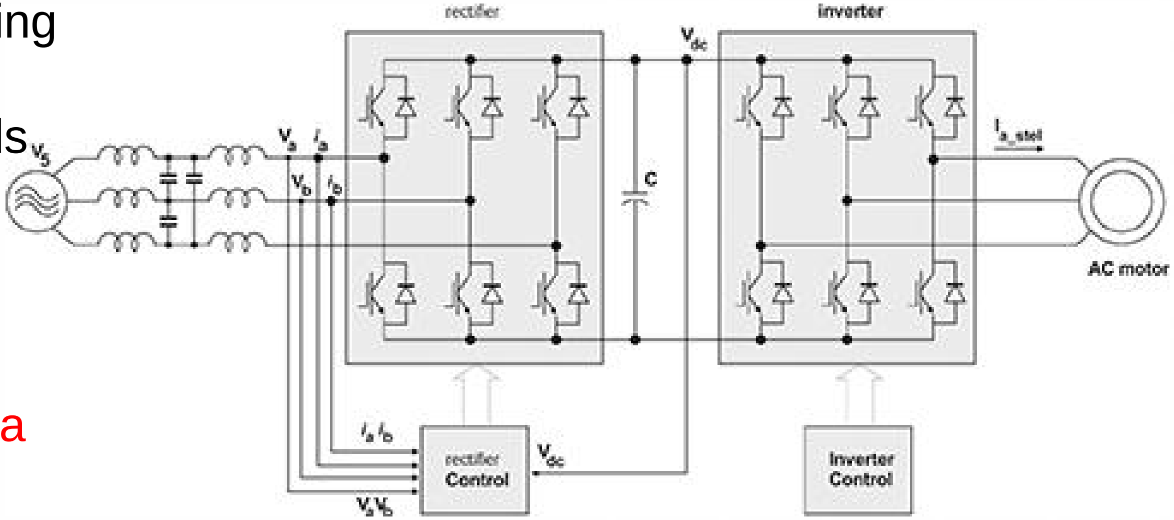
- Line unbalance reduces performance
- Large Physical Size
- Custom - Long Lead time for Manufacture & Repair
- Cost
- Limited HP Range
- Less efficient than 6 pulse



Control of Harmonics in electrical Power Systems, American Board of Shipping, Copyright 2006

Active Front End Drives

- 5% Solution out of the box. No calculations.
- No major issues with loading or unbalance.
- Ideal for regenerative loads
    - Elevators
    - Cranes



- High components count - equivalent to 2 VFDs and a passive filter
- Larger and more expensive than 6 pulse.
- Devices in series – lower efficiency
- Series active device – in critical path

Active Harmonic Filter

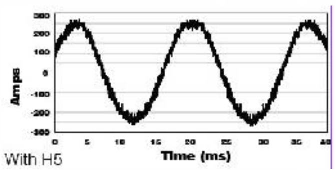
- ❑ System applied on standard 6 pulse VFDs
- ❑ Very cost effective for multiple or redundant drives
- ❑ Harmonic reduction – 5% TDD

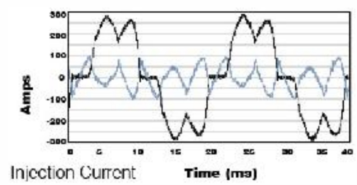
- ❑ Monitors bus, injects counter current to cancel out harmonic currents
- ❑ Provides Power Factor Correction
- ❑ Corrective Current / ratings – 50/100/150/200/300

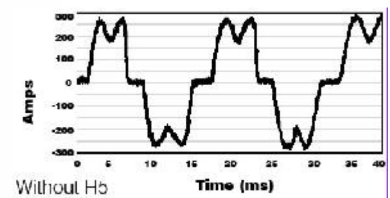
- ❑ HMI – Modbus / Ethernet

- ❑ Shunt active device – not critical path

Active Harmonic Filter Locations

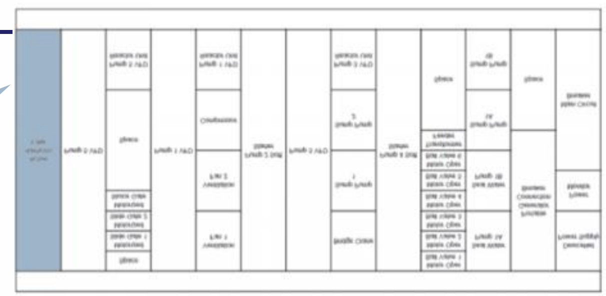






CTs

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

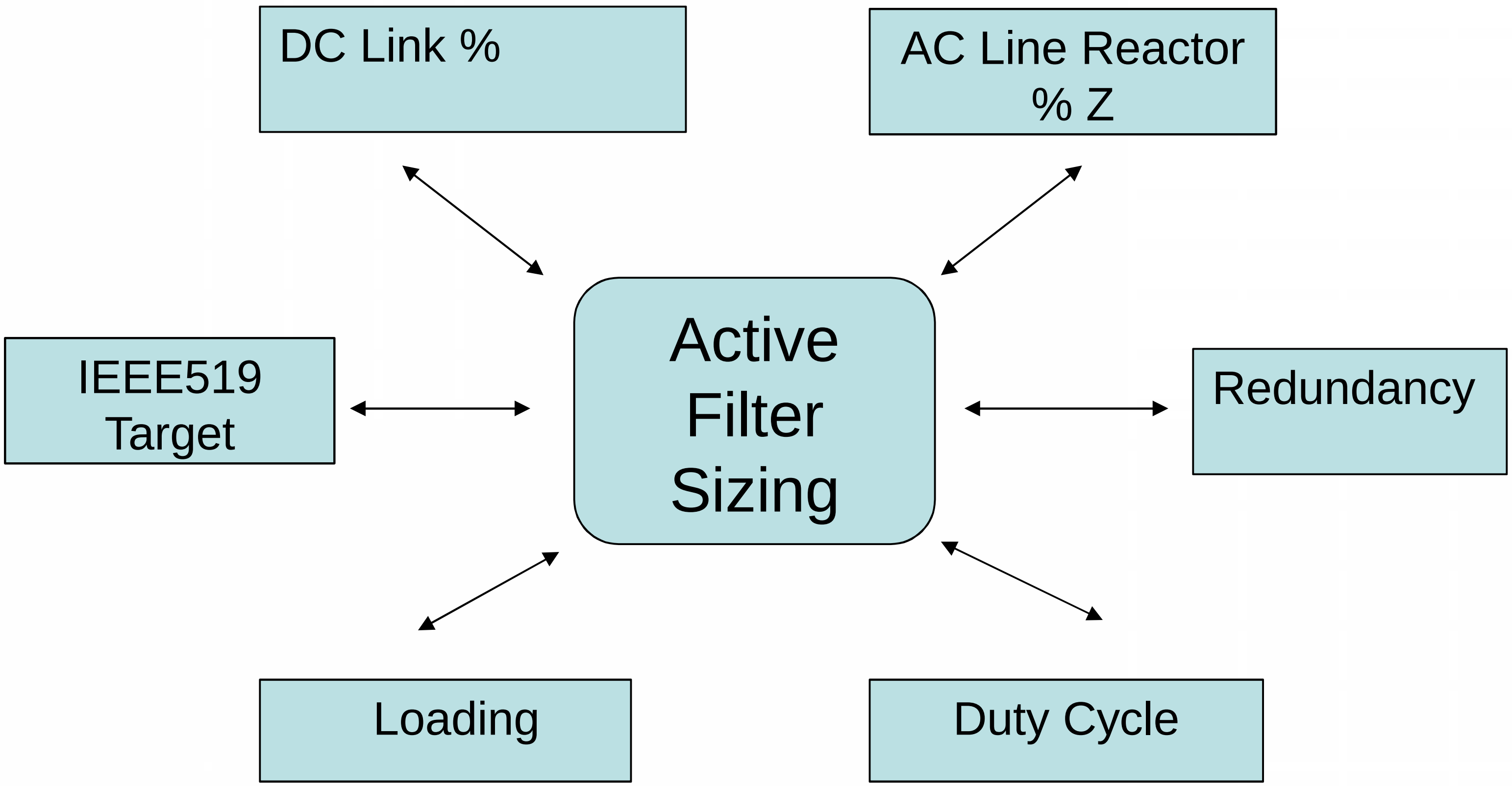


Typical MCC

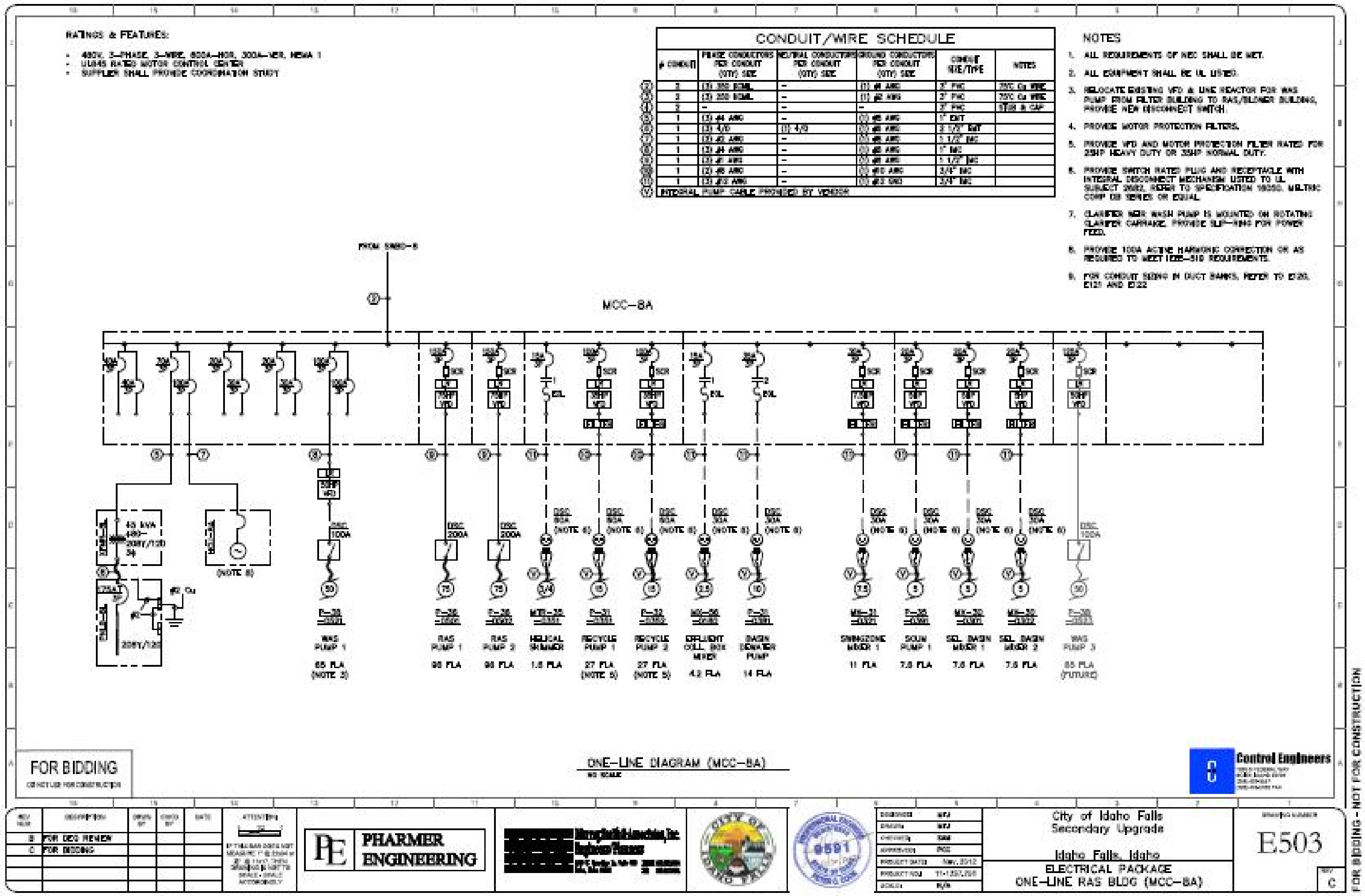
The CTs monitor the harmonic distortion on the Bus. The active filter injects the appropriate correction based on loading at the time to eliminate the distortion.

Sizing of Active filters

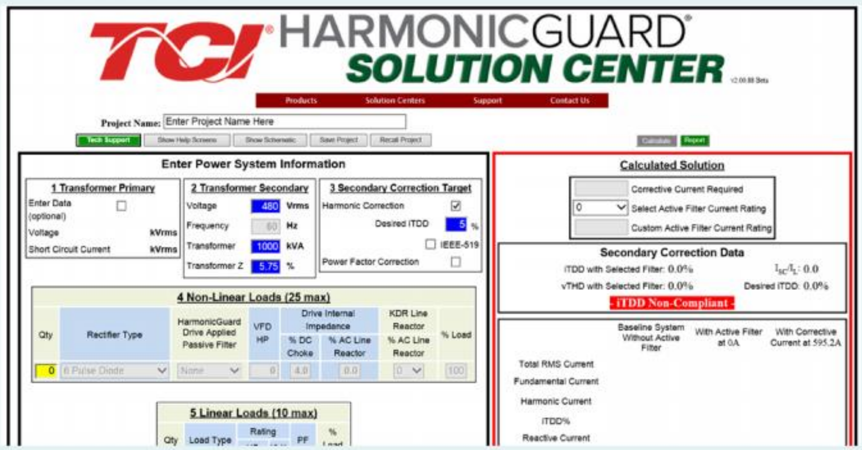
Depends on:



Sample of a 1-Line Plant Drawing



New On Line Harmonic Calculator



- IEEE519 Compliance Report.
- Sizing of Active Filters.
- Design Most Cost Effective Harmonic Solution.

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 Analysis

- Using TCI sizing software can optimize your solution
- Can show where your system baseline is without any harmonic mitigation.
- Allows use of combinations of solutions to give you the most cost effective IEEE519 solution.
- Tradeoff Line reactors, Passive, Active Filters
- Can be used for specification development
- Free to use, register on website: http://hgsc.transcoil.com/
- No downloads or executables – fully web based

Case Study

- *480V/60Hz*
- *600 HP total vfd load (3 x 200HP)*
- *50 HP of linear load*
- *MCC Type 1 enclosure*
- *Meet IEEE519 (one way or another)*

6-pulse vfd's w/DC link choke and 3% AC input line reactor

480V/60Hz/200 HP	480V/60Hz/200 HP	480V/60Hz/200 HP
vfd with DC Link choke and 3% input line reactor (1)	vfd with DC Link choke and 3% input line reactor (2)	vfd with DC Link choke and 3% input line reactor (3)
<------- 30" ------->	<------- 30" ------->	<------- 30" ------->

<----------------------- 90" ------------------->

30 - 39% iTHD at input of each vfd

Total Sections:	3
Depth:	20"
Weight:	1500 lbs
Losses:	10,296 watts
Footprint:	1800 in^2
Price factor:	100%

6-pulse vfd's w/DC link choke and passive harmonic filter

480V/60Hz/200 HP	passive filter	480V/60Hz/200 HP	passive filter	480V/60Hz/200 HP	passive filter
vfd with DC Link choke (1)	200 HP 5% or 7% iTHD input, passive, harmonic filter (1)	vfd with DC Link choke (2)	200 HP 5% or 7% iTHD input, passive, harmonic filter (2)	vfd with DC Link choke (3)	200 HP 5% or 7% iTHD input, passive, harmonic filter (3)
<------- 30" ------->	<---- 20" ---->	<------- 30" ------->	<---- 20" ---->	<------- 30" ------->	<---- 20" ---->
<--- 150 " --->					

5 - 8% iTHD
at input of each vfd

Total Sections:	6
Depth:	20"
Weight:	3,000 lbs
Losses:	11,346 watts
Footprint:	3,000 in²
Price factor:	158%

18-pulse vfd's w/ phase shifting transformer

480V/60Hz/200 HP		480V/60Hz/200 HP		480V/60Hz/200 HP	
Phase shifting Auto-Transformer (1)	18p vfd (1)	Phase shifting Auto-Transformer (2)	18p vfd (2)	Phase shifting Auto-Transformer (3)	18p vfd (3)
<------- 35" ------->	<------- 30" ------->	<------- 35" ------->	<------- 30" ------->	<------- 35" ------->	<------- 30" ------->
<-- 195" -->					

<5% iTHD
at input of each vfd

Total Sections:	6
Depth:	25"
Weight:	4,175 lbs
Losses:	18,015 watts
Footprint:	4,875 in²
Price factor:	386%

Reliable / Advanced Power Quality

6-pulse vfd's w/DC link choke and 3% AC input line reactor & bus applied Active Harmonic Filter

Active Filter	480V/60Hz/200 HP	480V/60Hz/200 HP	480V/60Hz/200 HP
ALC200AW00H4000 - CM200A00	vfd with DC Link choke and 3% input line reactor (1)	vfd with DC Link choke and 3% input line reactor (2)	vfd with DC Link choke and 3% input line reactor (3)
<----------- 34" ---------->	<------- 30" ------->	<------- 30" ------->	<------- 30" ------->

<-- 124" -->

<5% iTHD
at input of the MCC

Total Sections:	4
Depth:	20"
Weight:	2105 lbs
Losses:	17,296 watts
Footprint:	2480 in²
Price factor:	232%

Redundancy Scenario

Active Filter	480V/60Hz/200 HP	480V/60Hz/200 HP	480V/60Hz/200 HP
ALC150AW00H4000 – CM100A00	vfd with DC Link choke and 3% input line reactor (1)	vfd with DC Link choke and 3% input line reactor (2)	vfd with DC Link choke and 3% input line reactor (R)
<------ 20" ------>	<------ 30" ------>	<------ 30" ------>	<------ 30" ------>

<-- 110"-->

<5% iTHD
at input of the MCC

Total Sections:	4
Depth:	20”
Weight:	2105 lbs
Losses:	15,546 watts*
Footprint:	2200 in²

Price factor: 214%

Solution Summary

	performance	losses (watts)	weight (lbs)	footprint (in^2)	Price	Lead
6 pulse w/ active	<5% active response to load changes	17296	2105	2480	232%	ETO
Active Front End (estimate)	<5% active response to load changes	21346	4500	4800	386%	ETO
18 pulse	<5% (balanced system)	18015	4175	4875	386%	ETO
6 pulse w/ passive	5% - 8% down to 50% load	11346	3000	3000	158%	Quick Ship
6 pulse w/ line reactor	30% - 35% at full load	11346	1695	1800	100%	Quick Ship
6 pulse only	35% - 40% at full load	10,000	1500	1800	97%	Quick Ship

Presentation Takeaways

- All solutions have their place…..
- Loosen up bid specs to include “system approach”
- Specifying 18 pulse or Active rectifiers locks out potential lower cost, higher reliability, higher efficiency solutions.
- Utilize free web based tool to optimize solution
- Line reactors make a big difference for all solutions but reduce total cost when used with active filters.
- If your system includes multiple or redundant VFD’s, active filters make a great solution.

Thank you!

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