Better Plants
U.S. DEPARTMENT OF ENERGY

Motor Systems
Virtual INPLT Training & Assessment

Session 4

Motors Virtual INPLT Facilitator

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- Many industrial clients – both in the US and internationally

Safety and Housekeeping

- Safety Moment
  - Uncontrolled downstream voltage from VFDs can cause catastrophic motor failure that could injure nearby personnel
  - Extreme levels of harmonics can cause equipment overheating and fires
- You are welcome to ask questions at any time during the webinar
- When you are not asking a question, please MUTE your mic and this will provide the best sound quality for all participants
- We will be recording all these webinars and by staying on-line and at the meeting you are giving your consent to be recorded
  - A link to the recorded webinars will be provided, afterwards

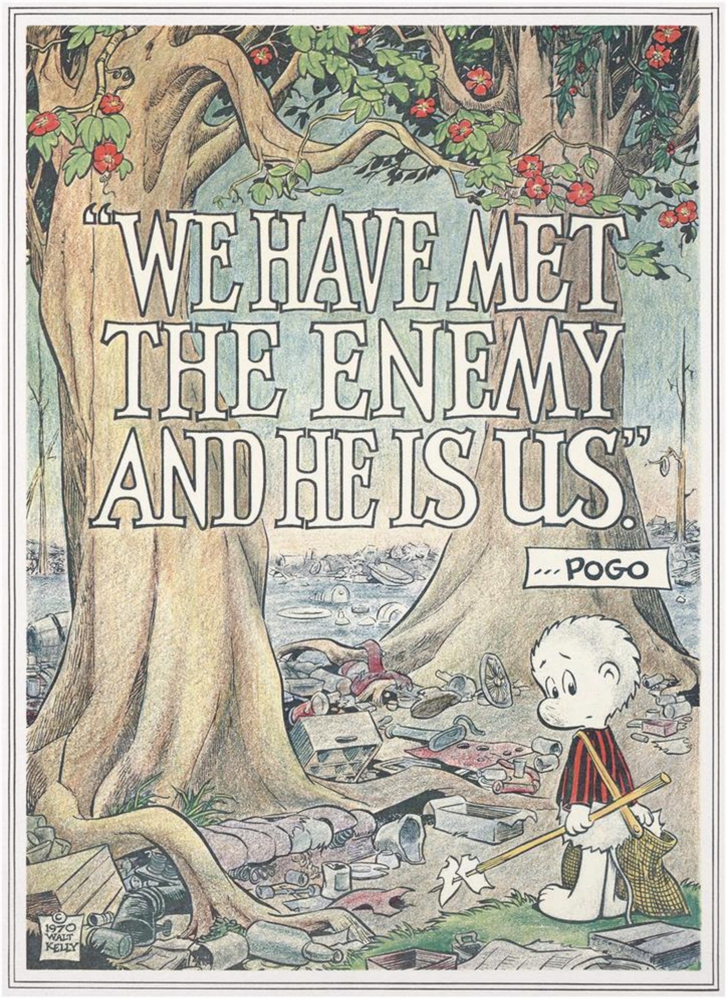
Learning Objectives

- List 3 strategies to minimize sources of potentially damaging Harmonics from VFDs.
- List 3 strategies to prevent harmonics produced by VFDs from adversely affecting other equipment

Agenda

- The perpetrator/victim link between VFDs and power quality
- Summary
- Review key points from previous sessions
- Student Presentations

The Perpetrator/Victim Link Between VFDs and Power Quality



Improper Grounding

- Improper grounding can wreak havoc
- Follow VFD installation and grounding guidelines to a "T"

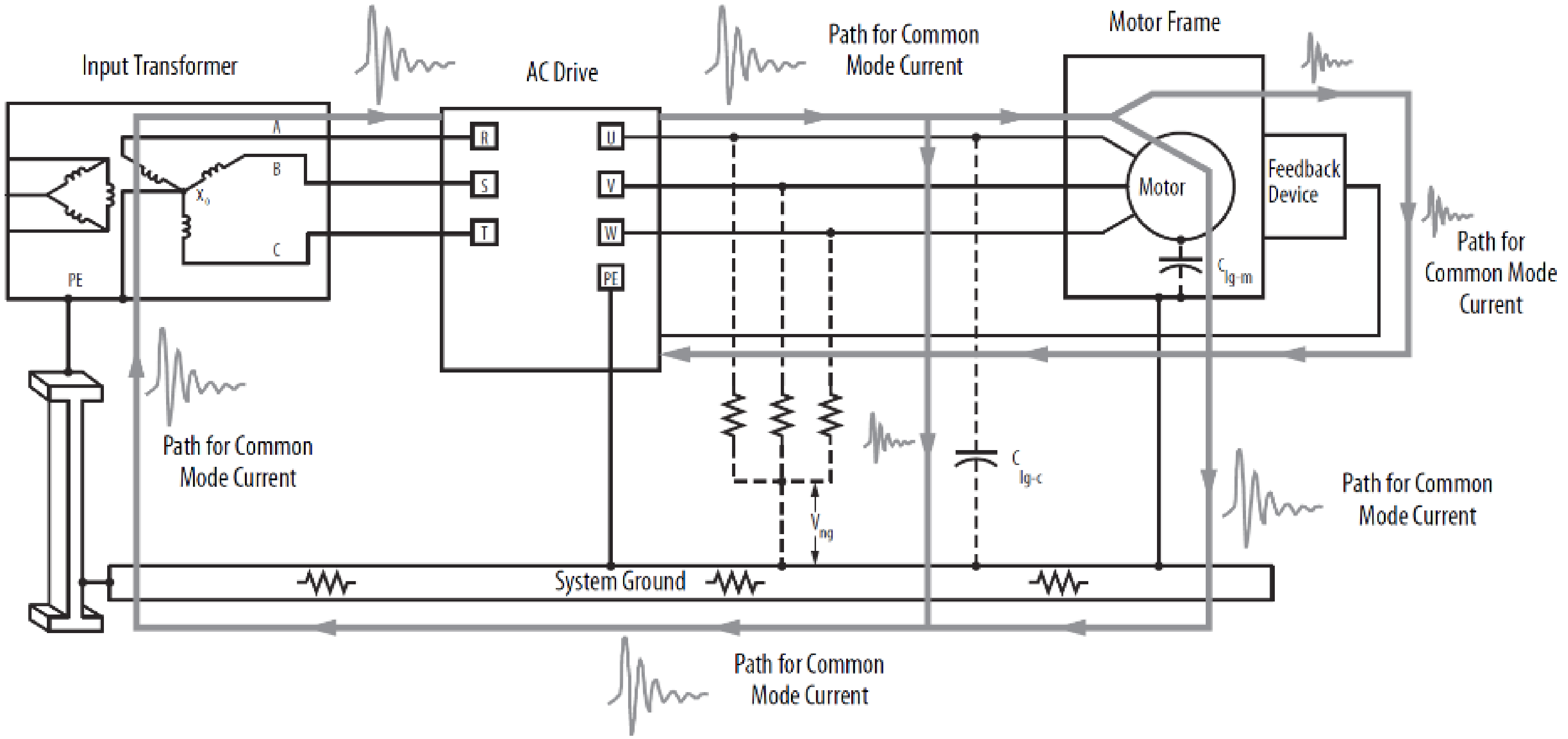


Figure courtesy AB-Rockwell

Poor Power Quality

Poor power quality can cause VFDs to trip off-line.

Types of power quality problems:

- Voltage sags
- Voltage swells/transient
- Current harmonics

Sags Trigger Low Bus Voltage Fault

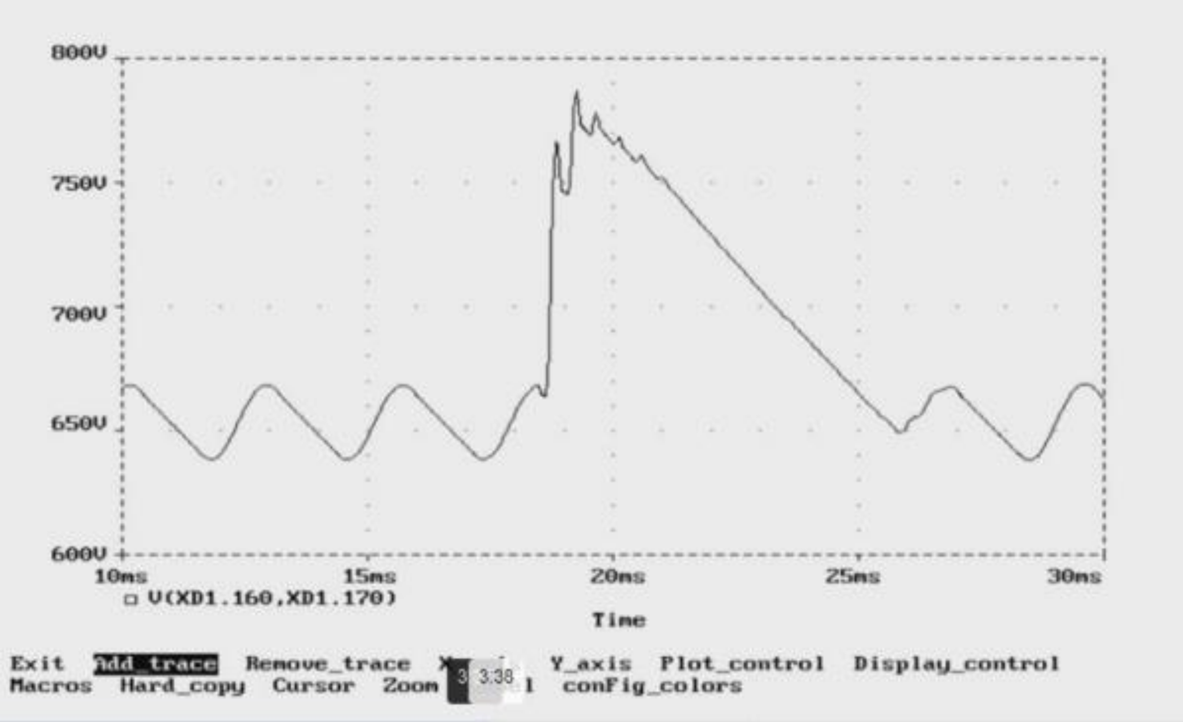
Possible Causes:

- Sudden inrush of current to start large motors
- Sudden inrush of current to energize a transformer
- Automatic line re-closers that utilities use to correct from faults such as trees momentarily hitting the electric line.

Swells Trigger High Bus Voltage Fault

Possible causes:

- Utility switching capacitors on and off
- Large switchgear opening and closing
- Instabilities or resonances in the electric circuit



Use zero-crossing switches to avoid transients.

Figure courtesy Dan Carnovale

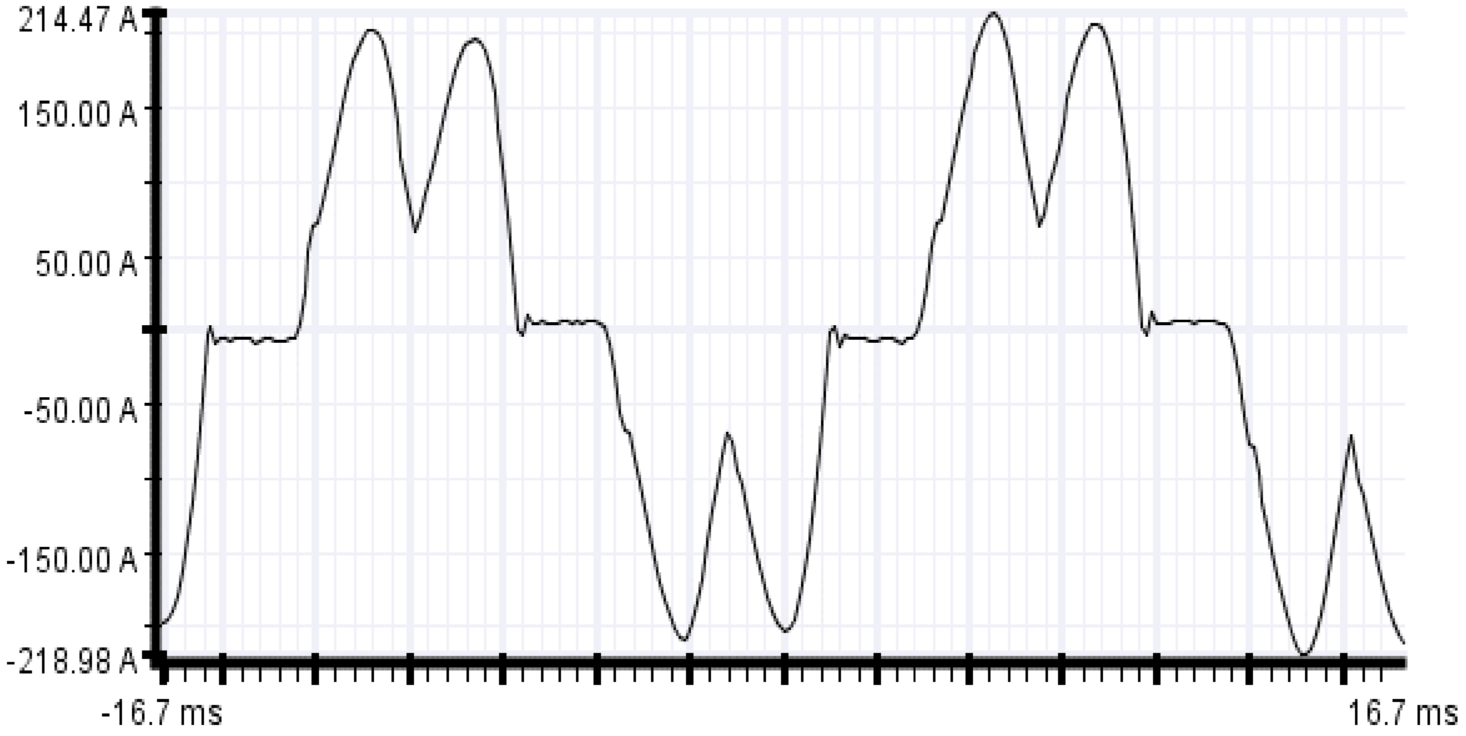
Video

Video link

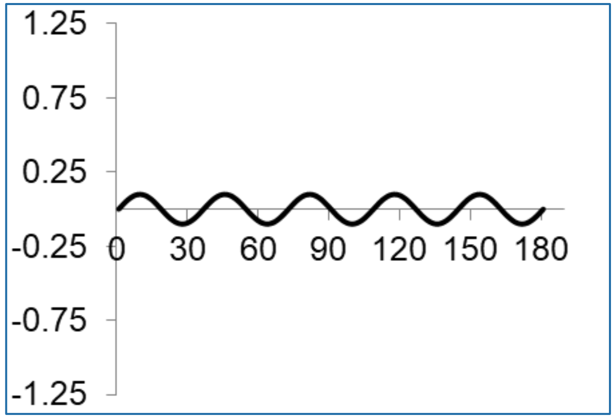
Eaton Electric Harmonics video

Harmonics Trigger High Bus Voltage

Ironically, VFDs are a major source of harmonics due to highly non-linear current draw.

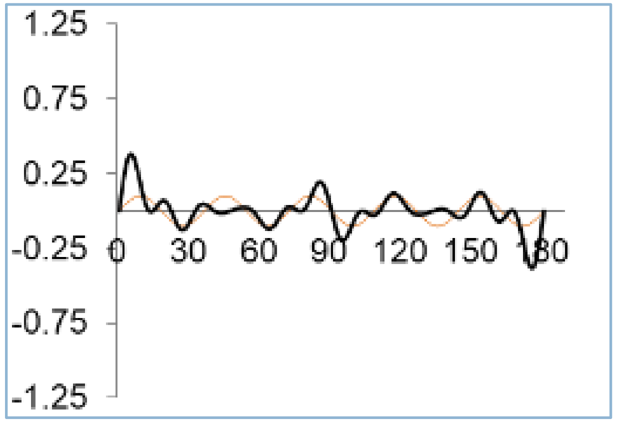


Visualizing Harmonics

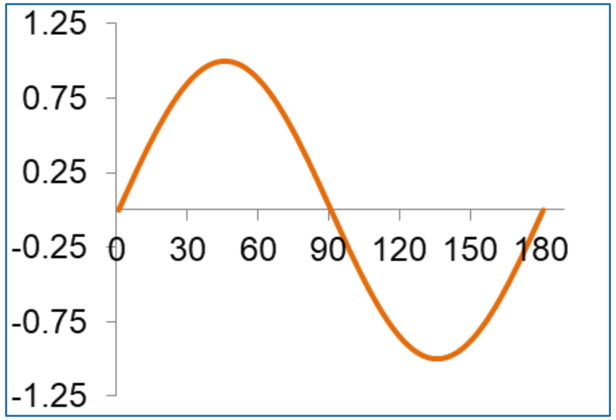


5th Harmonic

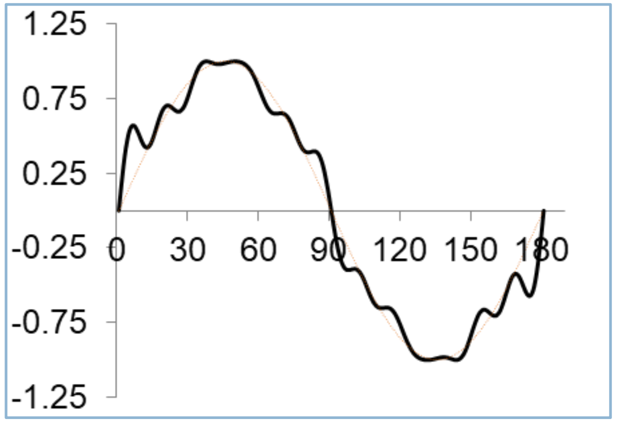
The distorted voltage wave is comprised of the fundamental 60hz power provided by the utility company plus the nuisance harmonic waves.



All Harmonics 5, 7, 11,13, etc.



Fundamental



Distorted voltage

Signs of Damaging & Dangerous Levels of Harmonics

- Over-current/overheated capacitors
- Overheated motors/short motor life
- Overheated transformers
- Overheated neutral feeders
- Clicking or banging transformers
- Clicking noise from motors
- Circuit breakers nuisance tripping
- Nuisance fuse blowing
- Malfunctioning voltage regulator
- Generator won’t synch
- Computer or PLC lockup/shut down
- Control signal errors
- Timing or clock errors
- Electrical fires

Figure courtesy Dan Carnovale

Possible Losses From Unmitigated Harmonics

Type of Loss

- Increased capital investment in oversized equipment
- Increased electrical losses
- Premature equipment failure

Equipment Affected

- Generators
- Transformers
- Cables
- UPS Systems
- Motors

Harmonics Effects on Nearby Across-the-Line Motors

Please address the underlying problem instead of using this chart!

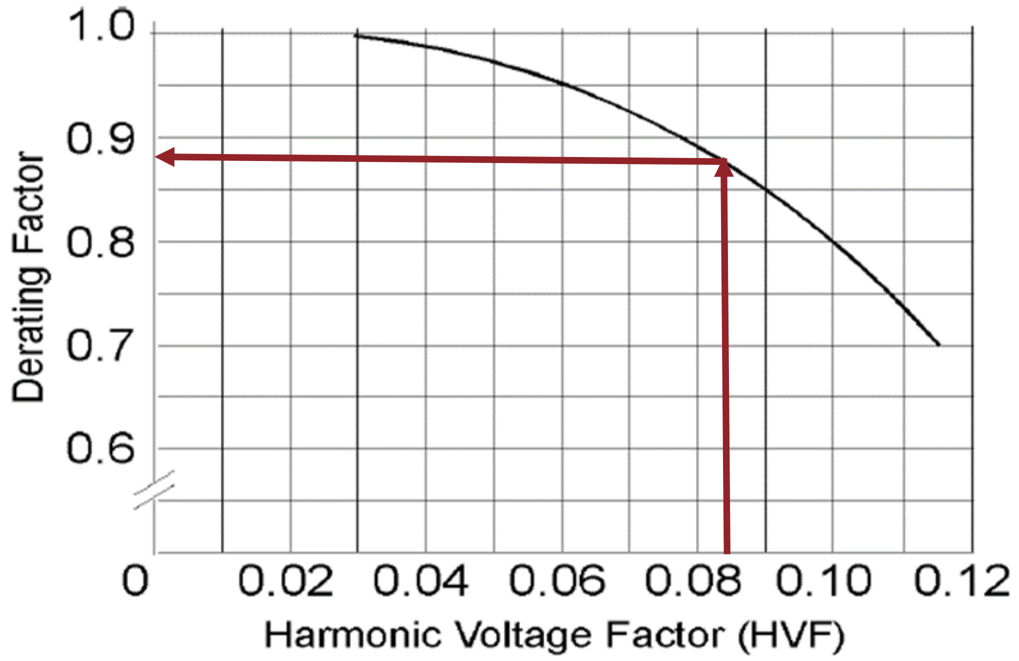
5th harmonic is particularly damaging to adjacent across-the-line motors because it produces reverse torque

$$HVF = \sqrt{\sum_{n=5}^{n=\infty} \frac{V_n^{\,2}}{n}}$$

$$HVF = \sqrt{\frac{0.15^2}{5} + \frac{0.11^2}{7} + \frac{0.07^2}{11} + \frac{0.05^2}{13}}$$

$$HVF = 0.083$$

De-rate factor with 0.083 HVF = 0.88



"Harmonics Only Become a Problem When…

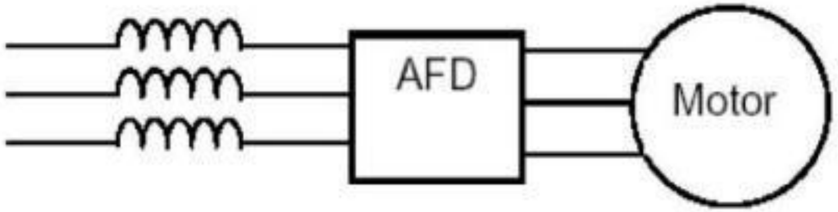
…they *are* a problem."
Dan Carnovale, Eaton Corp.

Each facility has a different level of sensitivity.

Non-linear transformer load	Concern level
Less than 10%	*Probably* no problem
Between 10% and 20%	Beware – thin ice
More than 20%	Mitigating likely required

Recommendation:
Use a 3%- or 5%-Line Reactor upstream of the VFD

- For pennies on the dollar, you can knock out ½ to $^{2}/_{3}$ of the harmonic junk.
- AND protect the drive from transients



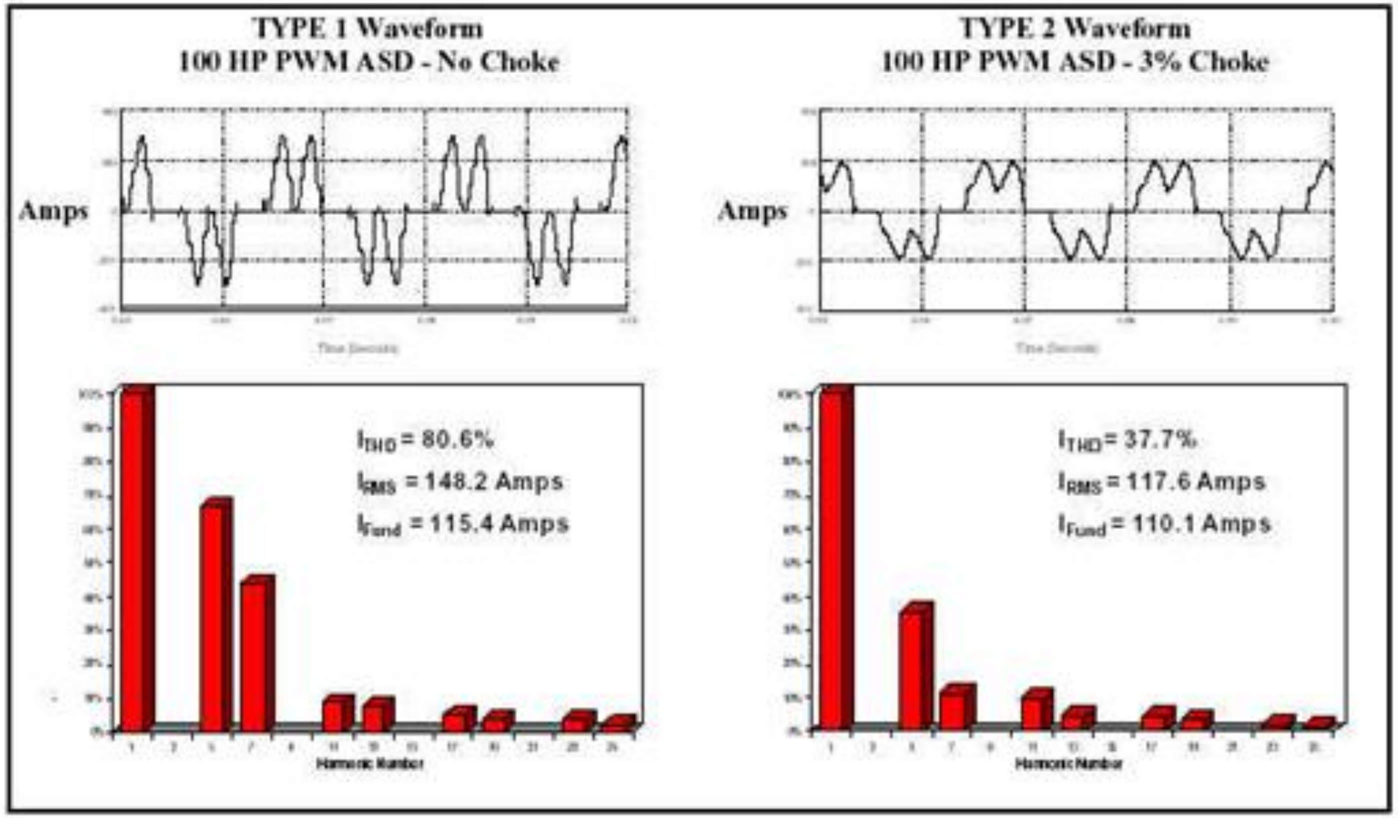


Figure courtesy Dan Carnovale - Eaton

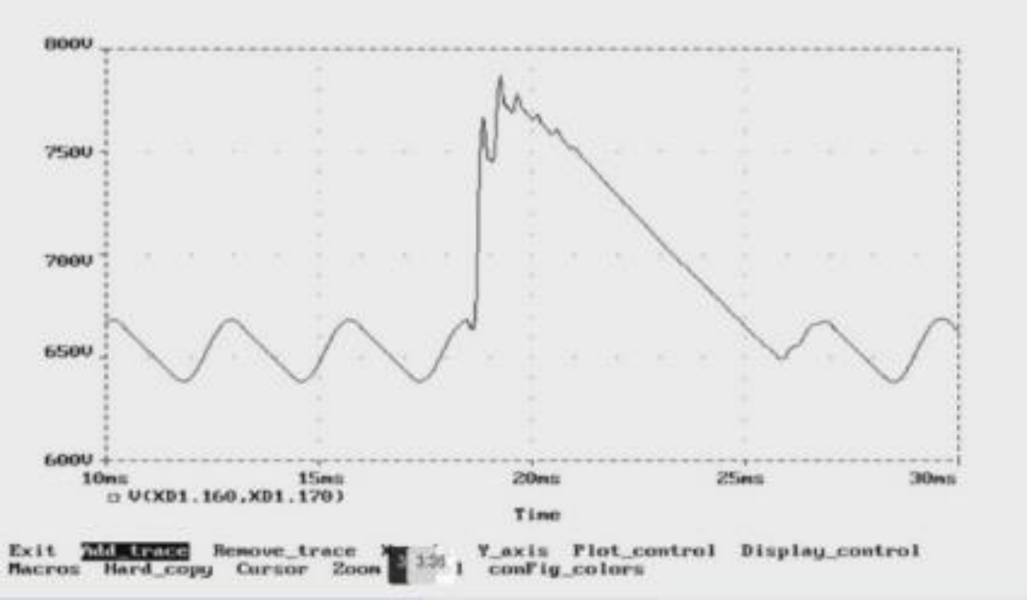
Recommendation:
Use a 3%- or 5%-Line Reactor upstream of the VFD

Harmonic Order	*Reactor Size*				
	0.5%	*1.0%*	*3.0%*	*5.0%*	*10.0%*
5th	80.0%	60.0%	40.0%	32.0%	23.0%
7th	60.0%	37.0%	16.0%	12.0%	7.5%
11th	18.0%	12.0%	7.3%	5.8%	4.0%
13th	10.0%	7.5%	4.9%	3.9%	2.8%
17th	7.3%	5.2%	3.0%	2.2%	0.4%
19th	6.0%	4.2%	2.2%	0.8%	0.2%
I_{THD} (%)	102.5%	72.2%	44.1%	35.0%	24.7%
I_T / I_1	143.0%	123.0%	109.0%	106.0%	103.0%

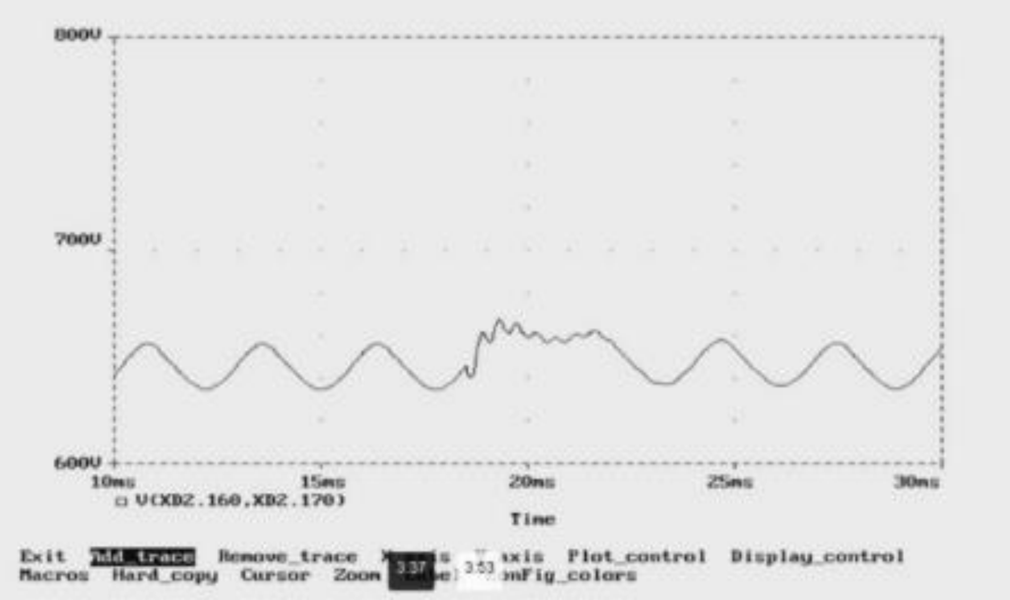
Figure courtesy Dan Carnovale - Eaton

Line Reactor Protects VFD from Overvoltage Transients

- DC bus voltage without reactor, VFD trips offline due to high bus voltage.



- DC bus voltage with reactor, no overvoltage trip.



Commercial and Industrial Sources of Harmonics

Expected sources (*commercial and industrial)	**I_{thd} (Un-compensated)**	**Harmonics generated**
VFD – 6 pulse rectifier	75-80%	5, 7, 11, 13, 17, 19…
12 pulse rectifiers	15-20%	11, 13, 23, 25…
18 pulse rectifiers	2-3%	17, 19, 35, 37…
Devices using electric arcs		2, 3, 4, 5, 7,
Computers (SMPS)	30-50%	3, 5, 7, 9, 11, 13…
Fluorescent lighting	10-30%	3, 5, 7, 9, 11, 13…
Transformers		2, 3, 4

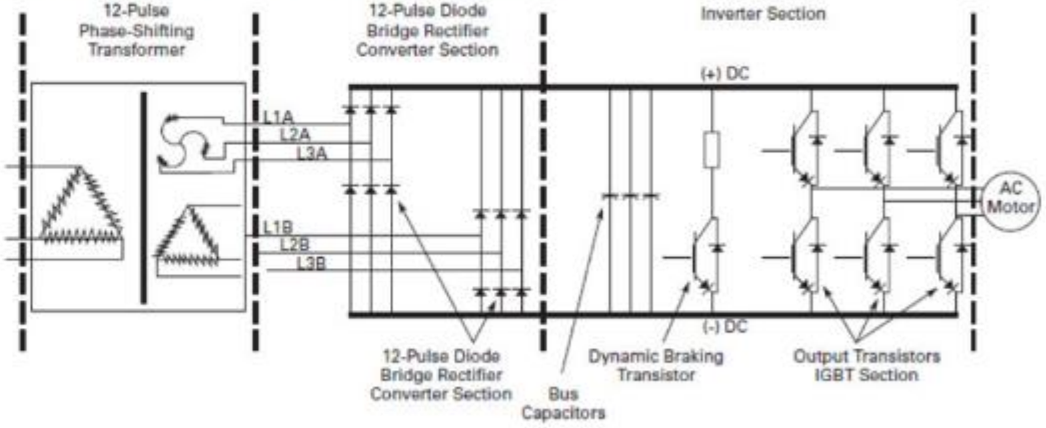
Reducing Sources is Better Strategy

Harmonics Reduction Strategy	Description
3% or 5% Line reactors	Reduces source 50-60%, Plus protects the VFD
For medium size drives, 12-step diode bridge at front end	Cancels out ¾ of the harmonics
For large drives, 18-step diode bridge at front end	Cancels out 97% of the harmonics
Use VFD with “active” front end	Instead of a diode bridge, uses digital IGBT circuit to develop DC power
Phase shifted transformers serving multiple VFDs or multiple MCCs	cancel out the harmonics with DIY version of 12 or 18 step diode bridge

12-Pulse Diode Bridge

- For VFDs >50 or 100 hp recommend 12-pulse diode bridge.
- Generates only ¼ of the harmonics as compared to 6 diode bridge.
- THD 15-20%

Basic 12-Pulse Rectifier with "Phase Shifting" Transformer



500 hp 480V Drive with 12-Pulse Rectifier

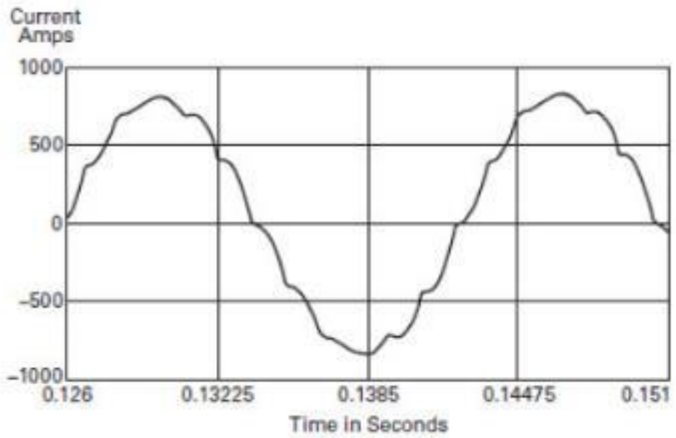
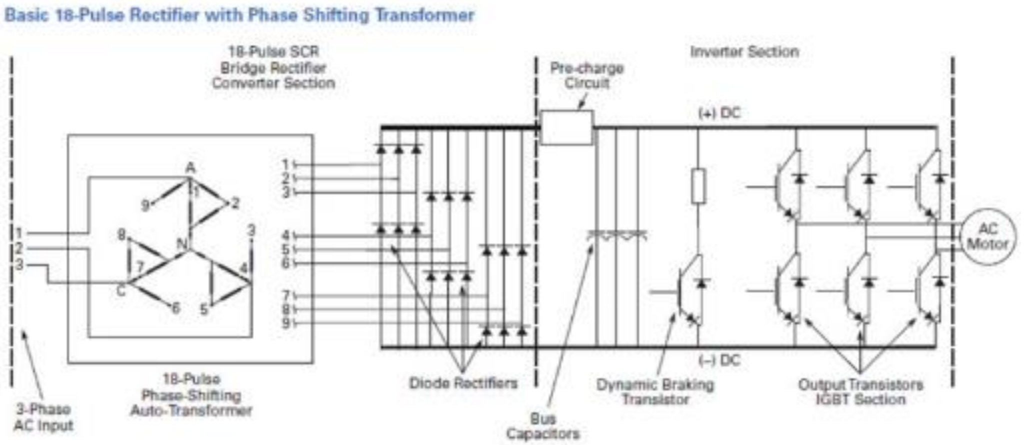
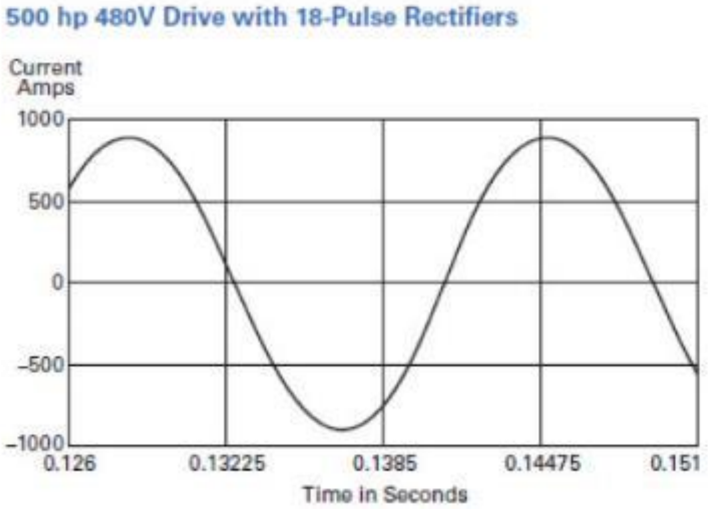


Figure courtesy Dan Carnovale, Eaton

18-Pulse Diode Bridge

- For VFDs >200 hp recommend 18-pulse diode bridge.
- 97% less total harmonic distortion than the 6-pulse





- Bonus – with a 12- or 18-pulse diode bridge, the DC bus voltage is much more stable, which prolongs the life of the IGBTs and reduces nuisance offline tripping.

Figure courtesy Dan Carnovale, Eaton

Coping Strategies for Harmonics

Use only after employing all practical strategies for reducing the sources

Coping Strategy	Description
Passive filters tuned to a particular Harmonic (i.e. 5^{th})	Requires careful analysis and planning
Isolation transformers	Contains the problem
K Rated Transformer	Can handle harmonics without overheating and damaging itself
Upsize transformers, generators	Larger size carries load without damage
Active Filters	Very effective, but very expensive

Key Points – Motor types

- AC induction TEFC motors are the workhorse of industry
- AC induction ODP motors prevalent throughout commercial applications
- NEMA Design B is most prevalent motor style
- NEMA MG-1 dictates the starting torque, maximum inrush and frame size
- Take precautions to preserve vital nameplate data
- Service factor indicates the motor *can* produce extra hp in a pinch, but don’t use it except in extraordinary circumstances

Key Points Continued

- Premium and super premium efficiency motors might be 3-5% more efficient than older standard efficiency motors
  - Copper rotor motors
  - Permanent magnet rotor motors
- Switched reluctance motors are a new generation of motors
  - computer controlled
  - High efficiency
  - Speed can be pre-programmed or controlled as needed
  - Speed not limited to 3600, 1800, 1200, 900 rpm like induction motors

Key Points – Motor Maintenance

- Don’t neglect or abuse your motors
  - Keep them clean
  - Feed them a nutritious and balanced diet
    - Correct voltage
    - Balanced voltage
    - Minimize harmonics
    - Correct power factor as needed
  - Provide training and tools for staff for the complex job of lubricating the motors
    - Use correct schedule
    - Use correct grease
    - Use correct amount of grease
    - Purge the old grease
- If they need to be rewound, make sure the shop follows EASA procedures
- Employ predictive maintenance strategies on critical motors

Key Points VFD-driven systems

- Not every motor is a good VFD candidate – use them judiciously
- Use the proper cable between VFD and motor
  - Fixed geometry cables - not twisted conductors
  - Don’t re-use the individual phase cables lying loose in the cable tray
  - XLPE insulation / low capacitance
  - Dedicated ground conductor, or for large drives, the 3 + 3 configuration
  - Shielded with foil and / or braided wrap
- Use correct cable terminators to maintain RF shield

Key Points for VFD-Driven Systems (cont.)

- Avoid reflected voltage phenomena
  - Review factory guidelines for maximum cable length
  - Check the insulation rating on the motor
  - Use appropriate insulation rating on the cable
  - Adjust the carrier frequency of the drive if needed
  - Use output filters, reactors, or line termination networks to control voltage
- Avoid problems with bearings
  - Use proper cable
  - Proper grounding
  - Insulated bearings
  - If all else fails ground the shaft

Key points – VFD and Power Quality

- Use 3% reactor upstream of VFD
  - Protects the drive
  - Reduces harmonics by ~50%
- On drives over 100 hp consider using 12 or 18 diode bridge
- Take all practical steps to reduce harmonics before employing coping strategies

Questions

Thank you!

For Questions or Comments please reach out to the following:

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