VFD Topics:

1. Understanding Harmonics

2. Applying VFD's to Fan Arrays

Jay Jorczak – Central Regional Sales Manager
Jeff Childs – Regional Drive Specialist - Austin

Harmonics

Benefits of Drives

- **Electric AC Motors**
  - Consume 45% of the world's electrical energy.
- **Main Purpose of Drives**
  - Save Energy (Power)

- **Other Advantages**
  - Improved Efficiency
  - Improved Process Control
  - No Inrush current
  - Reduced Maintenance on Mechanical Couplings, Belts, Motors
  - Compact Design

Benefits of VFD's

Across the Line

1 Fan Across the Line

100% Speed → 100% Flow

= 100% Power

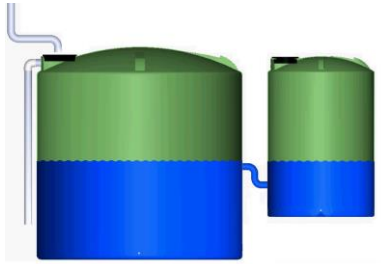
Motor Run by a Drive

70% speed → 70% Flow

Total Power = 34%

66% Power Reduction

VFD's and Harmonics



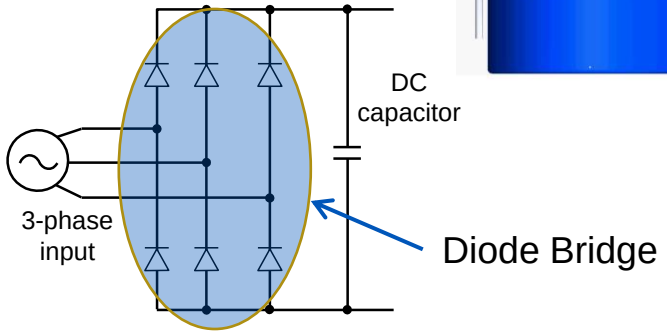
VFD's draw line current when needed.

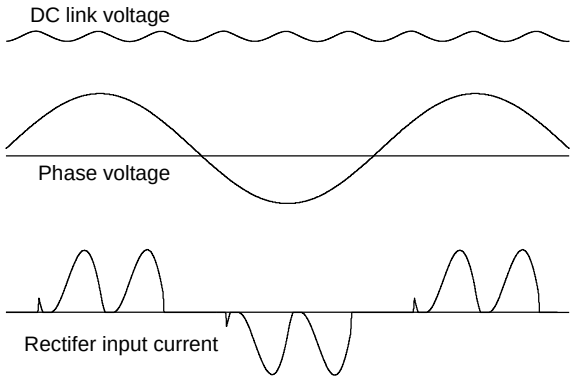
- Diode rectifiers.
- Current draw only occurs when

  AC voltage **>** DC Voltage
- AC > DC at peak of AC voltage
- Resulting current draw is non-linear.

The current waveform is distorted.

Distortion → Harmonics





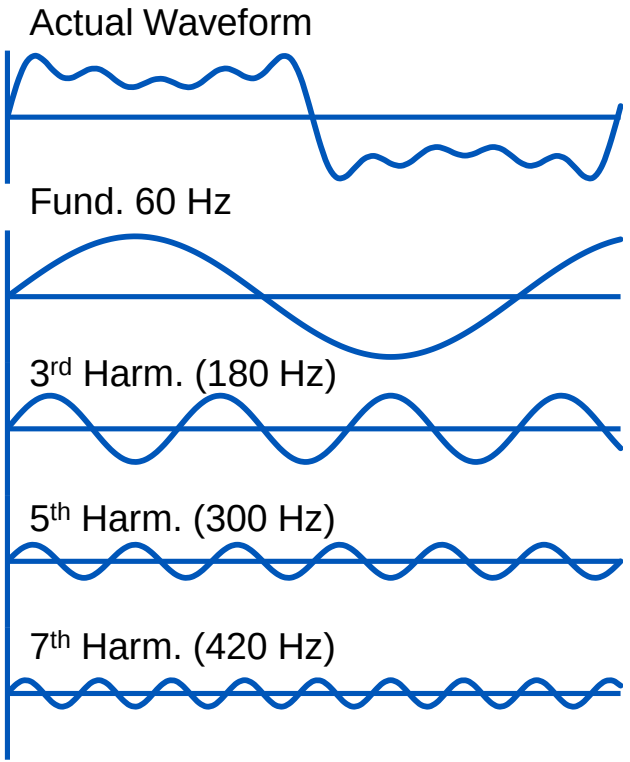
What are Harmonics?

Harmonics → breakdowns of a waveform

- Math used to find a waveform's components.
- Components:
  - Fundamental Waveform
  - Harmonics
    - Multipliers of the fundamental frequency

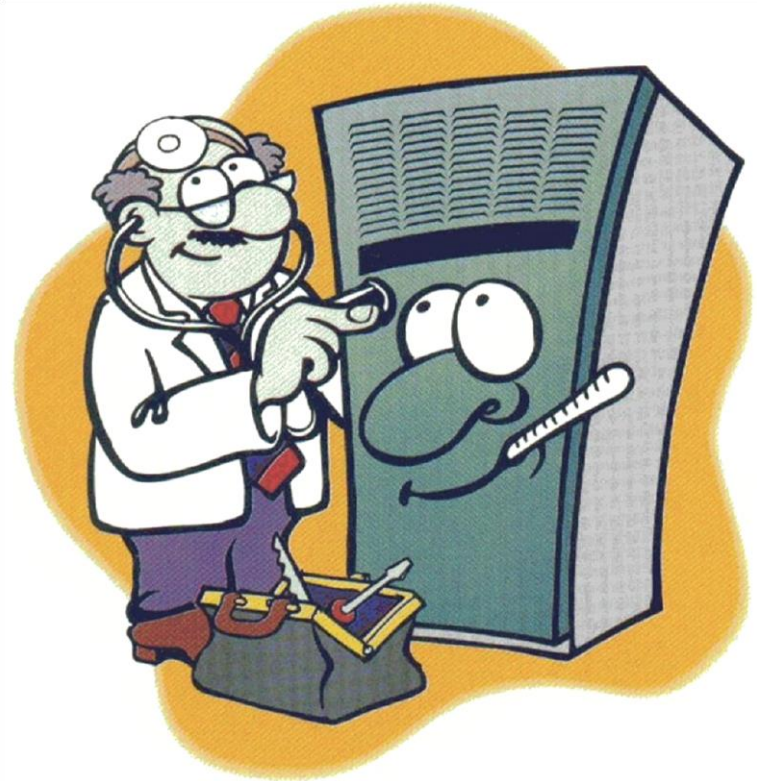
Ex:

- Fund Freq: 60 Hz
- 3rd Harmonic = 60 * 3 = 180 Hz
- 5th Harmonic = 60 * 5 = 300 Hz
- 7th Harmonic = 60 * 7 = 420 Hz



Input Current- Why it Matters?

- Voltage harmonics
- IEEE 519
- Conductor heating
- Transformer sizing & heating
- Power Factor reduction
- Lower efficiency
- Financial impact
  - Utility billing, fines



Non-Linear Loading

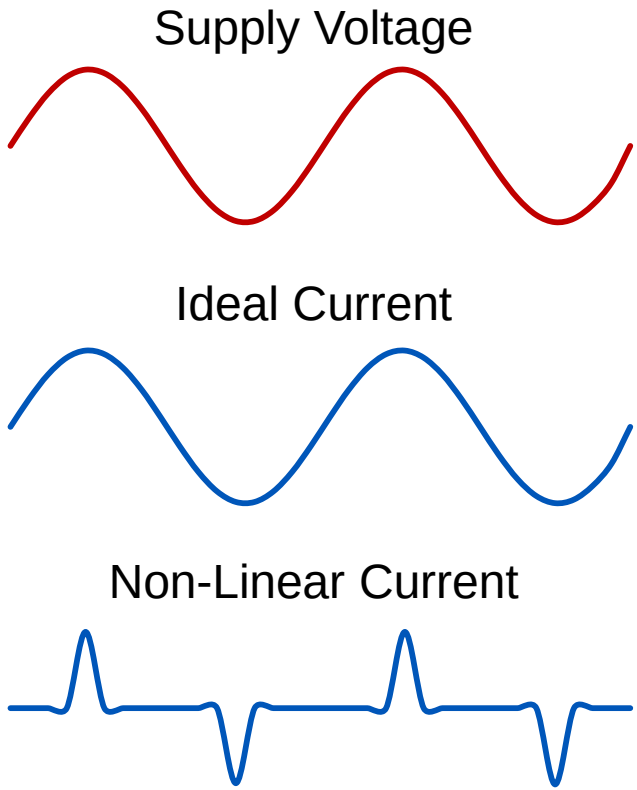
Drives are not the only non linear loads.

Other Non-linear loads:

- Electronic ballasts (lighting)
- Arc Furnaces
- UPS systems
- Medical Equipment
- Switching mode power supplies
  - Computers, servers, monitors, printers, photocopiers, Etc.
  - Data Centers

Input Current – What do we want?

- Voltage is typically supplied as a sine wave.
- Current should be drawn to match the supply voltage, i.e. current should look like a sine wave too!
- When current does not flow like the supplied voltage it is non-linear.



YASKAWA

IEEE-519

Changes Overview

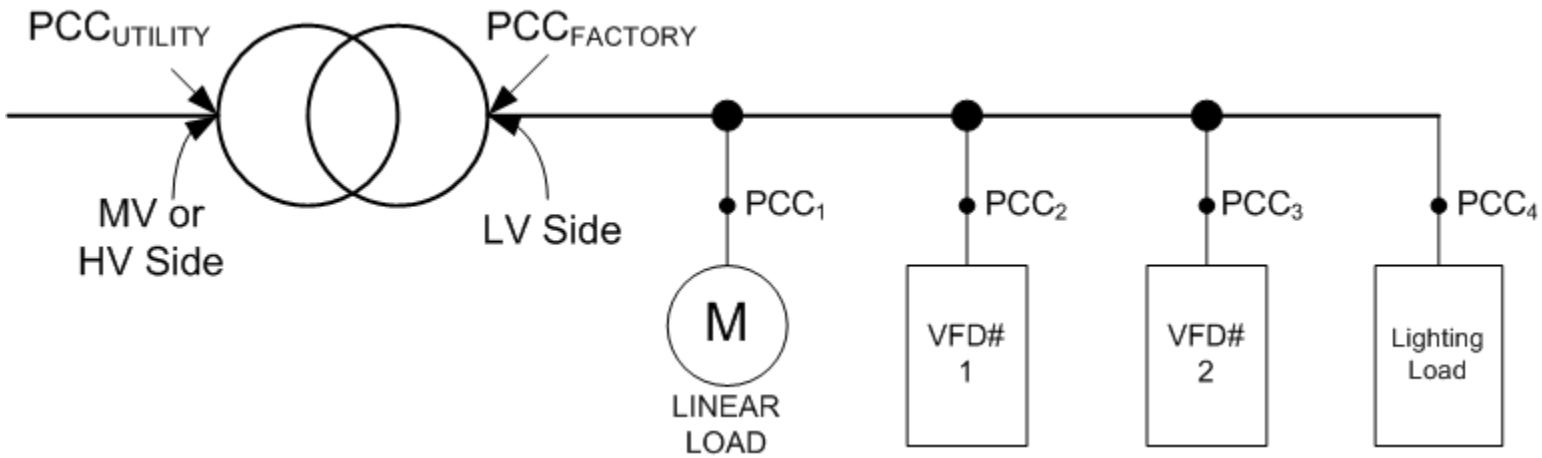
IEEE 519-2014 vs. IEEE 519-1992

- IEEE 519-1992
  - 101-page teaching document
  - PCC vaguely defined
  - Device-focused
  - Short-term measurements

- IEEE 519-2014
  - 29 page-document with no attempt to educate
    - 12 pages of intro, TOC, disclaimers, and participants
    - 10 pages of content
    - 7 pages of Annexes A-D
  - PCC clearly defined
  - System-focused
  - Long-term measurements

PCC in IEEE 519-1992

“Within an industrial plant, the PCC is the point between the nonlinear load and other loads.”

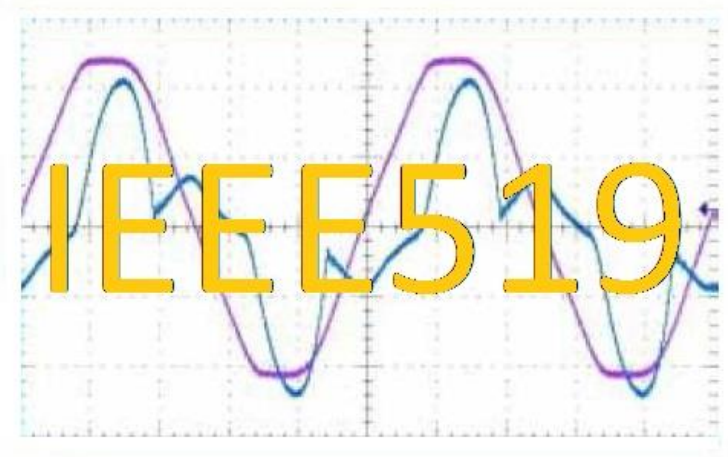


PCC Excerpt from IEEE 519-2014

"The recommended limits in this clause apply only at the point of common coupling and **should not be applied** to either **individual pieces of equipment** or at **locations within a user's facility**."

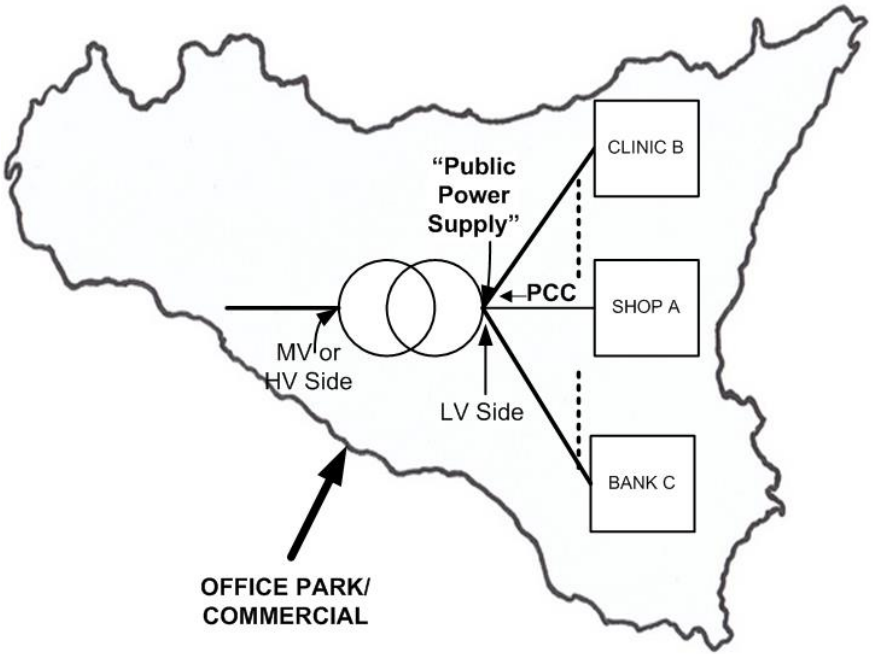
Limits apply only at the PCC, NOT:

- Specific equipment
- Locations within user's facility



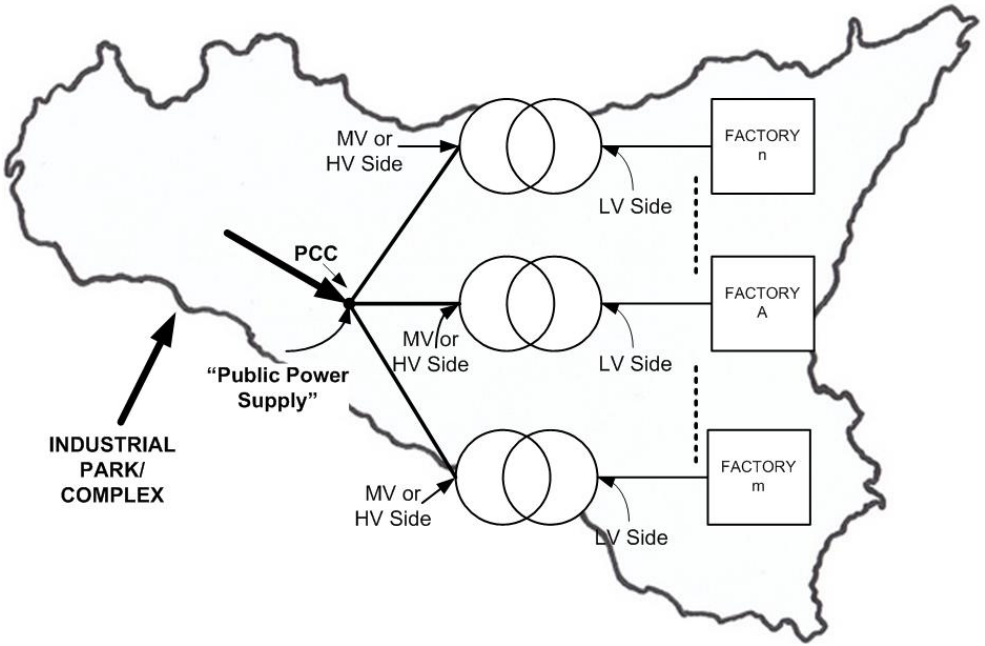
IEEE 519-2014 PCC for Commercial Users

- Low voltage side of the service transformer

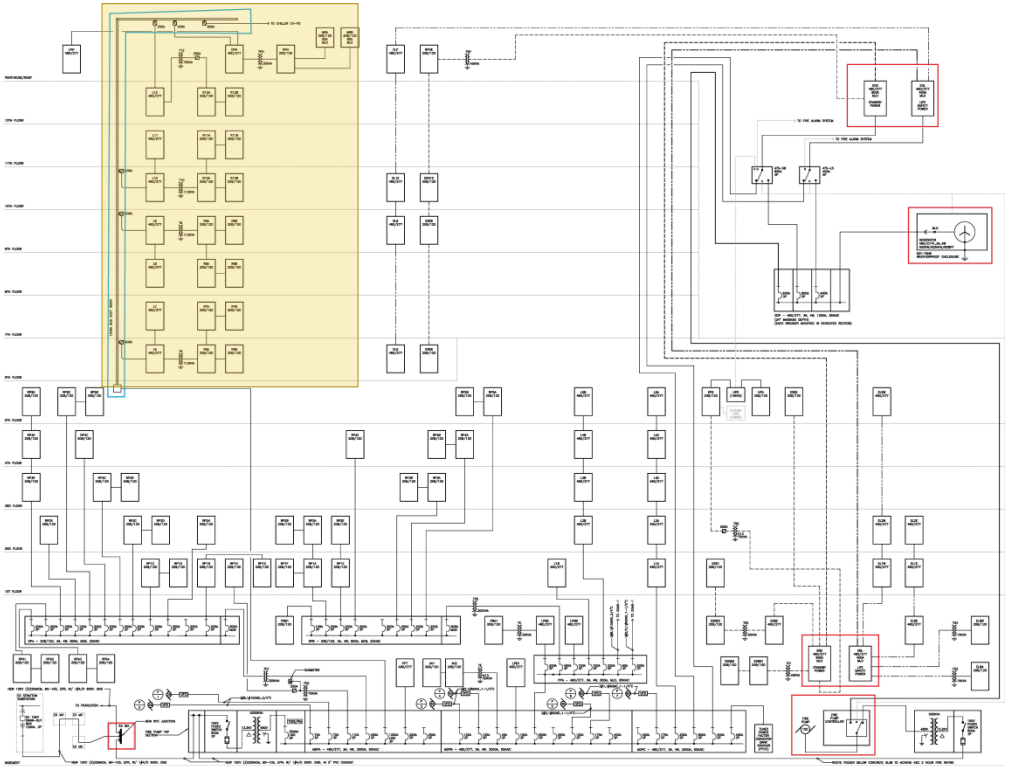


IEEE 519-2014 PCC for Industrial Users

- High voltage side of the service transformer



Why 5% Harmonics?



The Punch Bowl Analogy

PCC:
Point of Common Consumption

RHL 519
Responsible Host Limit: 5% alcohol

The Punch Bowl Analogy – What's it mean?

One 100 Amp Fan

5% Harmonics = 5 amps/fan

Total Harmonics

5/100 = **5%**

Two 100 Amp Fans

5% Harmonics = 5 amps/fan

Still 5%

Total Harmonics

10A/200A = **5%**

IEEE 519-2014 and VFDs

- Neither compliant nor non-compliant with IEEE 519-2014
- Not the only producers of harmonics
- Part of a larger user's system
  - Compliance measured at the prescribed point of common coupling
  - Harmonics estimation software available

- From IEEE 519-2014, 1.2 Purpose
  - "This recommended practice is to be used for guidance in the design of power systems with non-linear loads."

IEEE 519-2014 Harmonics Mitigation

"The limits in this recommended practice represent a **shared responsibility** for harmonic control between system owners or operators and users."

At the system level

- Phase-shifted buses at the service entrance (if necessary)
- Active Filters for large system loads

At the device level

- Conventional VFDs
  - Harmonic mitigation devices need to be added
- AC-to-AC and AFE VFDs
  - Harmonic levels (<5%) need no additional mitigation

Harmonic Mitigation Techniques For VFDs

What We Can Do About It?

Reducing VFD Harmonics

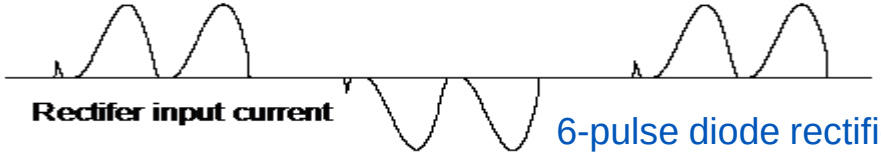
VFD harmonics mitigation

- DC reactor (DC link choke or AC line reactor)
  - High impedance to harmonic frequencies
- Passive harmonic filters
  - LC circuit used to filter current harmonics
- Multi-pulse rectifiers and transformers
  - Phase shifts in series to lessen current pulses
- Active front end VFD’s (AFE)
  - Dual-rectifier
  - AC to AC converter

Reactors

Can be standard in most VFD's or inexpensive options

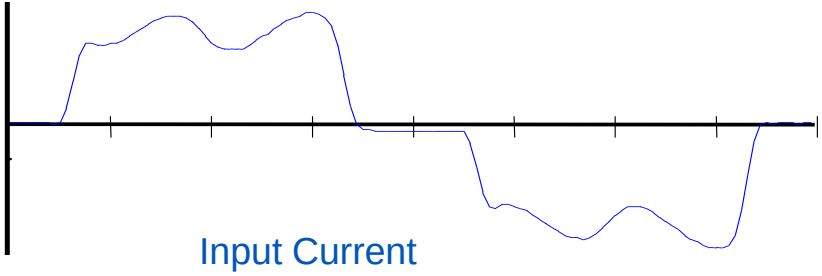
Total system Eff. – 96-97%



6-pulse diode rectification
w/o mitigation

w/ DC Link Choke

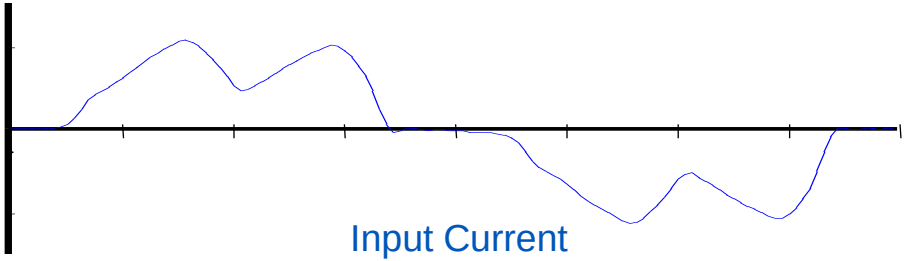
THD≈35 to 45%



Input Current

w/ AC Line Reactor

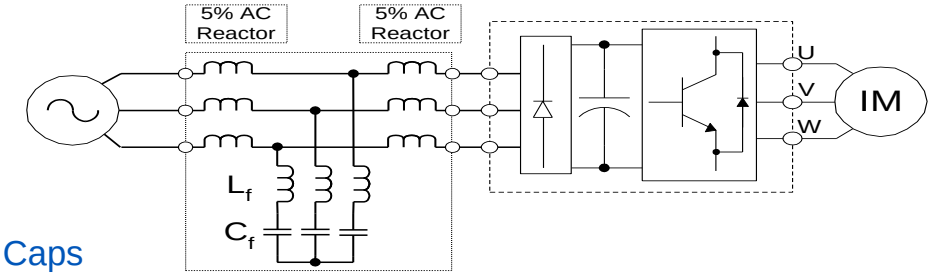
THD≈35 to 45%



Input Current

Passive Filters

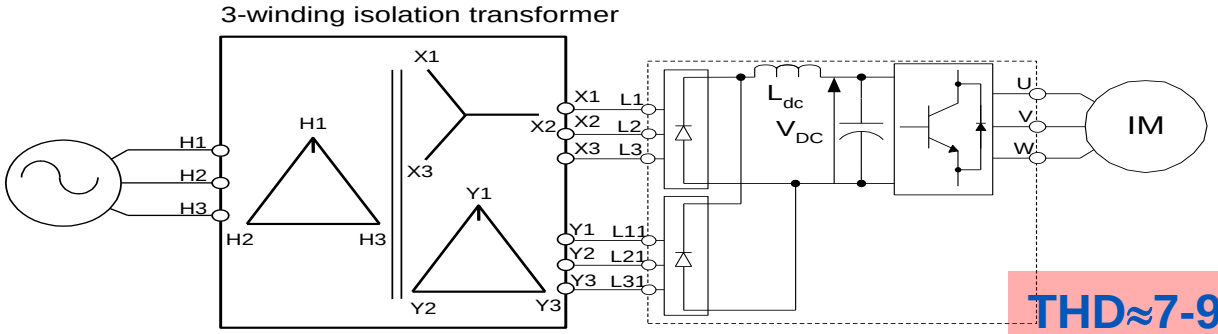
- Harmonic Filers
  - Series - tuned to offer high impedance to select harmonic frequencies
  - Shunt Filter– tuned to shunt (trap) select harmonic frequencies
  - Hybrid Filters – combination of above
- Pro's
  - Less Costly than other methods
- Con's
  - Power Loss, and higher stresses on DC Bus Caps
  - Generally multiple sections needed to capture enough harmonic orders
  - May not reduce iTHD enough
- Total Eff. – 94%



THD≈Less than 12%

12-Pulse

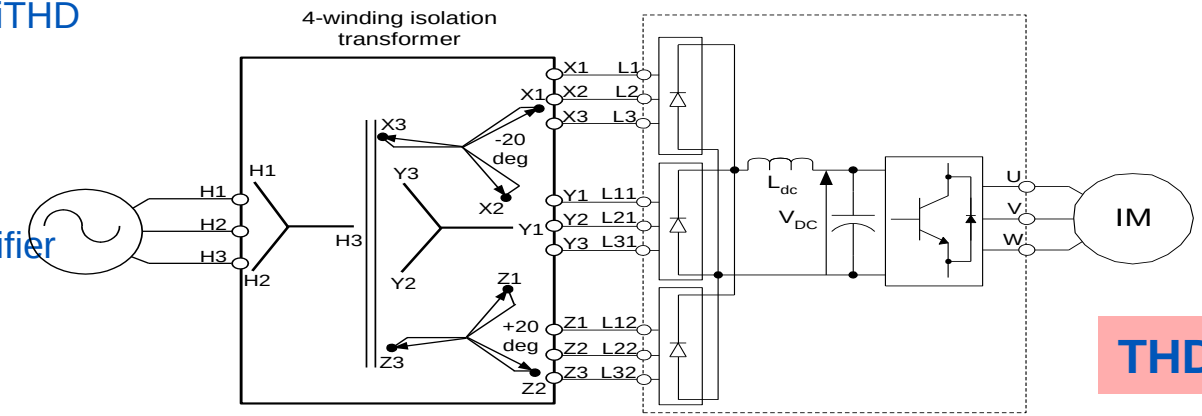
- Standard 12-Pulse
  - Higher the order of harmonic in a waveform, lower is the amplitude of the harmonic
  - Multi-pulse technique helps in increasing the lowest harmonic order
  - h=kq±1; For a six pulse system, q=6 and lowest pair of harmonics is 5th and 7th
  - For a twelve pulse system, q=12 and lowest pair of harmonics is 11th and 13th
- Pro's
  - More robust
- Con's
  - Bulky
  - Additional rectifier
- Total Eff. – 94%



THD≈7-9%

18-Pulse

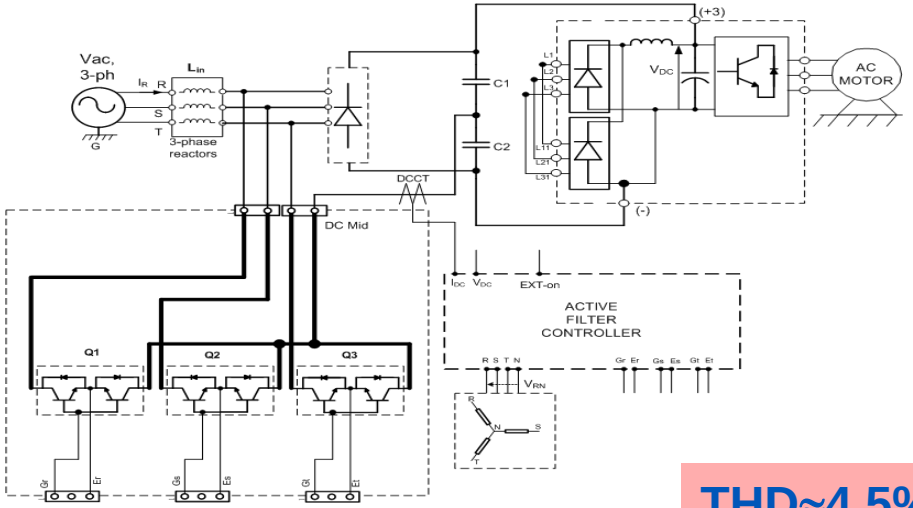
- Standard 18-Pulse
  - h=kq±1; For a six pulse system, q=6 and lowest pair of harmonics is 5th and 7th
  - For an eighteen pulse system, q=18 and lowest pair of harmonics is 17th and 19th
- Pro's
  - Less than 5% iTHD
- Con's
  - Cost
  - Bulky
  - Additional rectifier
- Total Eff. – 94%



THD≈4.5%

Active Filters

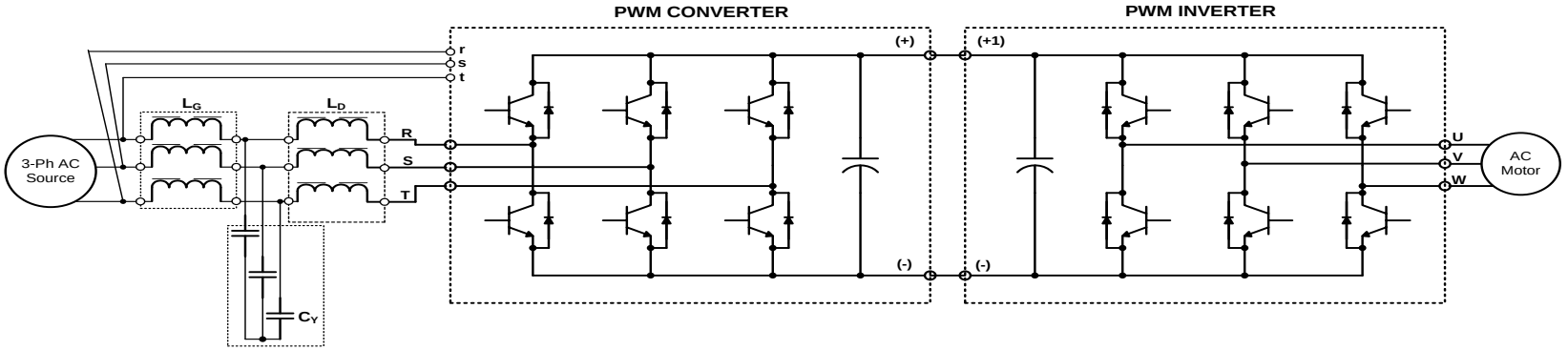
- Active Filter
  - Semiconductor switches
  - Energy storage devices
- Pro's
  - Smaller bus capacitors
  - Changes based on actual load
  - Current becomes continuous which lowers harmonics
- Con's
  - Inductor is large and bulky
  - cost
- Total Eff. – 94%



THD≈4.5%

Active Front End: Dual Bridge

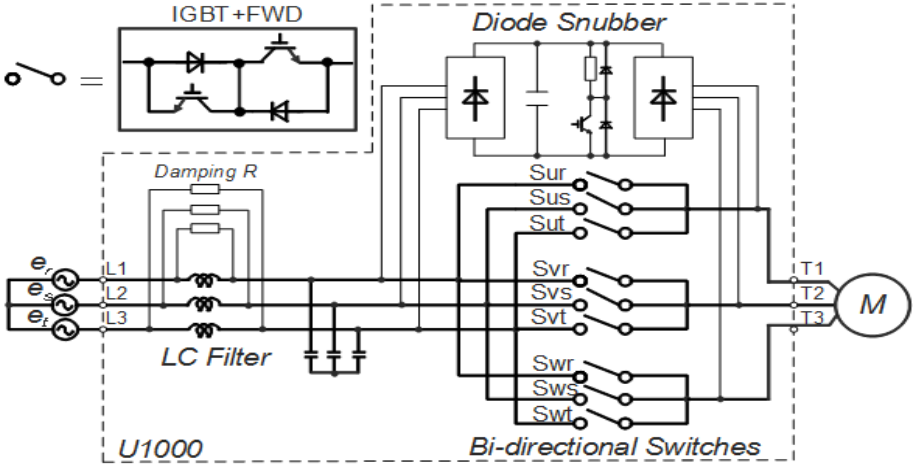
- Good Efficiency (96%)
- Better Power Factor than passive methods
- Low Harmonics (4-5% THD)
- Smaller space, less bulky
- Some have Regen capability
- Lower Cost



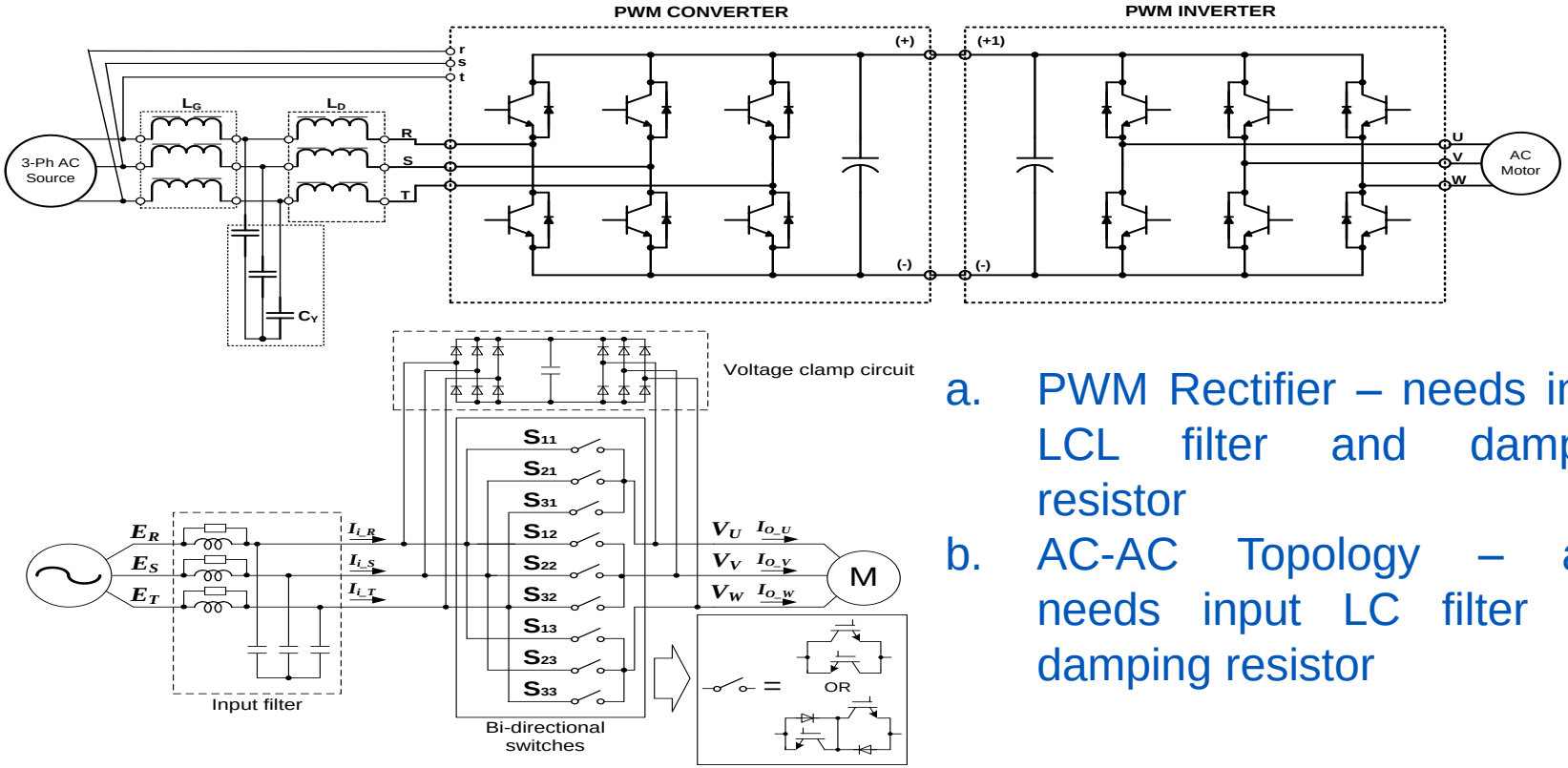
Active Front End: AC-AC

- Best Efficiency (98%)
- Better Power Factor than passive filters
- Low Harmonics (4-5% THD)
- Better performance at lower loads/speeds; eco-mode
- Smaller space, less bulky
- Regen capability
- Lower cost

【9 bi-directional switches】

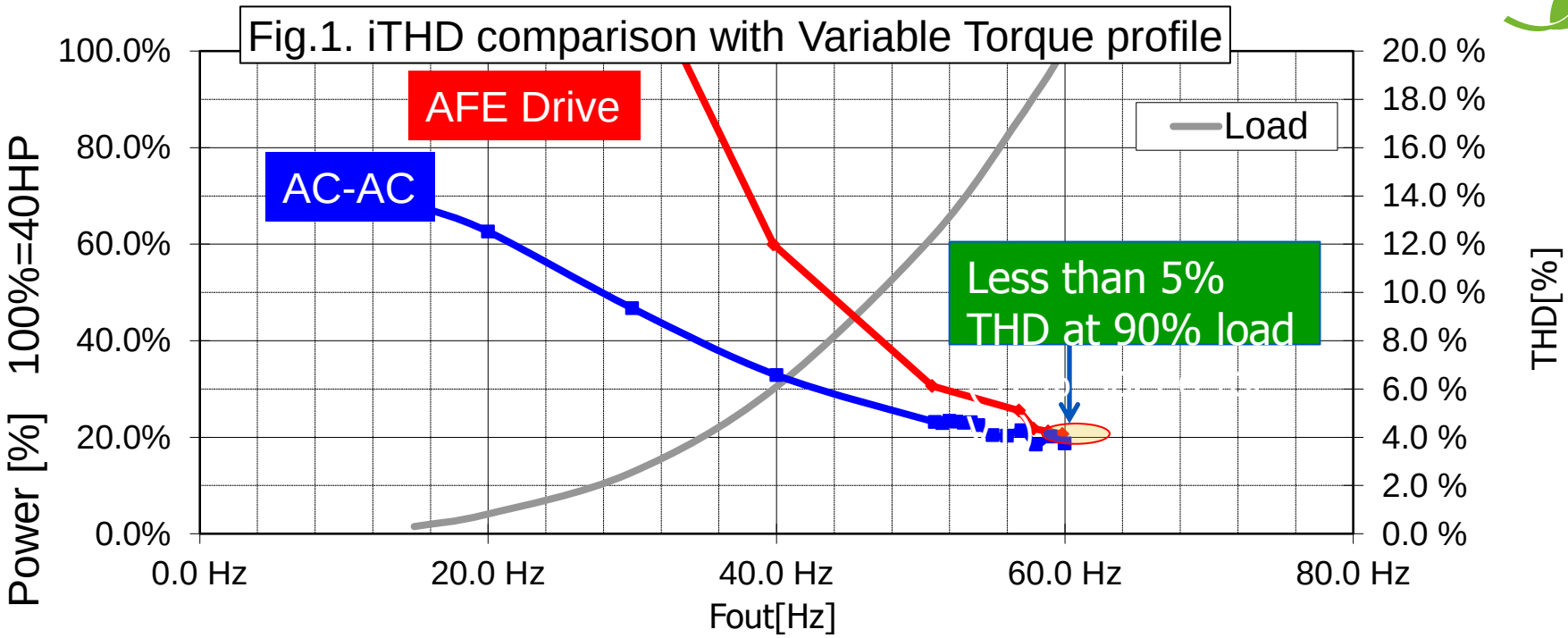


Active Front Ends

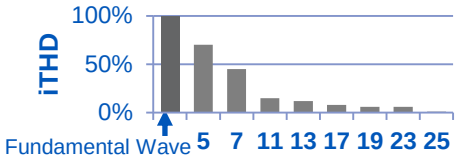
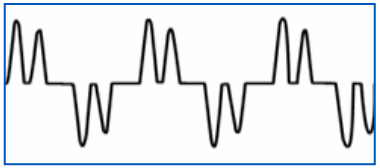
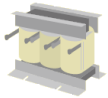
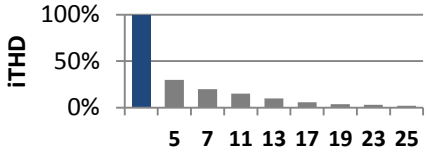
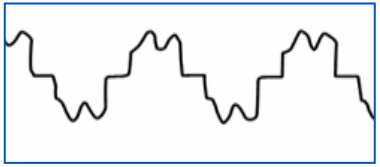
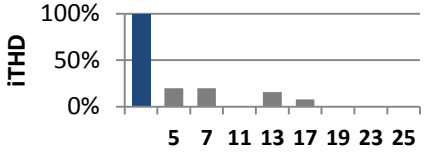
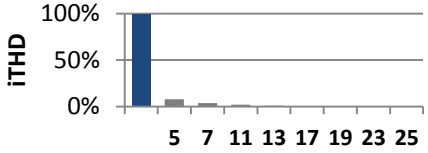
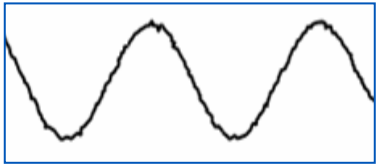


a. PWM Rectifier – needs input LCL filter and damping resistor
b. AC-AC Topology – also needs input LC filter and damping resistor

Harmonic Performance Comparison (AC-AC vs. AFE)



Harmonics Performance Comparison Details

	Current Harmonics	Current Waveform	Current Distortion	True Power Factor*
VFD			88%	0.75
 VFD			33%	0.90
 VFD			5 to 12%	0.95
AFE			3 to 5%	0.98

Fan Arrays

Understand how to apply VFDs to fan arrays

Overview of terms that will be used
Fan Array
Bypass
MMP (Manual Motor Protector)
Redundant VFD Package

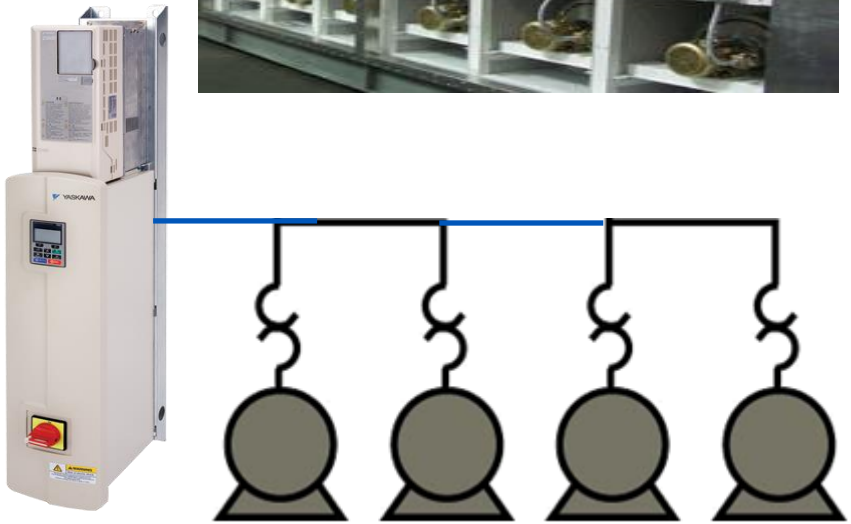
Fan Arrays – Topics

Using VFDs for fan array power and control

- What we're going to cover
  - A VFD for each motor in array
  - One VFD to power all motors in the full array or sections of the array
  - VFD with bypass to power all motors in the array
  - Redundant VFD package to power all motors in the array

Why Apply a VFD to a Fan Array?

- Energy savings
  - Operating below 60hz saves energy
- Variable torque load
  - More energy savings
    - At 50% speed, 12.5% energy consumption
- Control
  - 0 Hz - +/- 240 Hz control

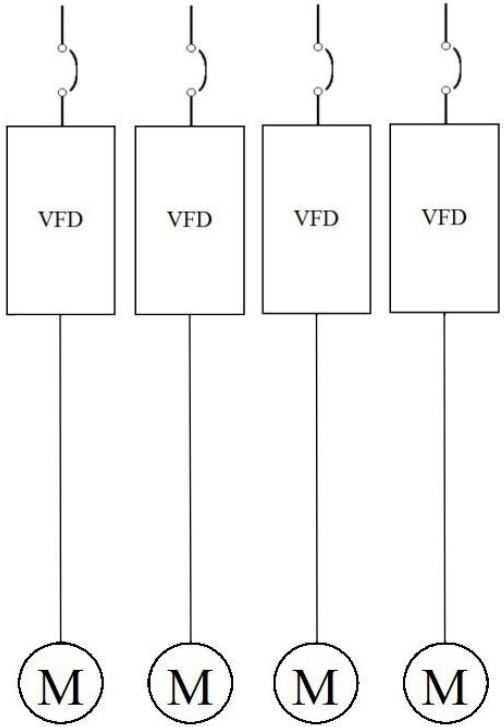


Fan Arrays – VFD per Motor

A VFD for each motor in the array

PRO'S:

- A VFD (or motor) failure will not take down more than the one motor it is running
- VFD provides complete motor protection
- Individual control if needed for any reason

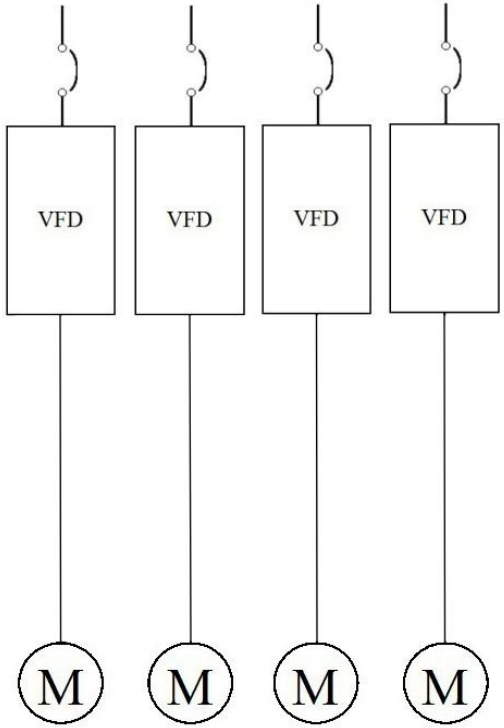


Fan Arrays – VFD per Motor

A VFD for each motor in the array

CON's:

- It may prove costly to provide an individual VFD for each motor in the fan array.
- Potential for overvoltage faults (windmilling)
- Mounting space. You need to have enough space somewhere to mount all the VFDs.
- Need to run separate power and control wiring for each VFD. (wiring cost)
- Harmonic Considerations (micro drives)

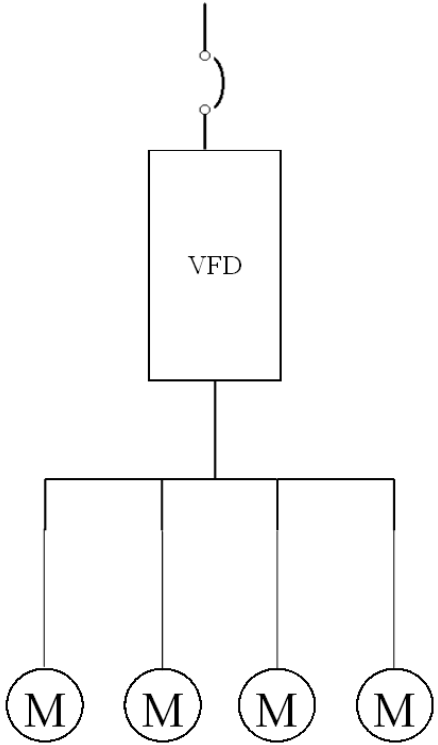


Fan Arrays – VFD for Array

One VFD to power all motors in the array

PRO'S:

- Minimal amount of panel space is required
- Simplified wiring – power in, power out
- Definitely uniform speed for the fan array
- One motor failure does not take down unit
- VFD can run remaining motors at higher speed to compensate until motor is repaired/replaced

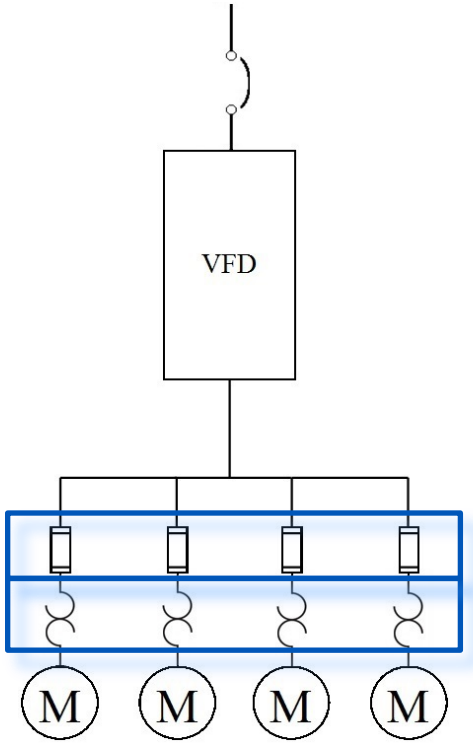


Fan Arrays – VFD for Array

One VFD to power all motors in the array

(Cons)iderations:

- With sharing of VFD output, each motor requires…
  - Overload Protection
  - Short Circuit Protection

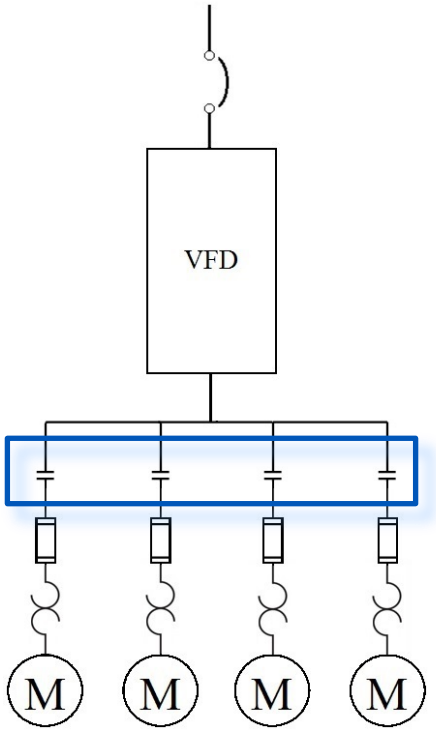


Fan Arrays – VFD for Array

One VFD to power all motors in the array

Considerations:

- With sharing of VFD output, each motor requires…
  - Overload Protection
  - Short Circuit Protection
  - Means to remove from circuit

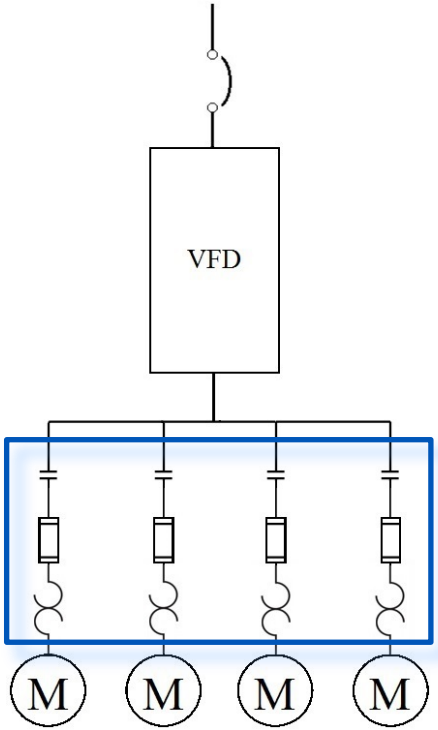


Fan Arrays – VFD for Array

One VFD to power all motors in the array

Considerations:

- Fuses, Contactors, and Overloads

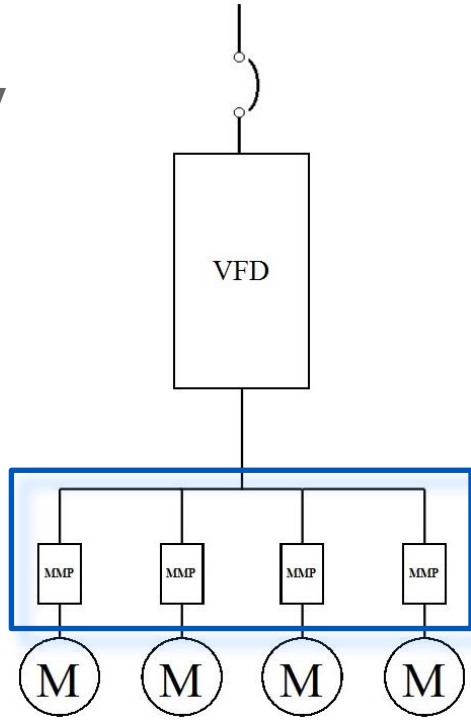


Fan Arrays – VFD for Array

One VFD to power all motors in the array

Considerations:

- Fuses, Contactors, and Overloads
- MMPs (Manual Motor Protectors)



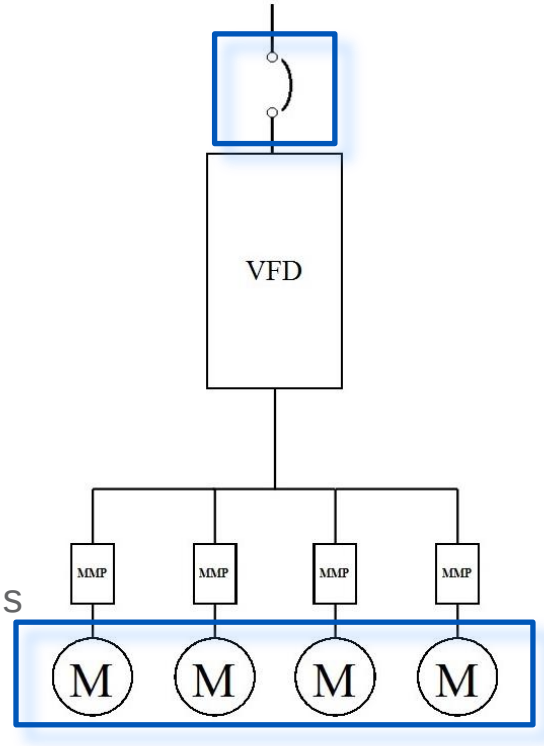
Fan Arrays – VFD for Array

One VFD to power all motors in the array

Conditions for MMPs in lieu of Fuses, Contactors, and Overloads?:

1. Circuit Breaker (or Fused Disconnect) for branch circuit protection

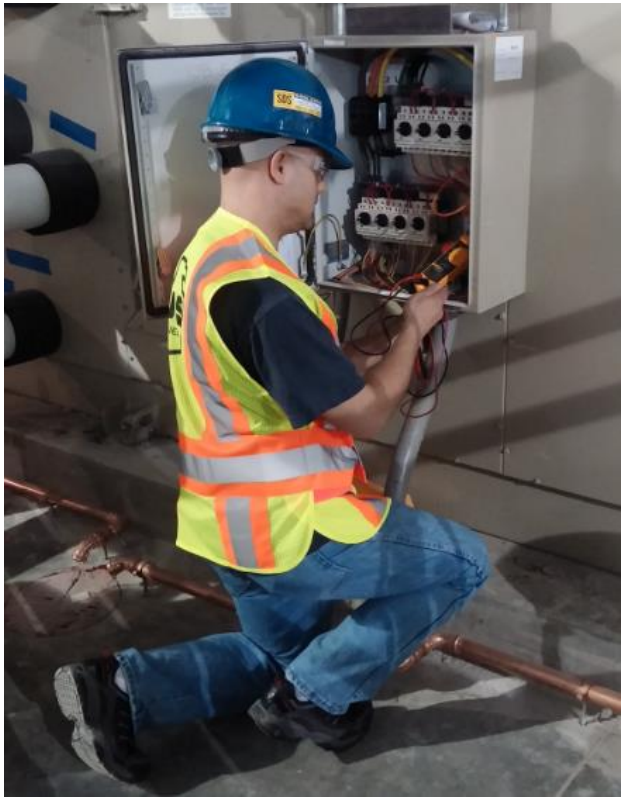
2. There is a limit to the number of motors in this arrangement, and is HP dependent



Fan Arrays – External from VFD Package

Does the motor protection have to be in the VFD enclosure?

- Not necessarily. However this may vary from region to region depending on local codes.
- Circumstances will dictate direction.
  - You can save valuable space in VFD enclosure
  - Standard packages vs. engineered packages (cost)

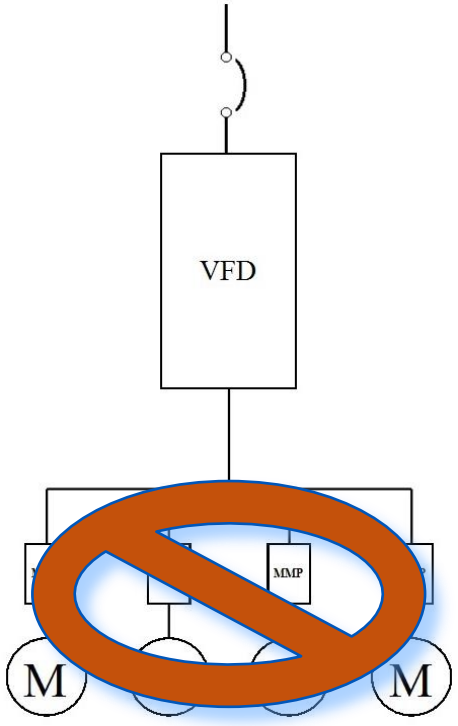


Fan Arrays – VFD for Array

One VFD to power all motors in the array

Cons:

VFD is a single failure point.

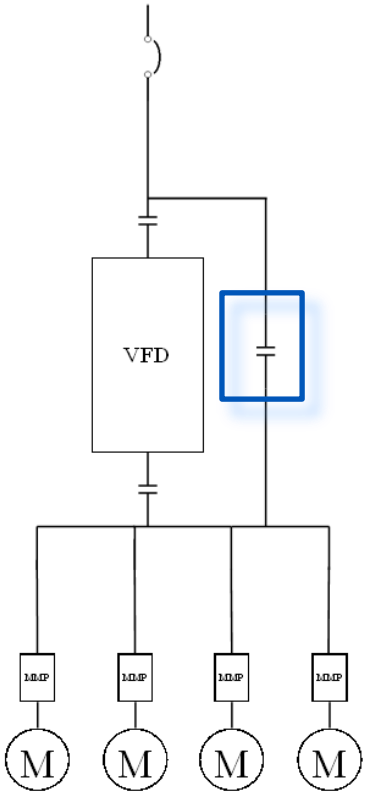


Fan Arrays – VFD with Bypass

VFD with Bypass

PRO’S:

- Now we have a backup means of running the motors while the VFD is “down”

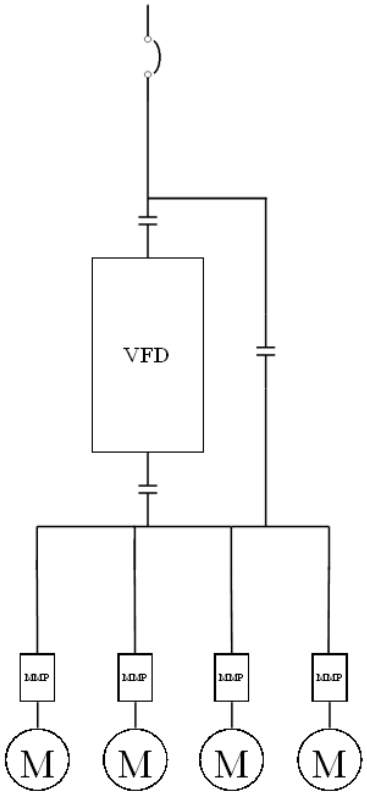


Fan Arrays – VFD with Bypass

VFD with Bypass

Considerations:

- Now we need to provide short circuit protection for when running across the line in bypass



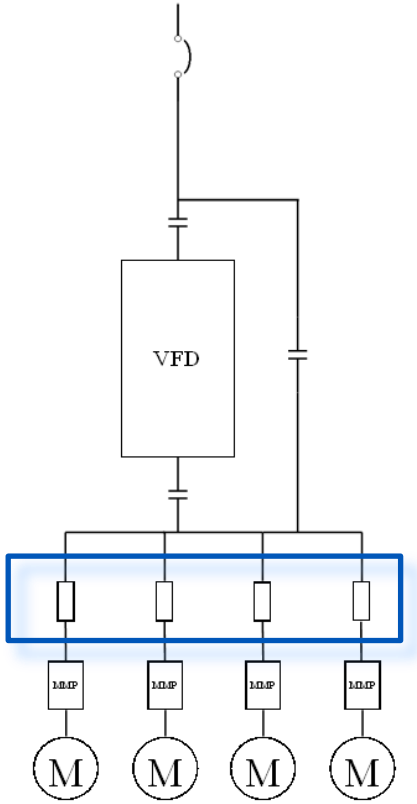
Fan Arrays – VFD with Bypass

VFD with Bypass

Considerations:

- Now we need to provide short circuit protection for when running across the line in bypass

- We can add fusing upstream of each motor…



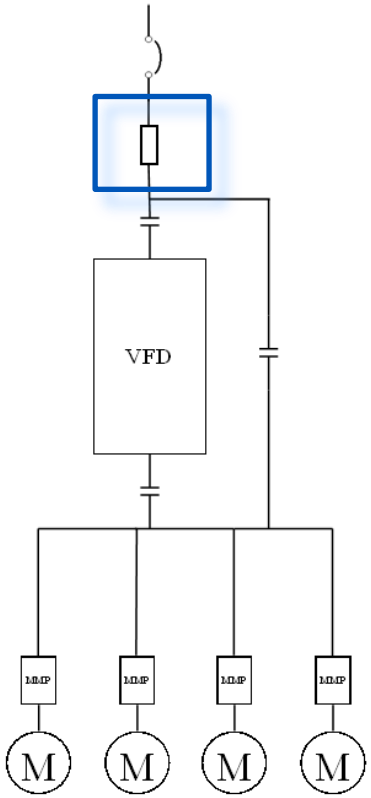
Fan Arrays – VFD with Bypass

VFD with Bypass

Considerations:

- Now we need to provide short circuit protection for when running across the line in bypass

- Or we can add fusing right after the breaker, or use a fused disconnect.

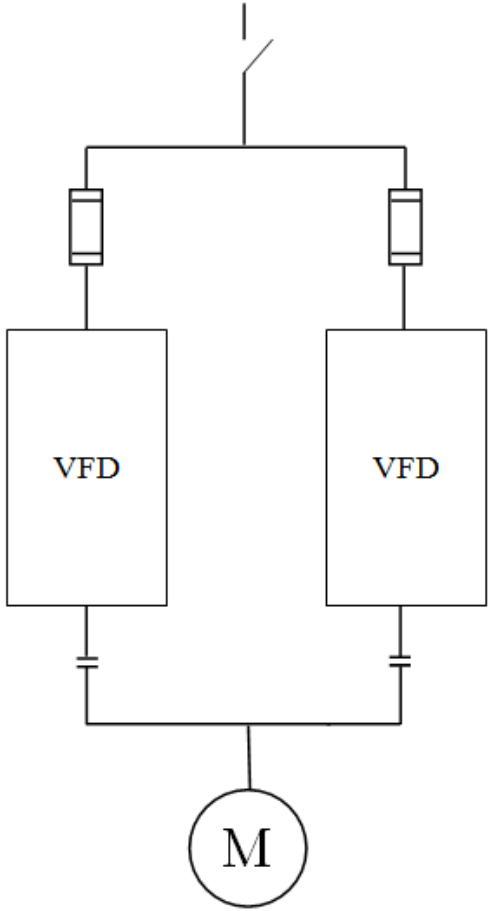


Fan Arrays – Redundant VFD

Requirements:

- Main Disconnect
- 2 full rated VFD’s
- Branch Short circuit protection
- Output contactors
- Dual control wiring
- Optional communications

Works for single motor or multiple motor applications



Fan Arrays – Redundant VFD

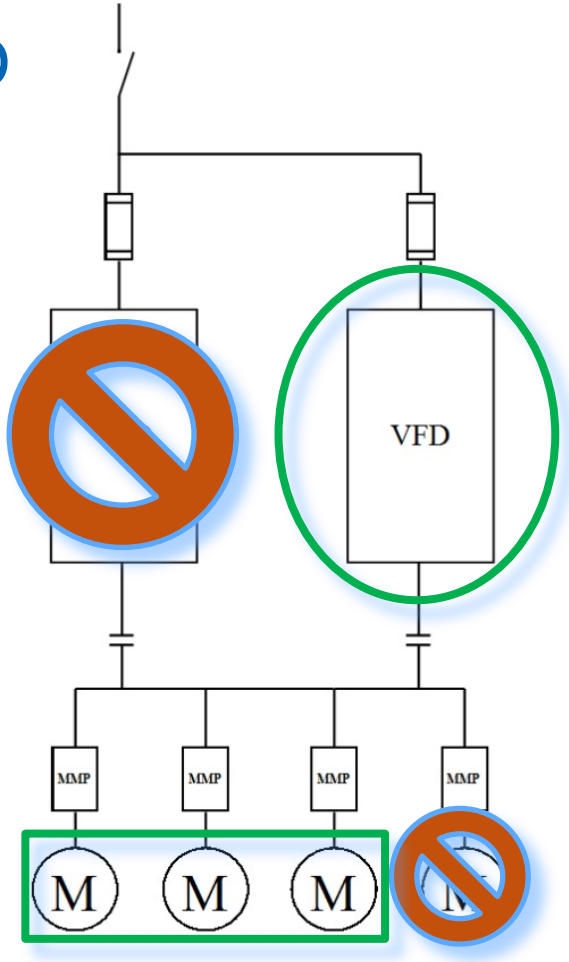
Redundant VFD

PRO’S:

- VFD failure does not bring down system
- Motor failure does not bring down system
- Maintain system Efficiency and control
- System requires VFD

CON’S:

- Cost
- Package size



Questions?

Thanks

Jay Jorczak – Central Regional Sales Manager
Jeff Childs – Regional Drive Specialist – Austin Area