Variable Frequency Drives – Lessons Learned

Presented by:

Trindera Engineering

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Introductions

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- Trindera Engineering – Coeur d'Alene, Idaho
- P.E. – WA, ID, MT, AK
- Electrical Consulting Engineer (12 years)
- Municipal Water and Wastewater Systems:
  - Water treatment plants
  - Booster stations
  - Wells
  - Reservoirs
  - Wastewater treatment plants and collection facilities
  - Standby generators
  - Instrumentation
  - Arc flash analysis
  - SCADA systems
  - Design reports and cost estimates

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Variable Frequency Drives – Lessons Learned

1. **Why VFD's?**
2. **What will you get out of this?**

Variable Frequency Drives – Lessons Learned

1. **How VFD's Work**
2. **How VFD's Impact Motors (Load Side)**
3. **Power Quality Considerations (Utility Side)**
4. **Lessons Learned**

Utility

VFD

Motor

How VFD's Work

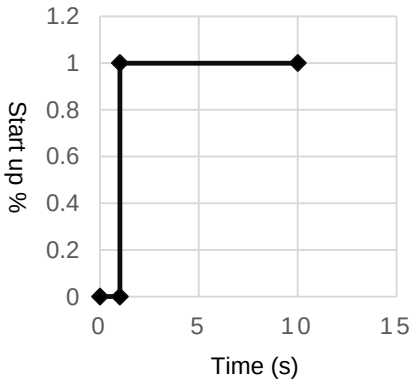
Utility

VFD

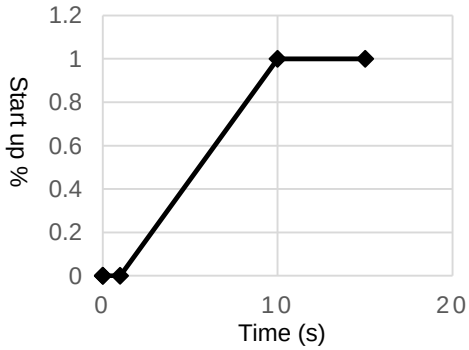
Motor

How VFD's Work

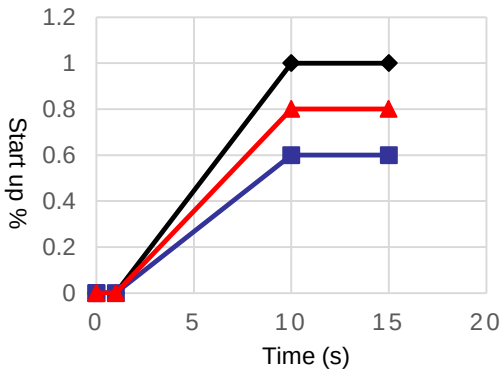
Contactor



Soft Starter



VFD



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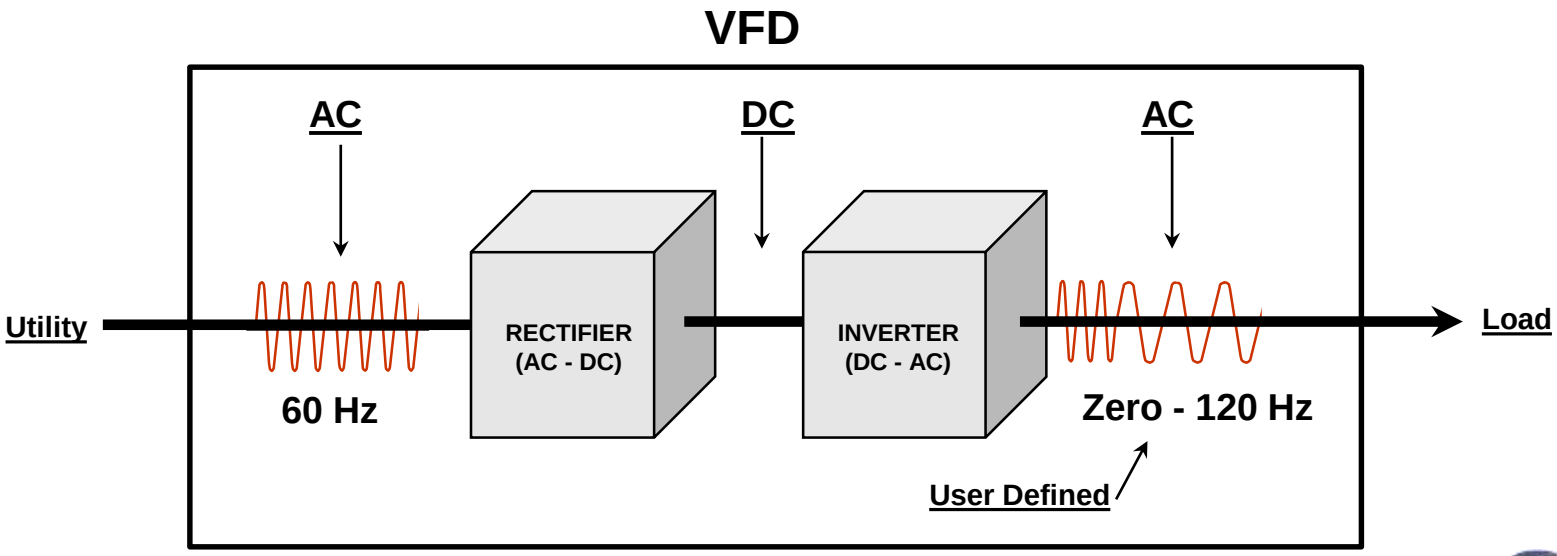
How VFD's Work

VFD's adjust frequency to control power supplied.



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How VFD's Work

AC Motor – Frequency Control

~500 RPM

60 Hz

~1000 RPM

120 Hz

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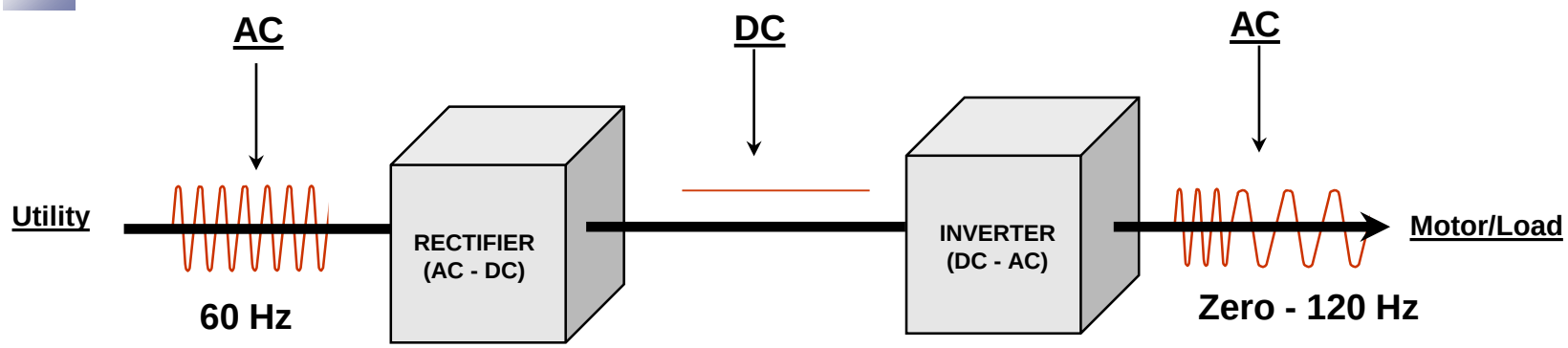
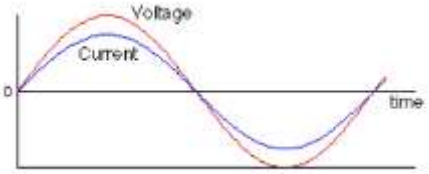
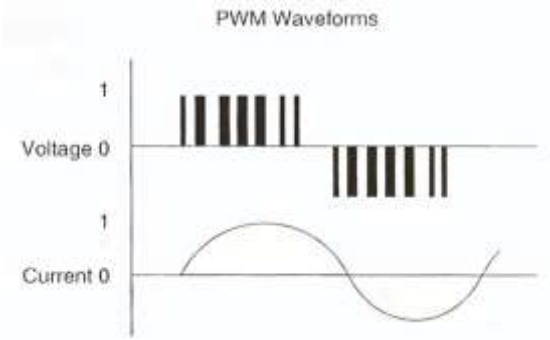
How VFD's Work







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How VFD's Impact Motors

Utility

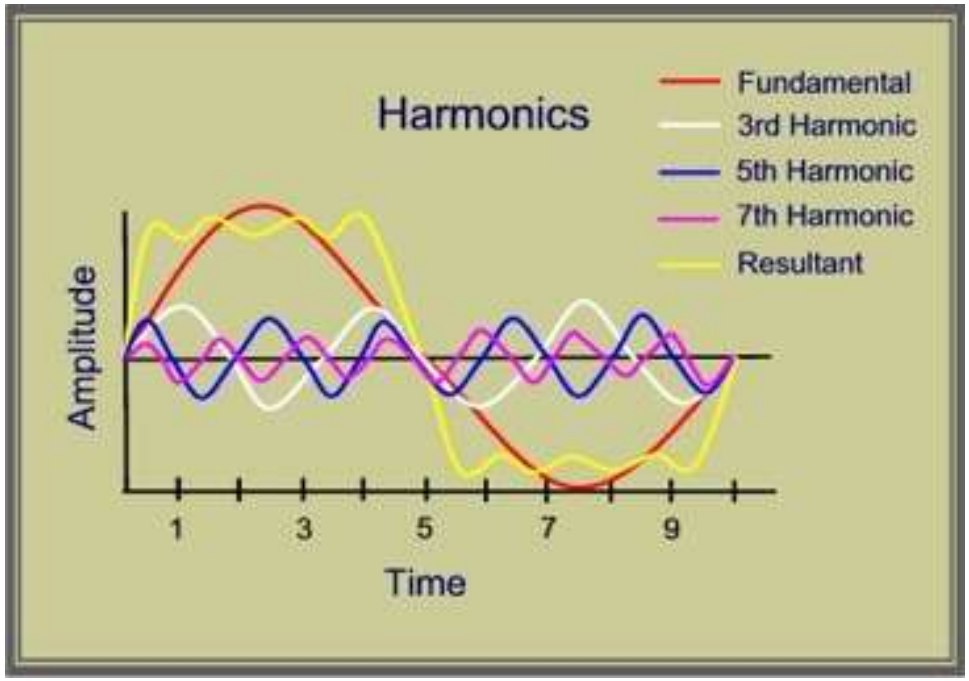
VFD

Motor

How VFD's Impact Motors

Harmonics

- Fundamental 60 Hz
- Harmonics 120, 180, 240…Hz



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How VFD's Impact Motors

Motor heating

- Additional currents

Motor insulation damage

- Voltage spikes

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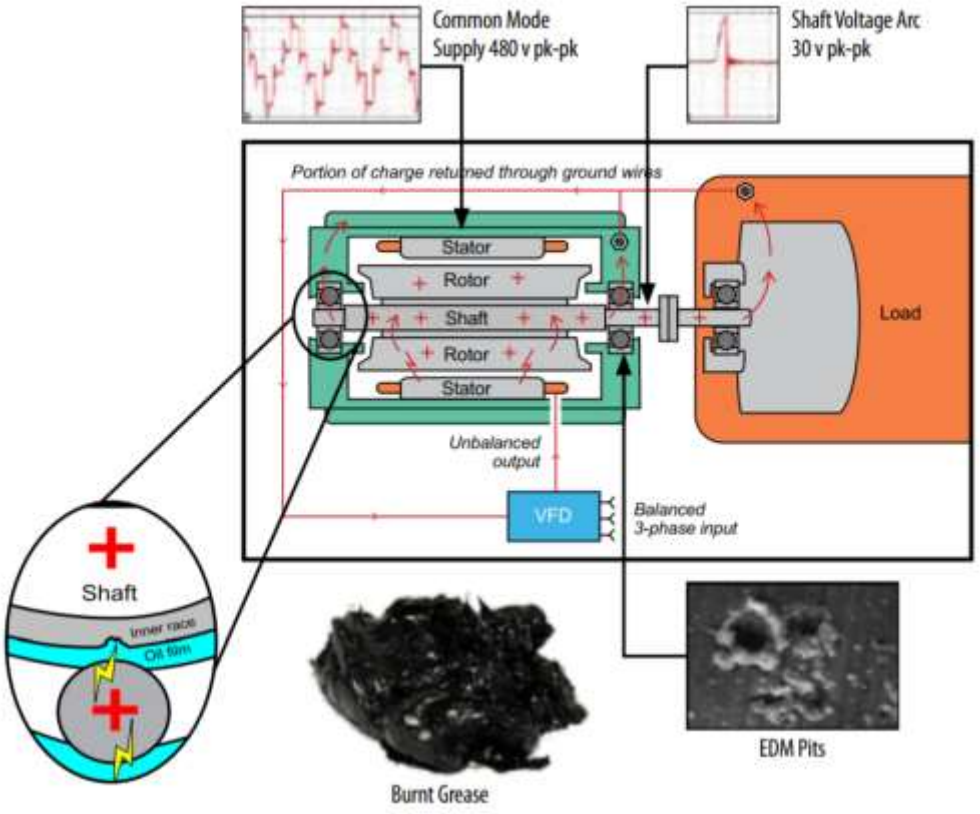
How VFD's Impact Motors

Pitting



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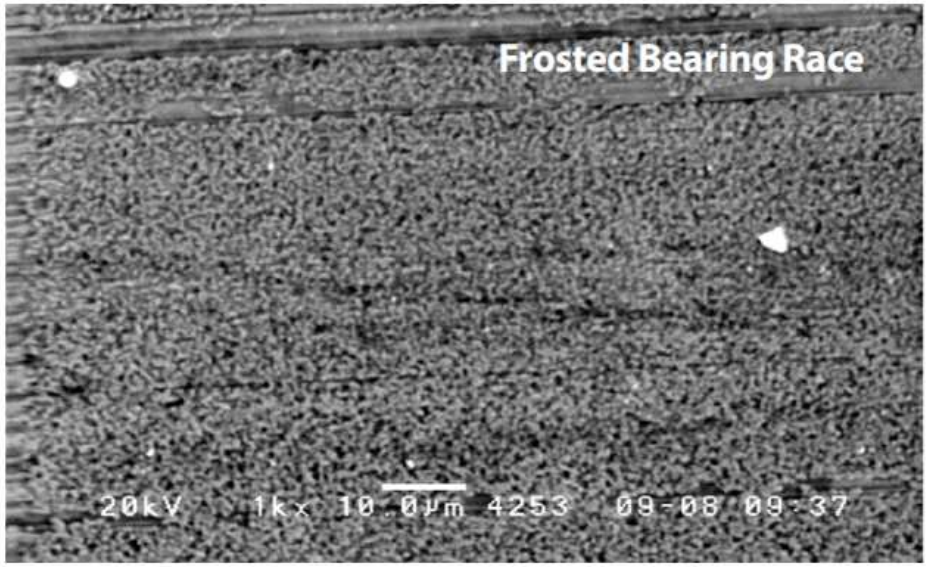
How VFD's Impact Motors

Pitting



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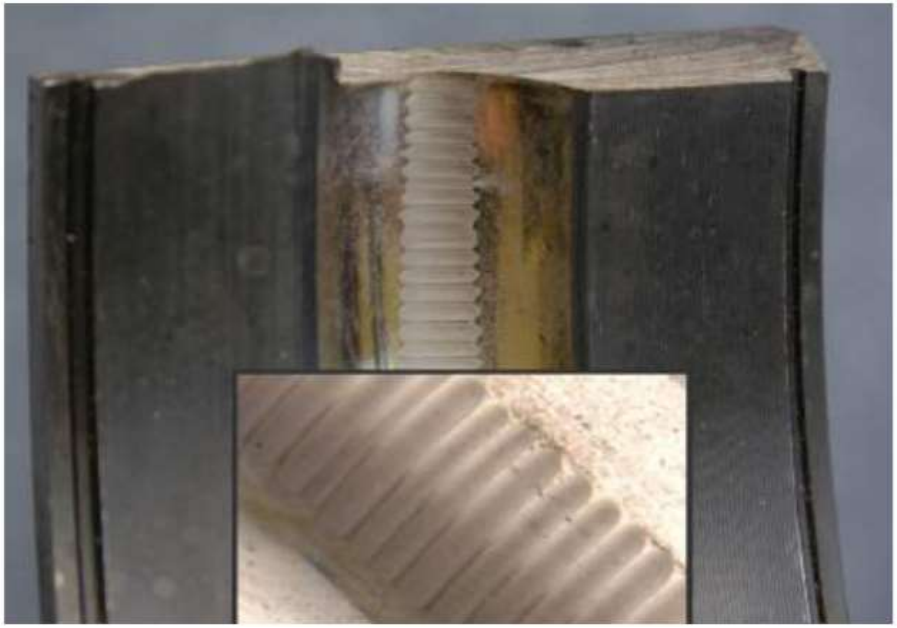
How VFD's Impact Motors

- Fluting



Power Quality Considerations

Utility

VFD

Motor

Power Quality Considerations

IEEE 519-2014 – Harmonic Voltage

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.

IEEE 519-2014 Table 1

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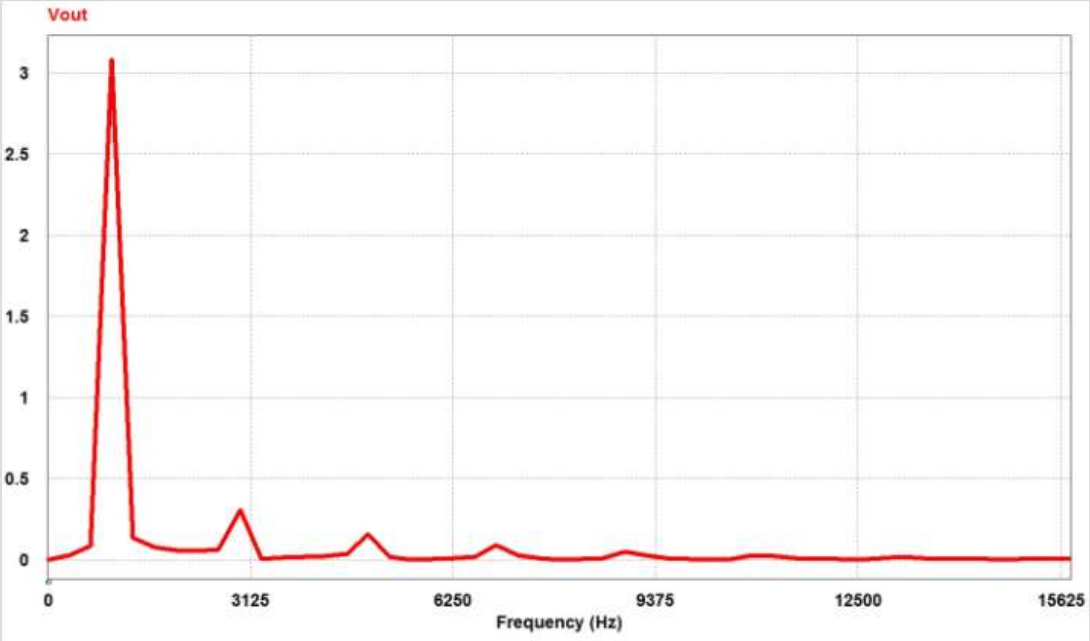
Power Quality Considerations

Harmonics



Harmonic	Amplitude (V)
1	3.100
3	0.308
5	0.159
7	0.090
9	0.0487
11	0.0253
13	0.0164
15	0.010

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} V_{n\_rms}^2}}{V_{fund\_rms}}$$

$$THD = \frac{\sqrt{0.308^2 + 0.159^2 + 0.090^2 + 0.0487^2 + 0.0253^2 + 0.0164^2 + 0.010^2}}{3.08} = 11.8\%$$

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Power Quality Considerations

IEEE 519-2014 – Harmonic Current

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

Total Demand Distortion (TDD)

[a]Even harmonics are limited to 25% of the odd harmonic limits above.

[b]Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

[c]All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.

where

I_{sc} = maximum short-circuit current at PCC

I_L = maximum demand load current (fundamental frequency component) at the PCC under normal load operating conditions

IEEE 519-2014 Table 2

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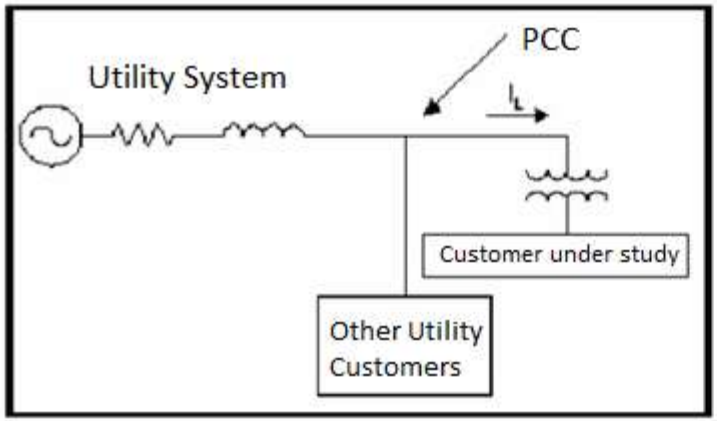
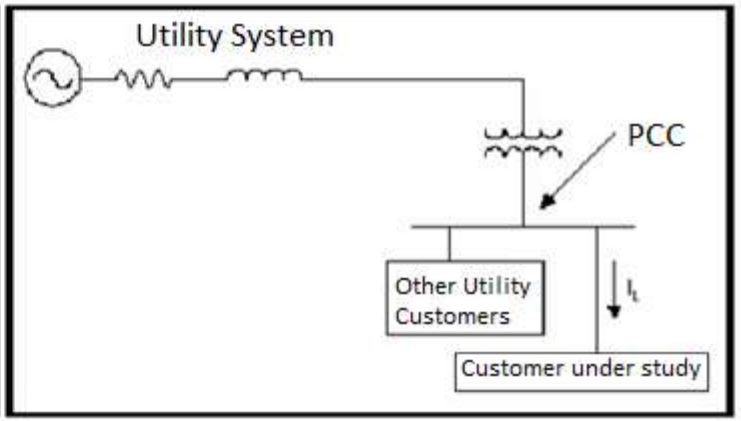
Power Quality Considerations

IEEE 519-2014

- Updated to better define the PCC (Point of Common Coupling)



Industrial users



Commercial users

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Lessons Learned

Lessons Learned

Utility

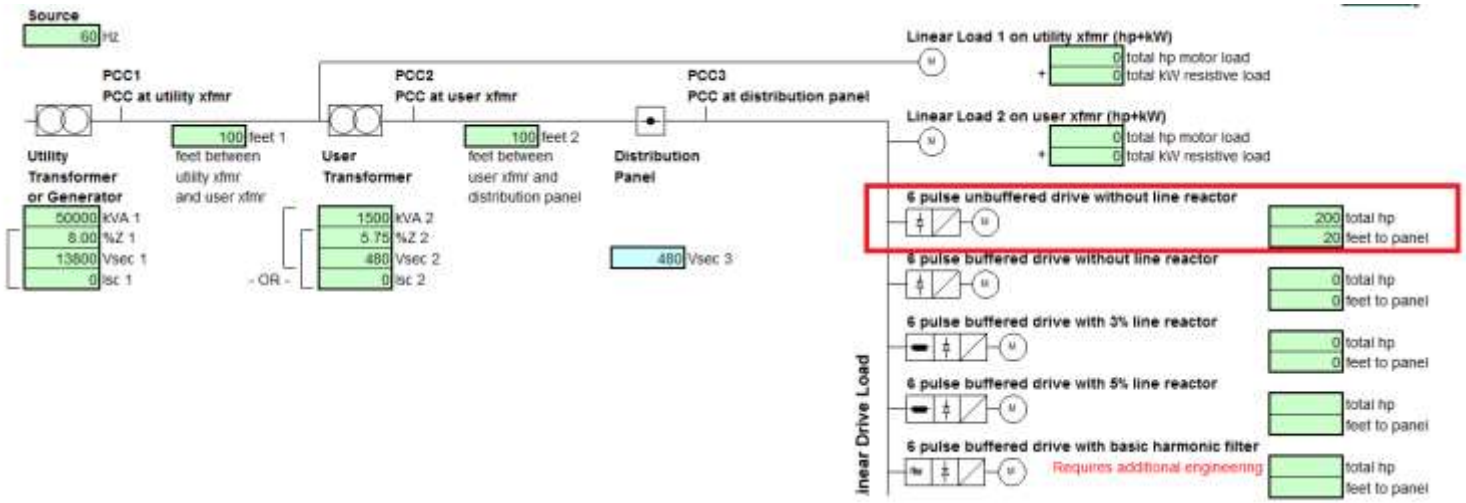
VFD

Motor

Lessons Learned

Voltage/Current Harmonics

- Basic Rockwell Automation Harmonic Calculator



Results [1]				IEEE compliance [2]			IEC
PCC location	Voltage THD, %	Current TDD, %	Isc/Iload	special	general	dedicated	compliance
PCC1	0.1	77.8	3571.5	NO	NO	NO	NO
PCC2	3.4	77.8	149.1	NO	NO	NO	NO
PCC3	4.9	77.8	102.4	NO	NO	NO	NO

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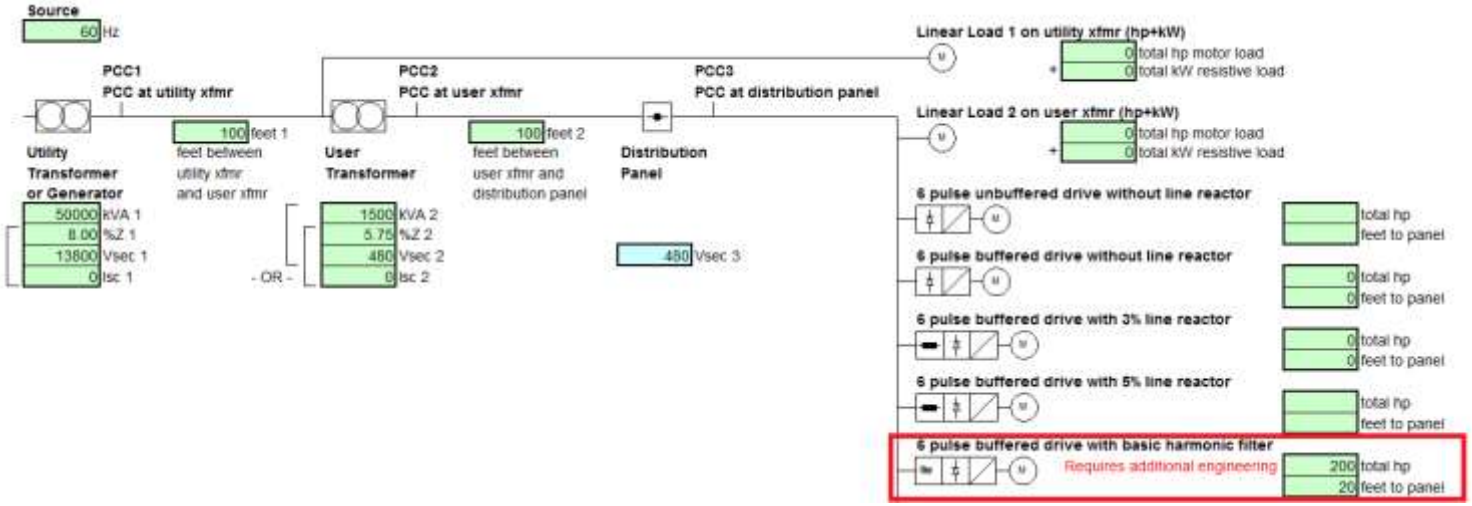
Lessons Learned

Voltage/Current Harmonics

- Basic Rockwell Automation Harmonic Calculator



Results [1]				IEEE compliance [2]			IEC
PCC location	Voltage THD, %	Current TDD, %	Isc/Iload	special	general	dedicated	compliance
PCC1	0.0	6.7	3383.0	YES	YES	YES	YES
PCC2	0.4	6.7	141.2	YES	YES	YES	YES
PCC3	0.6	6.7	97.0	YES	YES	YES	YES

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Lessons Learned

Filters (initial considerations)

- Size and space
- Cost

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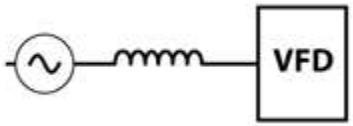
Lessons Learned

AC line reactor



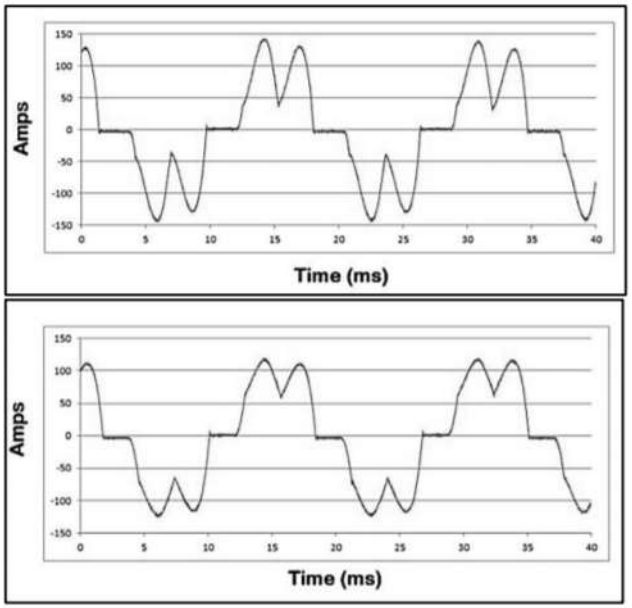


Figure 1: Line current waveforms without (top) and with (bottom) line reactor

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Lessons Learned

AC line reactor

- Not too big
- Not too costly
- Will use some energy
- May not be enough to meet IEEE-519

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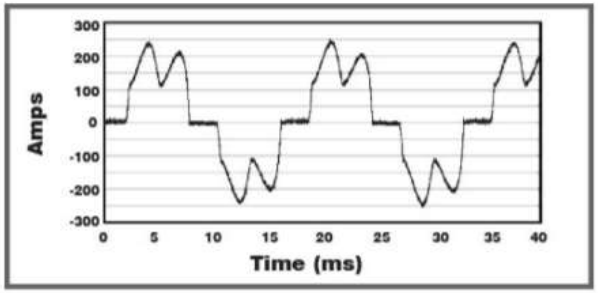
Lessons Learned

Passive Harmonic Filter



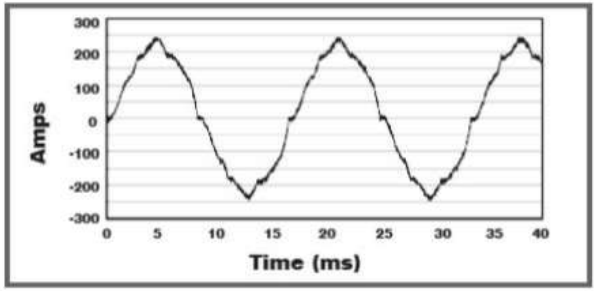


Figure 2: Line current waveforms without (top) and with a TCI HGP.

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Lessons Learned

Passive harmonic filter

- Bigger
- Costlier
- Has capacitors (switch out on generator)
- Often matched to motor size

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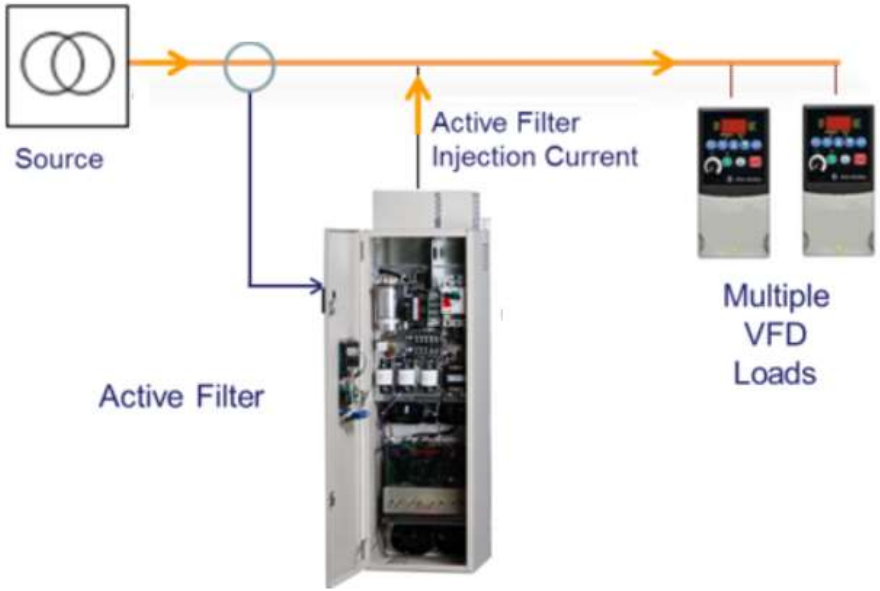
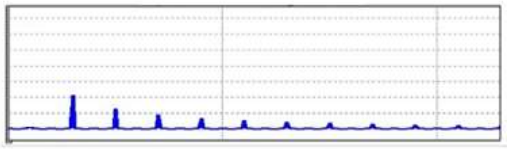
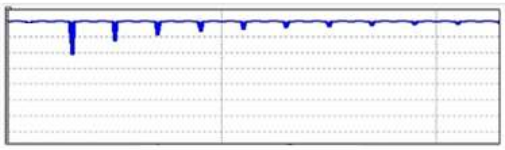
Lessons Learned

Active Harmonic Filter





Harmonics created by system



Harmonics injected by active filter

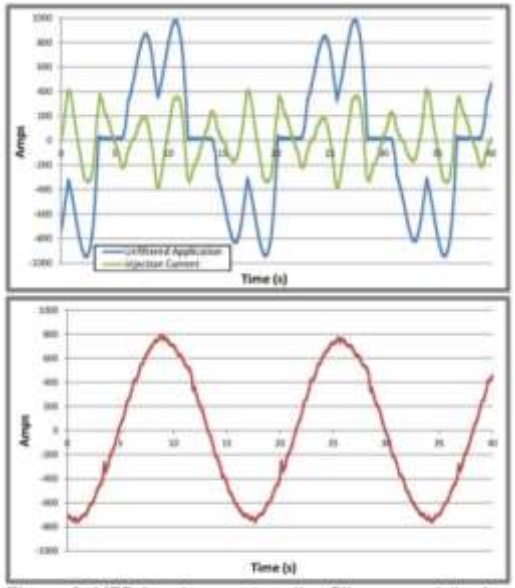


Figure 3: VFD input current, active filter current (top) and resulting line current (bottom) using a TCI HGA

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Lessons Learned

Passive harmonic filter

- Bigger
- Costliest
- Has capacitors (switch out on generator)
- Often tied to a system bus
- Heating and ventilation

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Lessons Learned

6,12,(18),24 Pulse

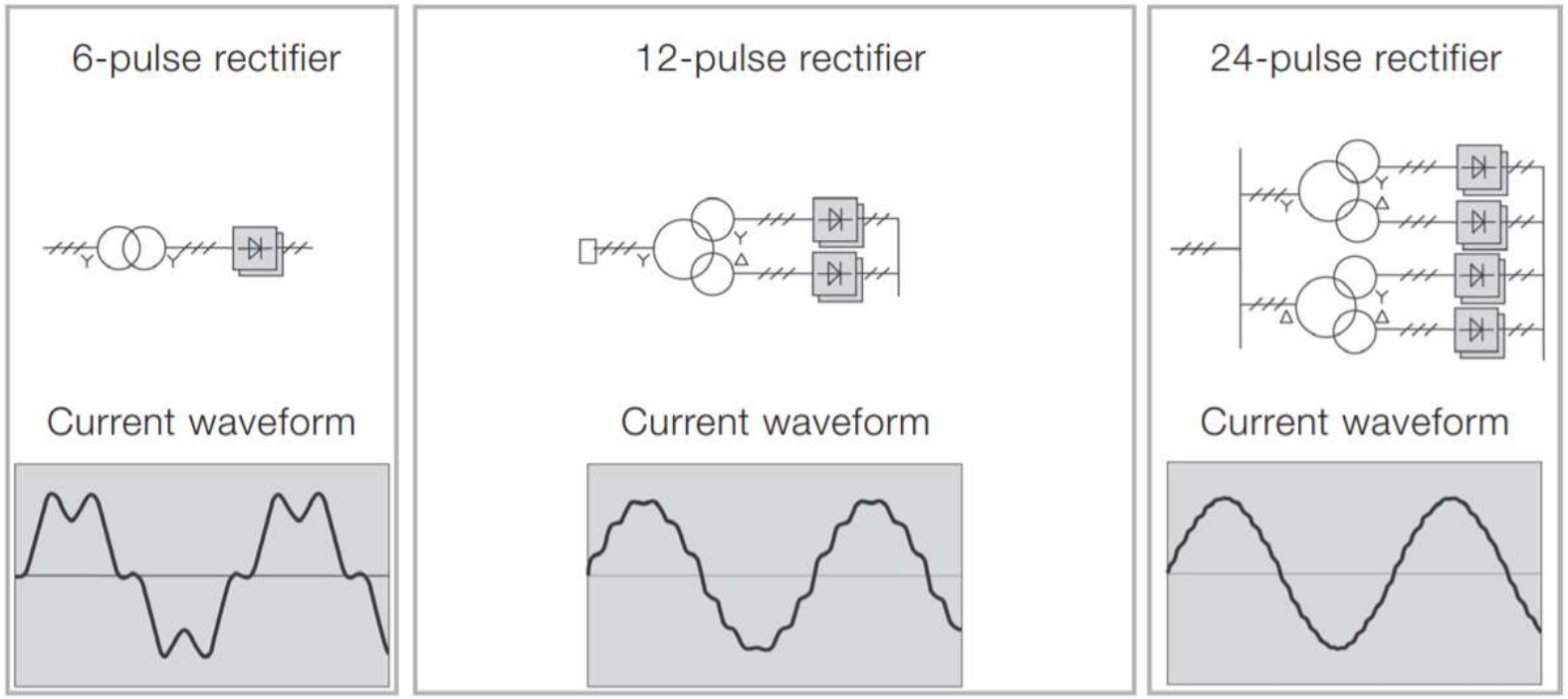

ABB “Guide to harmonics with AC drives”

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Lessons Learned

Greater than 6 pulse drives

- Expensive
- Will replacement be the same?

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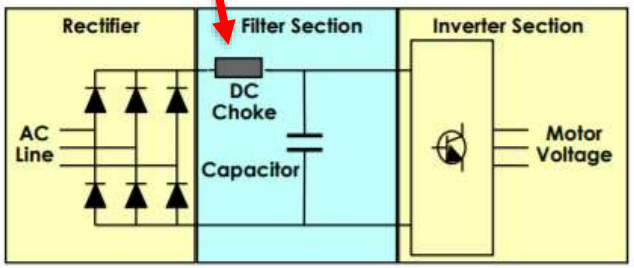
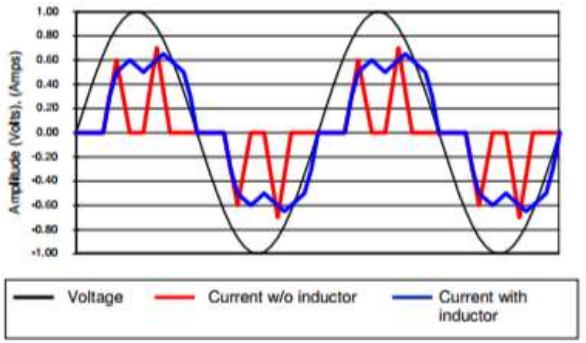
Lessons Learned

DC Choke





ABB

ABB

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Lessons Learned

Utility

VFD

Motor

Lessons Learned

Motors for use on VFD’s

“Inverter Duty Rated” vs. “Inverter-Ready”

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Lessons Learned

“Inverter-Ready” or “Inverter-Friendly”

- Inverter Ready is a marketing term.
- General-purpose and maybe suitable for use with variable torque loads.

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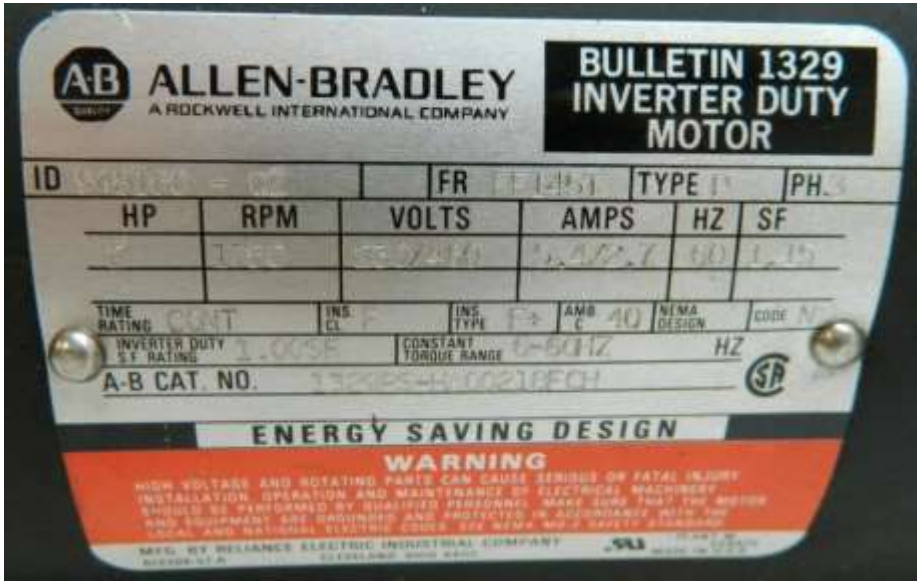
Lessons Learned

Inverter Duty Rated

- $$$
- Manufactured for VFD application following "NEMA MG 1 Section IV, Performance Standards Applying to All Machines, Part 31, Definite Purpose Inverter-Fed Polyphase Motors."



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Lessons Learned

“Inverter Duty Rated” vs. “Inverter-Ready”

- Example of costs:
  - 30 Hp motor went from $3,900 to $6,600 (1.7 times as much)
  - 50 Hp motor went from $10,200 to $17,800 (1.7 times as much)
- Consideration in retrofits

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Lessons Learned

Pitting and fluting: Insulation and alternate discharge paths

- Insulation
  - Insulated bearings
  - Ceramic bearings
- Alternate discharge
  - Conductive grease
  - Shaft grounding device
  - Bearing protection ring

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Lessons Learned

Insulation

- Insulated Bearings

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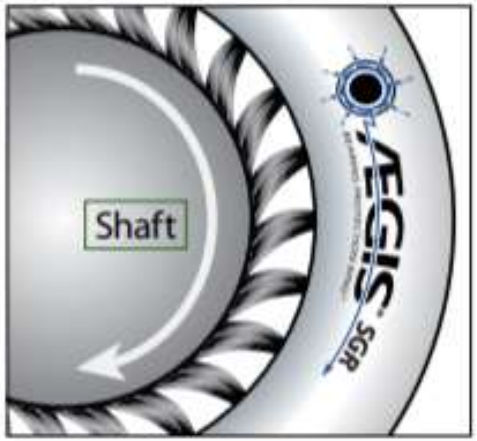
Lessons Learned

Alternate discharge paths

- Shaft Grounding Device
- 50 Hp: $500 - $900 200 Hp: $800 - $1400

AEGIS™ SGR uKIT



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Lessons Learned

Pitting and fluting

- Listen to your motors
- Units can be retrofitted

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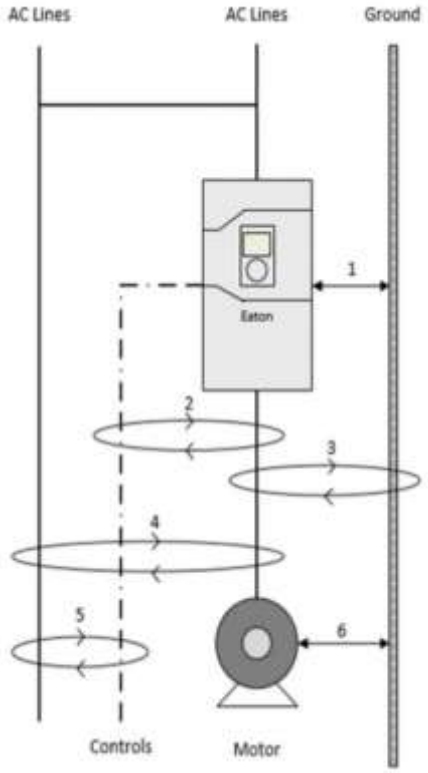
Lessons Learned

Picking a VFD cable to motor



Eaton “VFD Wiring Best Practices 2014”

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Lessons Learned

Conduit for VFD cable to motor

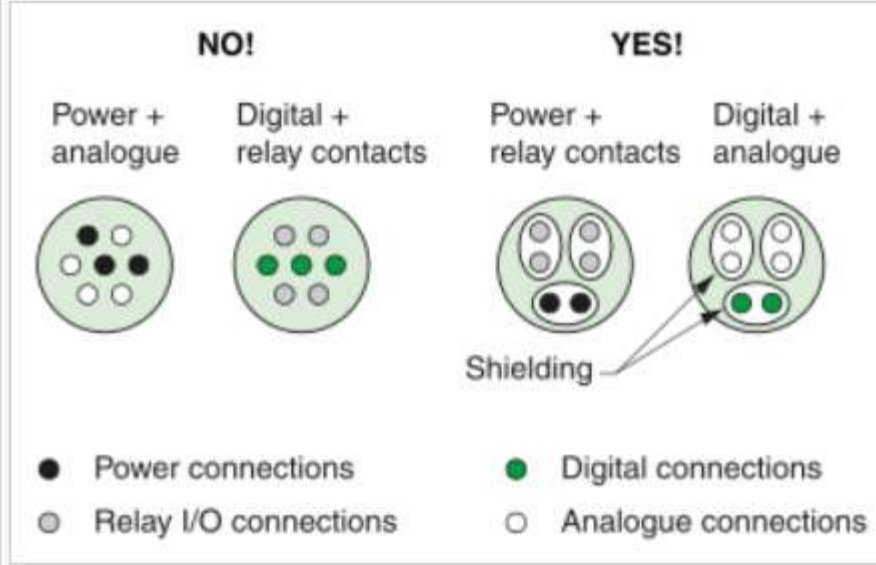

***Fig. R40**: Incompatible signals = different cables*

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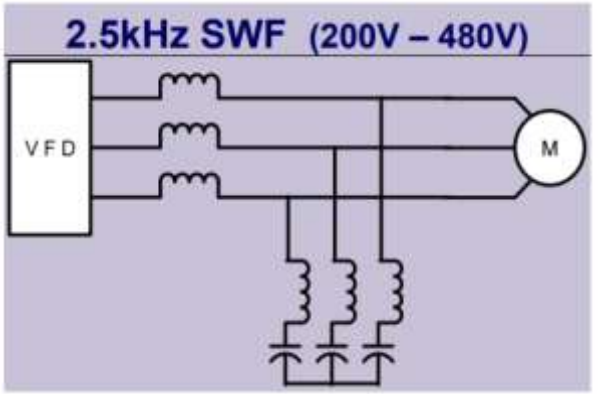
Lessons Learned

Sine/Reflected Wave Filter



When to use?

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Lessons Learned

What fits your application?

Contactor ? Soft Starter ? VFD

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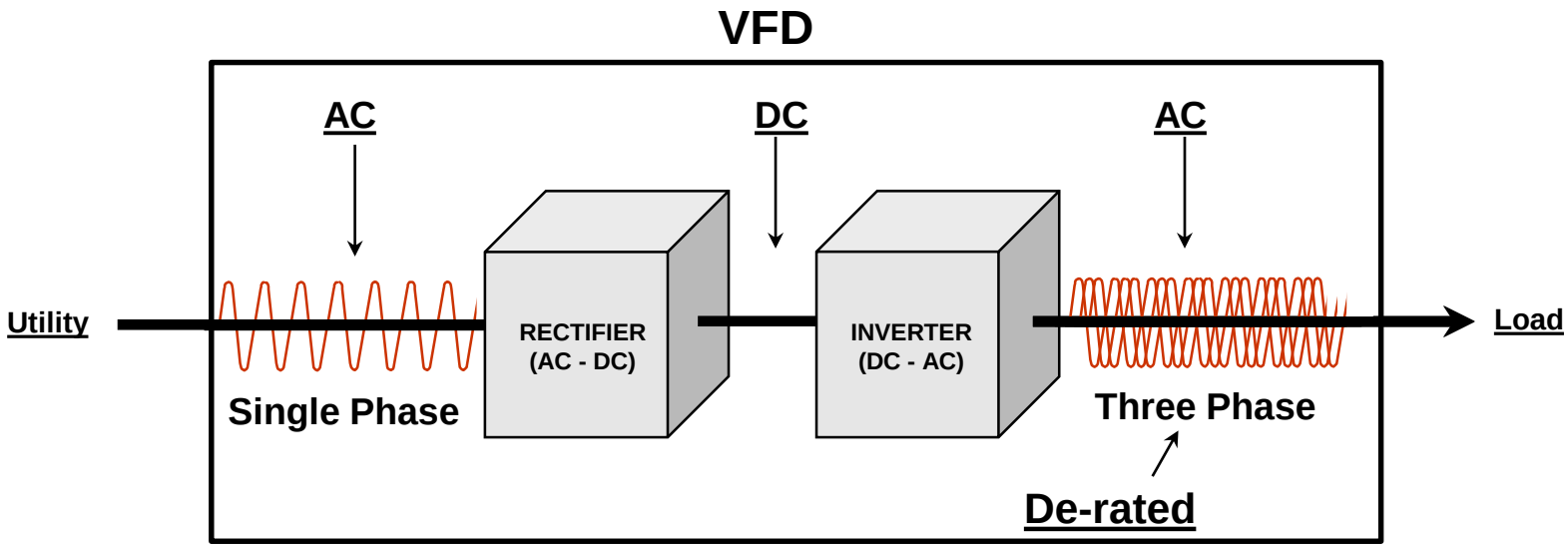
Lessons Learned

VFD's can go from single phase to three phase.



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Lessons Learned

VFD applications

- Phase conversion for larger horsepower (de-rate)
- Normal operation under demand factor
- Standardization for common spares
- Reduce generator size
- Integral software for PID control
- Energy rebates from utilities

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Lessons Learned

VFD drawbacks

- Engineering costs
- Equipment life
- Programming costs
- Complexity
- Motor cooling
  - Ramp times
  - Cooling periods
  - Be careful adjusting after installation

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Lessons Learned

VFD Heating and Cooling

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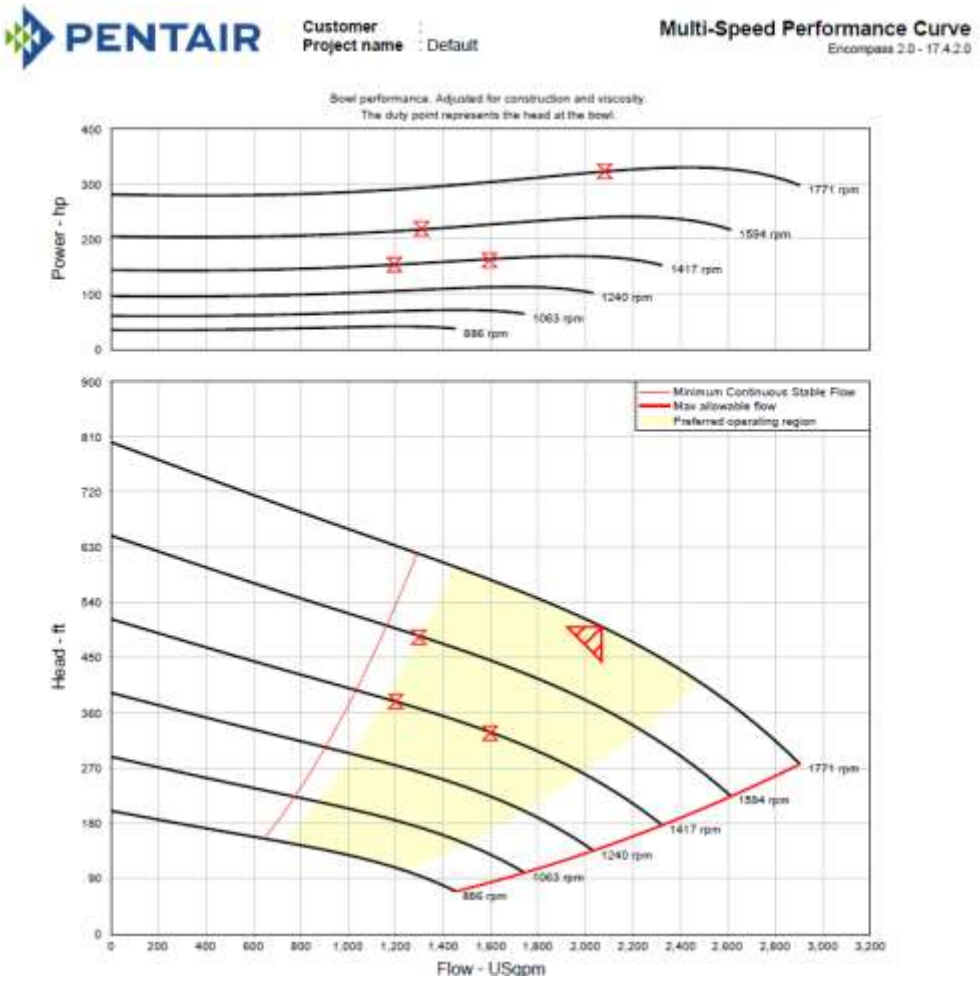
How VFD's Impact Motors

Variable Speed Pump Curves



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Lessons Learned

Pumping stations

- Sizing VFD for future load growth
- Multiple motors on single VFD

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Conclusion

Equipment with Installation cost based on RSMeans 2017

HP	Cost
5	$ 2,675.00
7.5	$ 2,900.00
10	$ 3,100.00
15	$ 4,175.00
20	$ 5,225.00
25	$ 6,550.00
30	$ 7,000.00
40	$ 7,825.00
50	$ 11,200.00
60	$ 13,700.00
75	$ 15,400.00
100	$ 17,400.00
125	$ 18,500.00
150	$ 21,800.00
200	$ 28,200.00

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Thank You!

Questions?