Best Practices for Electrical Power Quality

Power Quality Tutorial # PQ-116

DSPS Course # 962316

Professional Development = 1 hour

Power Quality Specialists

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Today's Program

Best Power Quality Practices for …

1) AC Motors
2) AC Motor Drives (VFDs)
3) Voltage Disturbances
4) Transients
5) LED lighting
6) Renewable Energy Sources

For a deeper dive into these subjects, please see our seminar list on last slide.

1) Best PQ Practices for AC Motors

- Maintain balanced voltages (<1% unbalance)
- Maintain voltage distortion below 2% THD-v
- Improve Power Factor (PF) to ≥ 95%
- Use soft starter to reduce inrush current
  - Minimize voltage sags
  - New harmonic source – delay PF capacitor energization
  - Use only “detuned” PF capacitors as needed
- Use VFD to eliminate inrush current (slow accel time)
  - Minimize voltage sags
  - Improves DPF to nearly 1.00 (100%)
  - New harmonic source – add 5% Z reactor or harmonic filter

Effects of Unbalanced Voltage on Motors

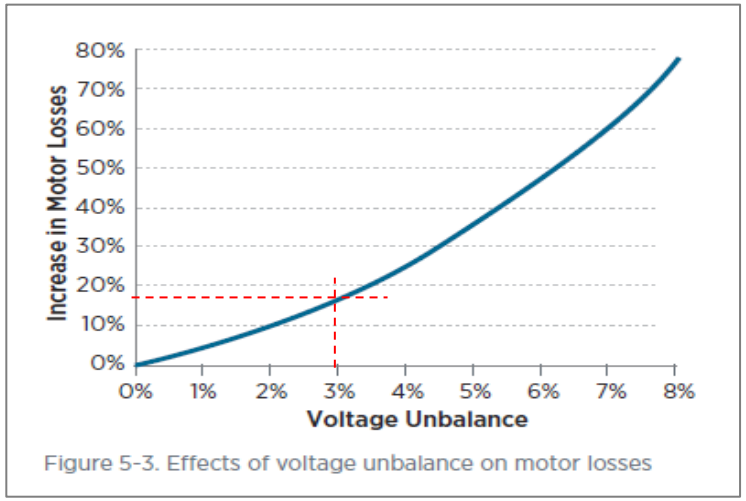
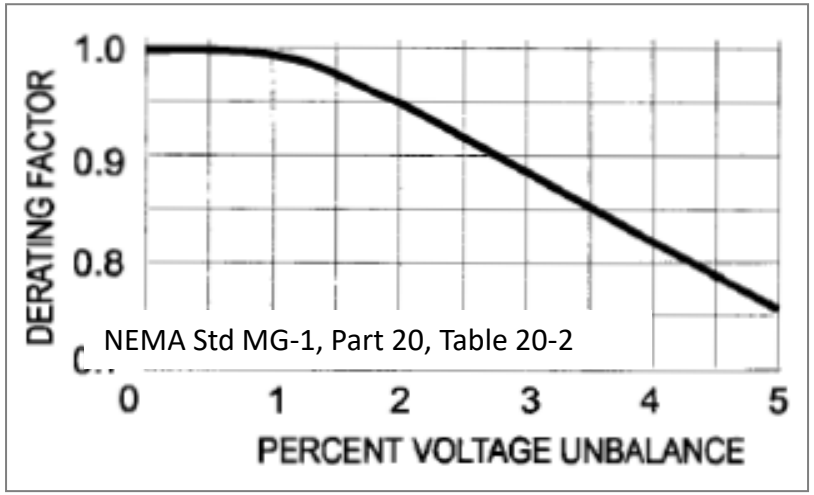


Figure 5-3. Effects of voltage unbalance on motor losses



NEMA Std MG-1, Part 20, Table 20-2

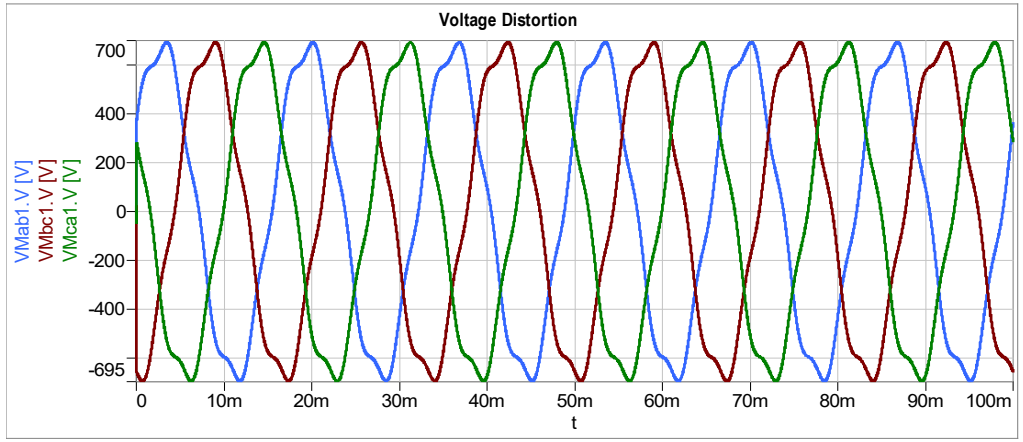
Table 5-3. Motor Performance with an Unbalanced Utilization Voltage

% Voltage Unbalance	Winding Temp °C	I²R Losses (% of Total)	Efficiency Reduction, %	Expected Winding Life, years
0	120	30	--	20
1	130	33	Up to ½%	10
2	140	35	1 to 2%	5
3	150	38	2 to 3%	2.5
4	160	40	3 to 4%	1.25
5	180	45	5% or more	Less than 1

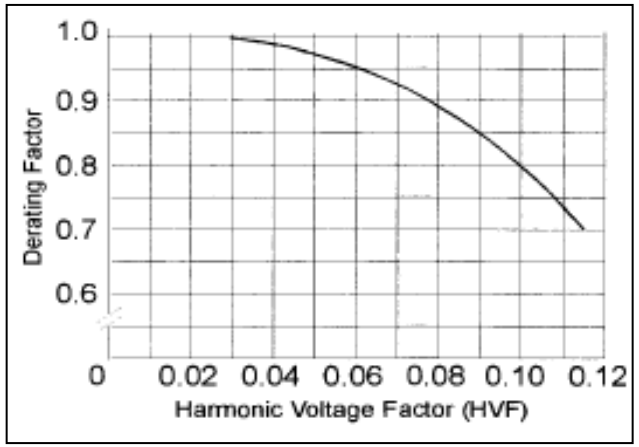
Table 5-3, Premium Efficiency Motor Selection and Application Guide (U.S. DOE)

Motor De-rating due to Voltage Distortion

5% THD-v



Motor De-rating Curve (THD-v)



Note: 700 V_{pk}, whereas Normal V_{pk} = 480 x 1.414 = 679 V

Characteristics of harmonic voltage distortion

1) Causes harmonic current to flow into all loads
2) Distortion often appears at the peak of the waveform
3) Peak voltage increases with little change to RMS voltage
4) Excessive peak voltage leads to premature dielectric failures

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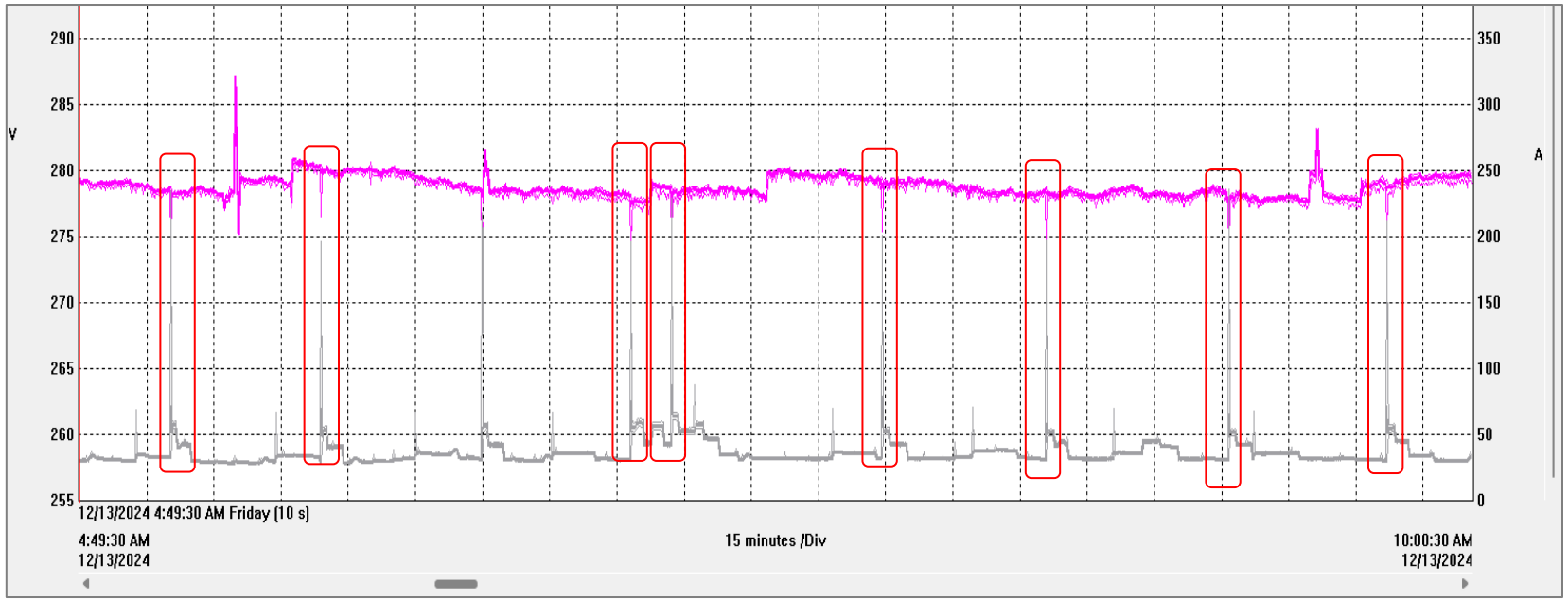
Control Motor Inrush Current

- #1 cause for voltage sags
- May shut down equipment
- May cause loss of voltage peak
- May activate UPS transfer to battery



Use soft starting methods to minimize inrush current.

1.1) Best PQ Practices for Power Factor

Maintain Displacement Power Factor (DPF) at ≥ 95%

- Add PF capacitors as needed
- Fixed Capacitor (few motors)
- Automatic PFC system (many motors)
- Use “detuned” PFC to protect capacitors from harmonics

NOTE: VFDs improve DPF to nearly 1.00 (100%)

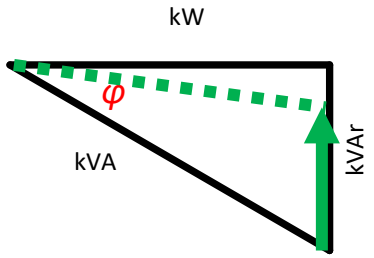
- But… High harmonic source:
  - add 5% Z reactor to reduce harmonic distortion
  - Add harmonic filter to reduce harmonic distortion
- and… low Total PF (PF)

$$PF = \frac{kW}{kVA}$$

$$PF = Cos\ \varphi$$

Improve Power Factor

Reduces Current & kVA



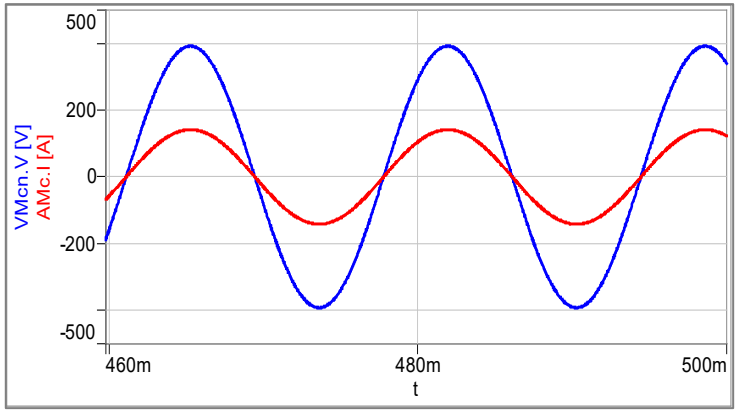
Benefits of High Power Factor (PF):

- Lower current
- Less kVA (demand)
- Minimize voltage sags
- Uses less transformer capacity
- Lower I^2R losses in conductors
- May reduce cost of electricity

PF Capacitor

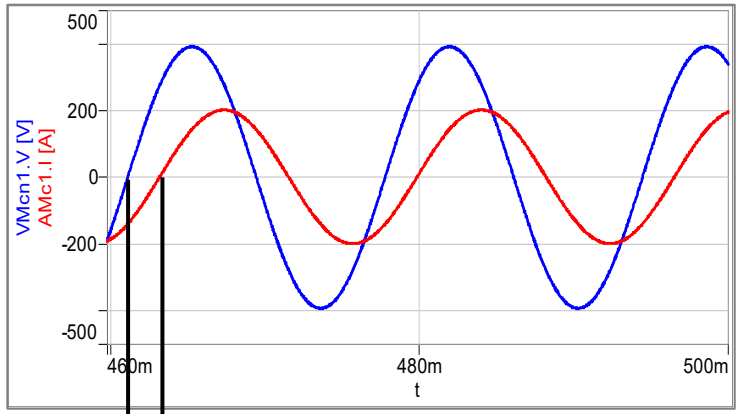
- Cancels kVARs
- Reduces kVA
- Reduces amps

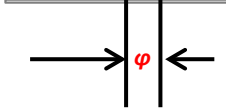
100% PF – With PF capacitor



Amps are 100 Arms

Low PF: AC motor





45°

Amps are 141 Arms

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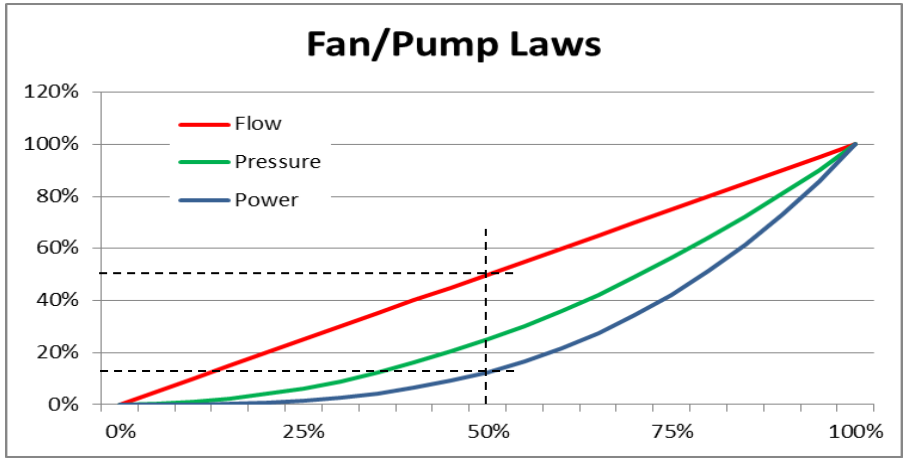
1.2) AC VFDs Benefits

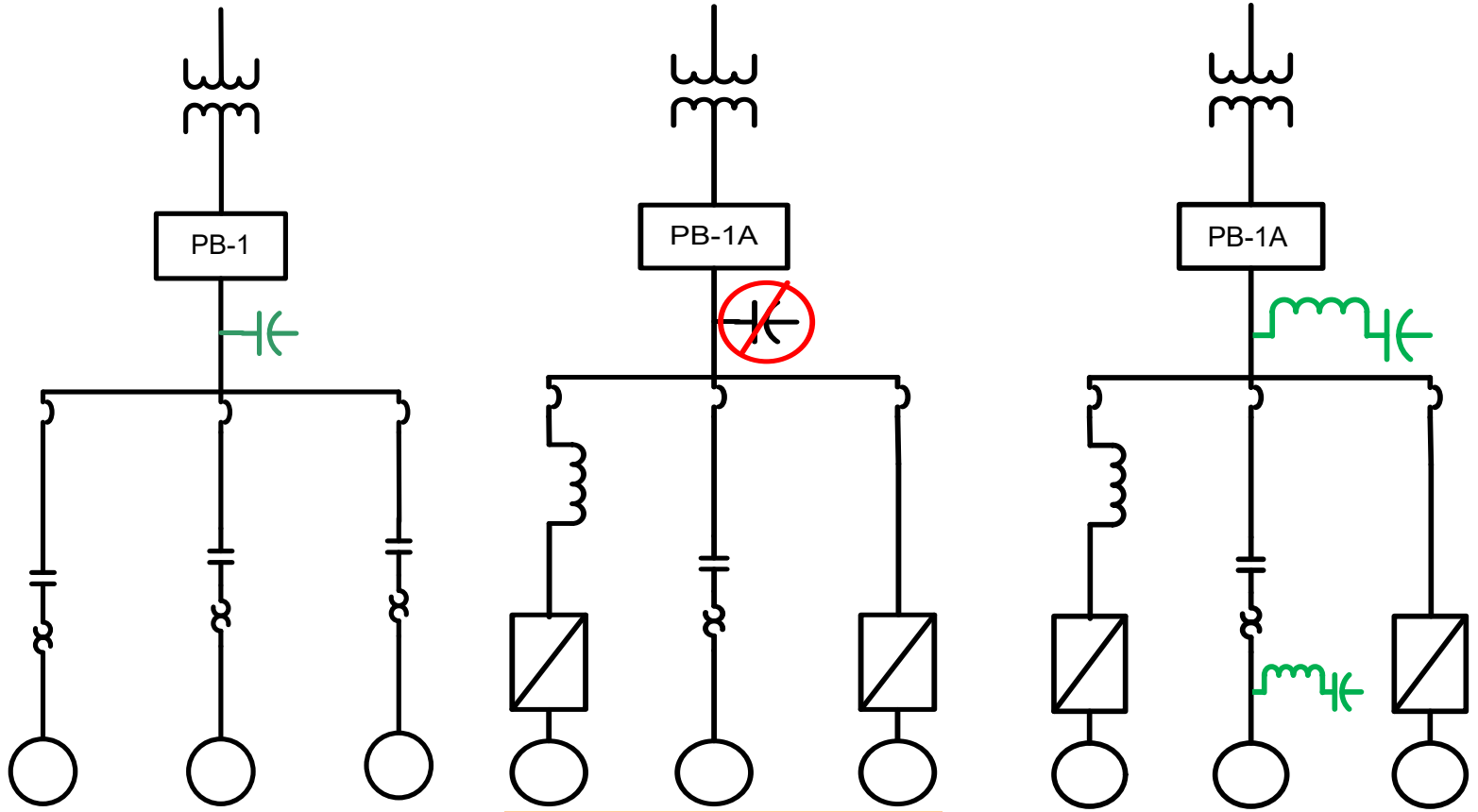
% Speed	% Flow	% Power
100%	100%	100%
90%	90%	73%
80%	80%	51%
70%	70%	34.3%
60%	60%	21.6%
50%	50%	12.5%



VFD Advantages	
Power usage reduces with motor speed (saves energy):	**Fans & pumps: Save energy at reduced speeds**
Acceleration rate can be controlled:	**Eliminates inrush current (sags)**
Input voltage and current are in phase with each other:	**Improves displacement PF of controlled motor**

Convert Motor Starters to AC VFDs

Original	Improper Retrofit	Proper Retrofit



Capacitors were used for PF improvement	VFD harmonics can damage PF capacitors	Less kVAR, Detuned PF Capacitors VFDs don't need PFC

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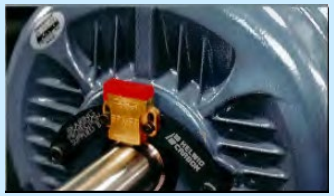
2) Best PQ Practices for AC VFDs

INPUT SIDE:

- Use 5% AC input line reactor
  - Reduces VFD harmonics (≤35% THDi at full load)
  - Solve DC bus OV tripping & protect input diodes

OUTPUT SIDE

- Use inverter duty motors
- Use 5% output load reactor: short cables
- Use sine wave filter: cables of any length
- Use motor bearing protection
  - Shaft grounding brush
  - Insulated bearings



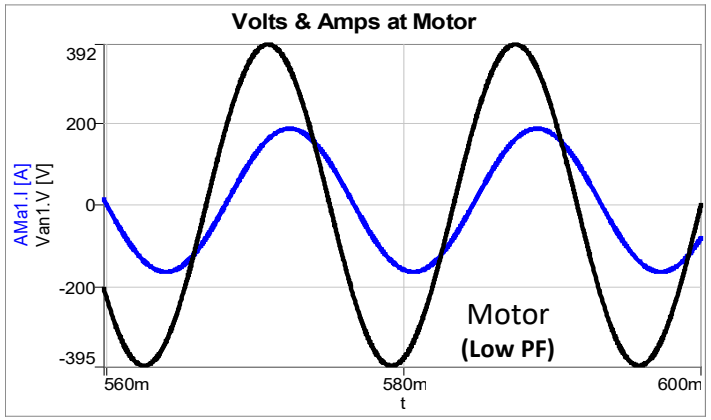
GENERAL

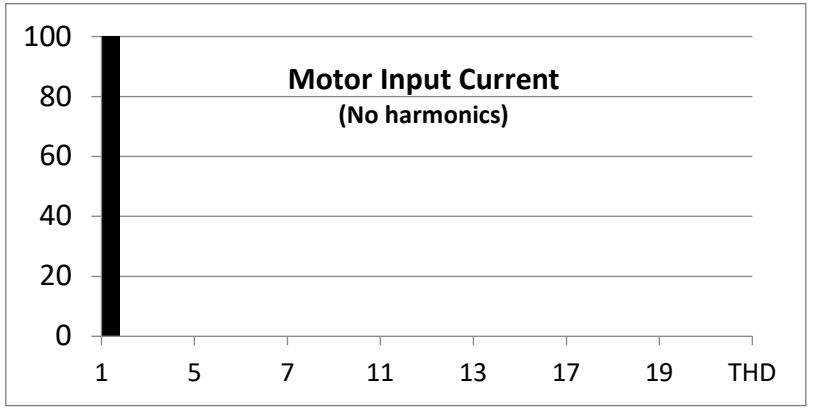
- Do not use capacitors for motor with VFD
- Use VFD cable for power wiring

For Fan & Pump Energy Savings, if possible:

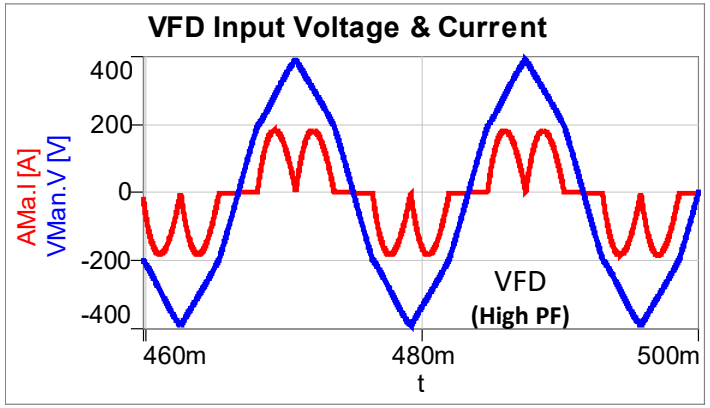
- Reduce fan/pump speed to save energy
- Set maximum speed (Hz) to 55 Hz or 57 Hz for savings

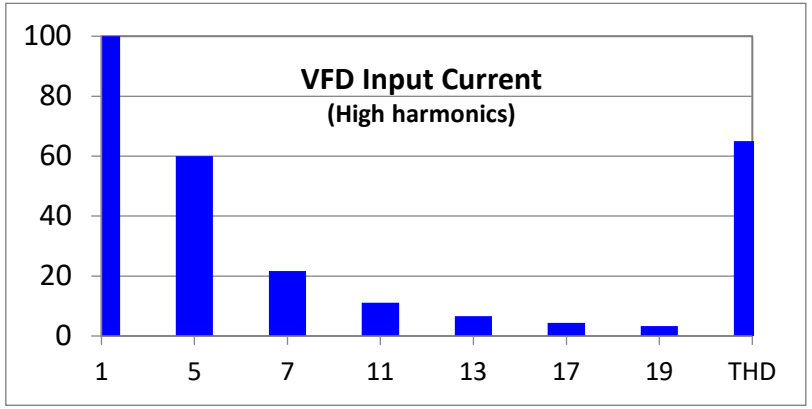
AC Motor Drive vs. Traditional Motor Control
Power Factor & Harmonics





5=300Hz; 7=420Hz; 11=660Hz; 13=780Hz; 17=1-2-Hz; 19=1140Hz





5=300Hz; 7=420Hz; 11=660Hz; 13=780Hz; 17=1-2-Hz; 19=1140Hz

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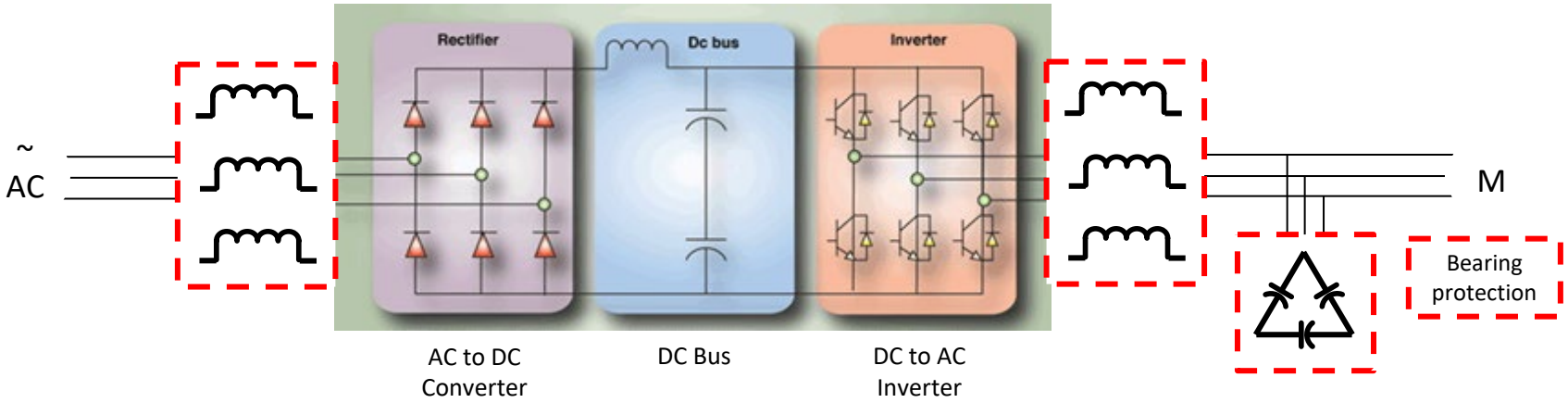
AC Motor Drives (VFDs)



Input Side	Function
5% Z AC Line Reactor	Reduces harmonic current to ≤ 35% THDi
	Minimizes OV nuisance tripping due to capacitor switching transients
	Protects input diodes

Output Side	Function
5% Z AC Line Reactor plus motor bearing protection	Protects motor at moderate lead length
Sine wave filter (SWF) Plus motor bearing Protection	Protects motor at long lead length

Lead Length	≤ 230 V	380-415 V	460 V	575 V	690 V	760 V
300 ft	5% Z	5% Z	5% Z	SWF	SWF	SWF
500 ft	5% Z	5% Z	SWF	SWF	SWF	SWF
1000 ft	SWF	SWF	SWF	SWF	SWF	SWF

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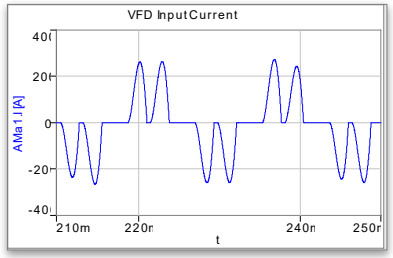
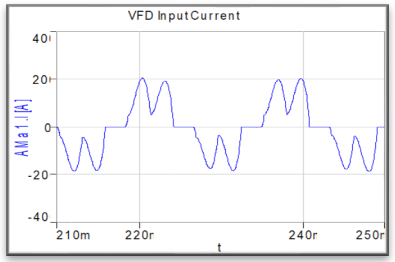
2.1) Best PQ Practices for Harmonics

- Maintain ≤ 2% THD-v; ≤ 5% THD-i
- Use low harmonic distortion motor drives (VFDs)
  - 12-pulse, 18-pulse, 24-pulse rectifier techniques
  - Active front end (AFE) converters
- Use passive harmonic filters
  - Series connected at input to individual drives
  - Parallel connected for system filtering (need PQ study)
- Use active harmonic filters
  - Parallel connected for system filtering
  - Add 3% line reactor to each drive

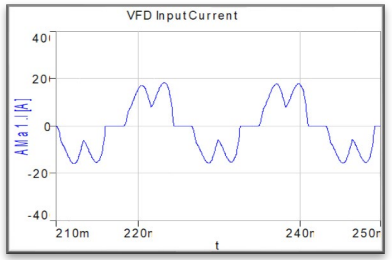
% Reactance vs %THD-i for Individual AC Motor Drives (VFDs)



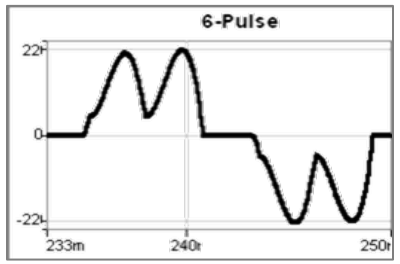
No reactor
~60 to 100% THD-i
5th, 7th, 11th, 13th, 17th, 19th



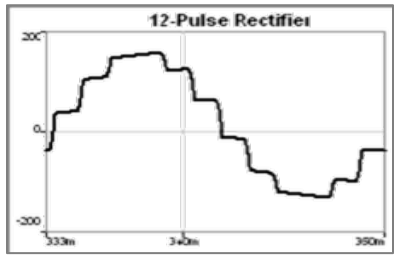
3% impedance
~45% THD-i
5th, 7th, 11th, 13th, 17th, 19th



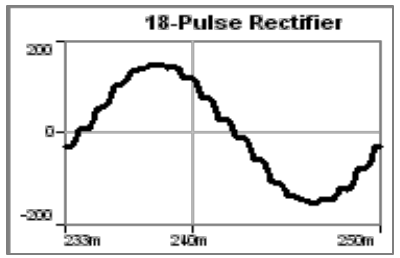
5% impedance
~35% THD-i
5th, 7th, 11th, 13th, 17th, 19th



6-pulse
~30% to 100% THD-i
5th, 7th, 11th, 13th, 17th, 19th



12-pulse
~12% to 15% THD-i
11th, 13th, 23rd, 25th



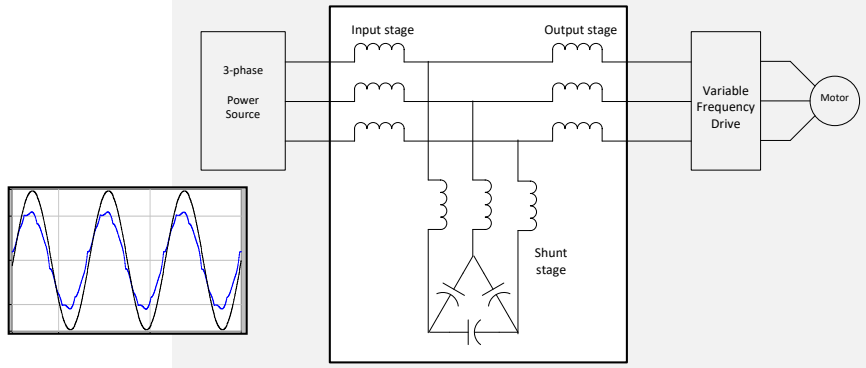
18-pulse
~5% to 6% THD-i
17th, 19th, 35th, 37th

≤ 5% THD-i

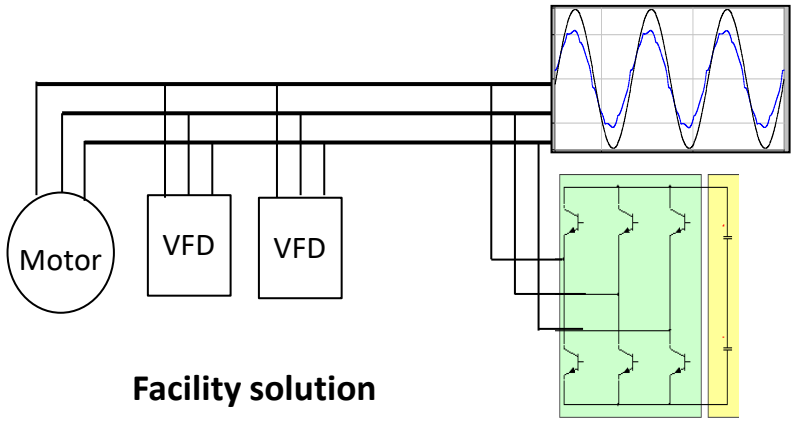
Low Distortion Harmonic Filters

Passive Harmonic Filter

- Inductors & capacitors
- Wide band harmonic filtering
- Apply for individual drives
- High PF near full load
- Select by VFD/motor FLA
- Reliable 5% TDD solution



VFD solution



Facility solution

Active Harmonic Filter

- Power semi-conductors
- Wide band harmonic filtering
- Or… filter specific harmonic(s)
- Bus connected for multiple loads
- Can maintain power factor near 1.0
- Select by total harmonic current
- Reliable 5% TDD solution

3) Best PQ Practices for Facility Voltage Disturbances

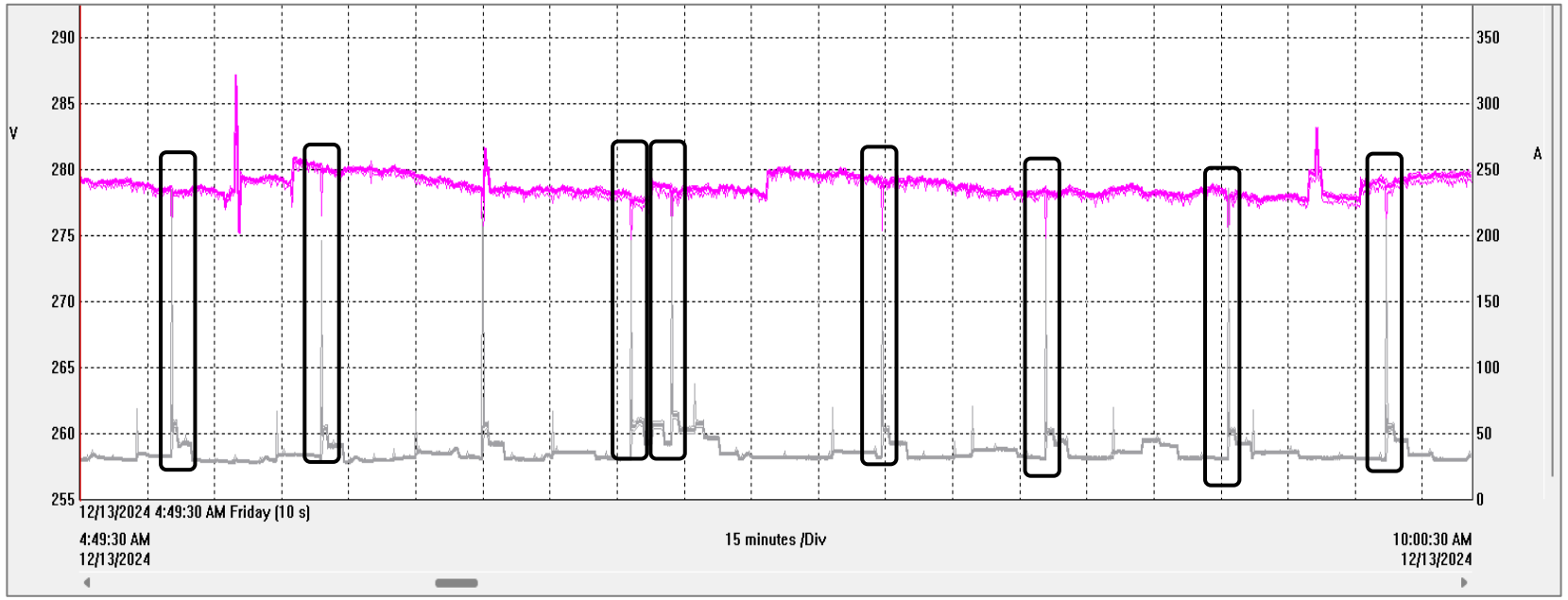
- Minimize motor starting inrush currents (sags)
  - Stagger start motors
  - Use motor soft-starters
  - Use VFDs (with slowed accel rate)
- Maintain ≥ 95% power factor (sags)
- Reduce load on transformer (sags)
- Remove excess PF capacitance (swells)

- Protect your sensitive or critical equipment with On-Line (double conversion) type UPS

Voltage Sags, Under-voltage, Swells, Over-voltage, Interruptions & Outages

Disturbance	Voltage	Duration
Sag	10% to 90% (RMS)	≤ 1 minute
Under-voltage	10% to 90% (RMS)	> 1 minute
Interruption	≤ 10% (RMS)	≤ 1 minute
Outage	≤ 10% (RMS)	> 1 minute
Swell	110% to 180% (RMS)	≤ 1 minute
Over-voltage	110% to 180% (RMS)	> 1 minute

Reduce Motor Inrush Current & Sags



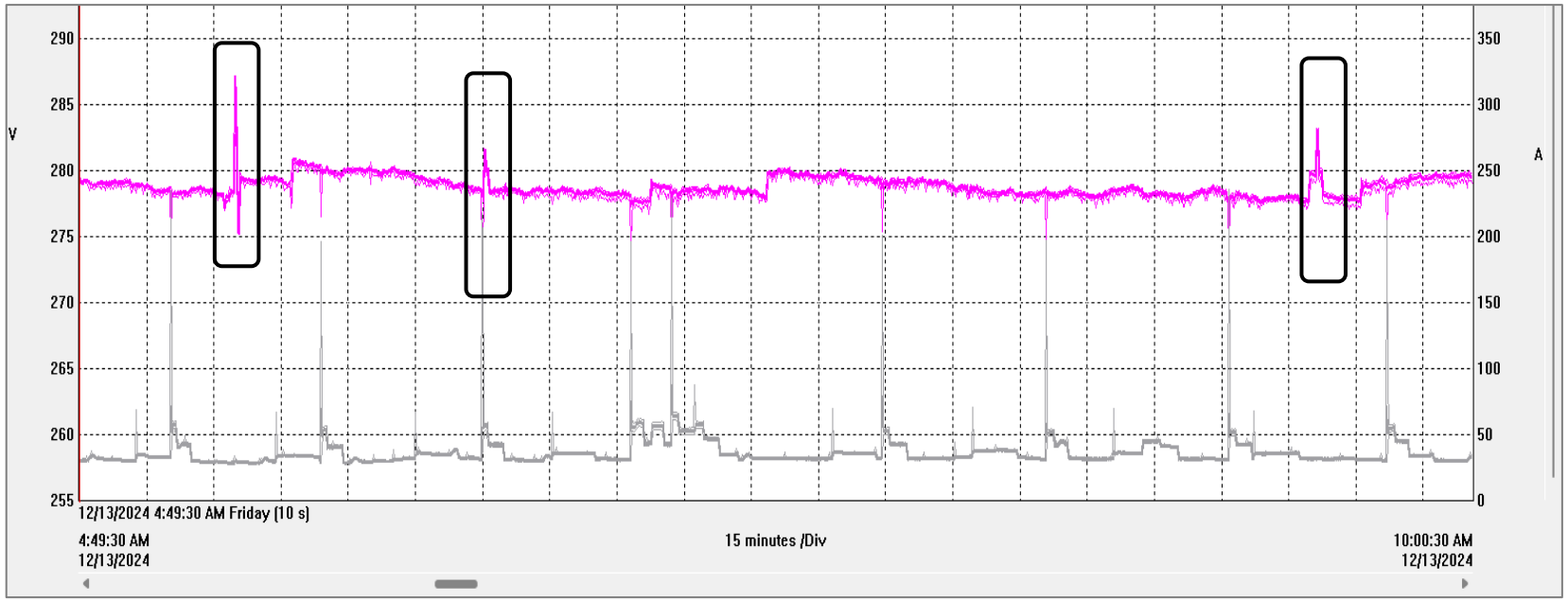
Methods to Reduce Motor Inrush Current

- Reduce transformer loading (kVA, RMS & peak current)
  - Peak current should be within transformer peak current rating
  - XFMR Peak current = XFMR rated RMS current x 1.414
- Use Soft-start or VFD for medium and large motors

Protect critical or sensitive equipment with On-line (double conversion) UPS.
Note: Select UPS based on load kVA and peak current.

Protect Equipment from Voltage Swells

Caused by Load Switching & Shedding events



Voltage swells often originate on utility system

Voltage swells can also be caused when you turn off large loads (i.e. motors)

Voltage swells can also be caused if you have excessive PF capacitance

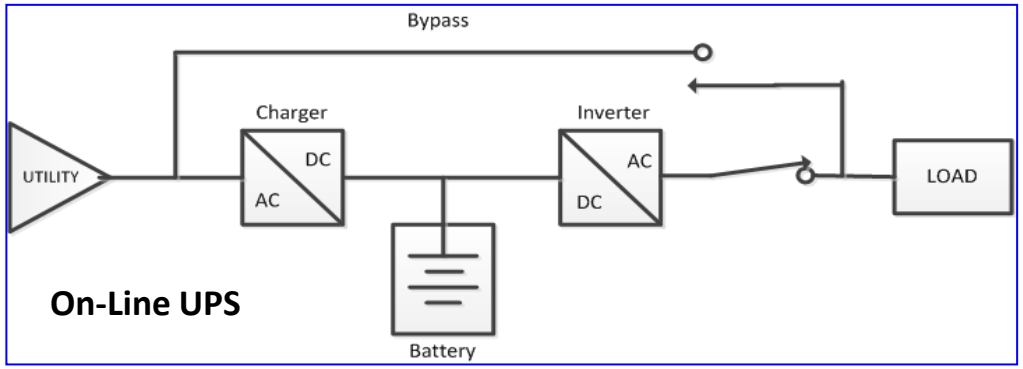
Protect critical or sensitive equipment with On-line (double conversion) UPS.
Note: Select UPS based on load kVA and peak current.

3.1) Best PQ Practices for UPS

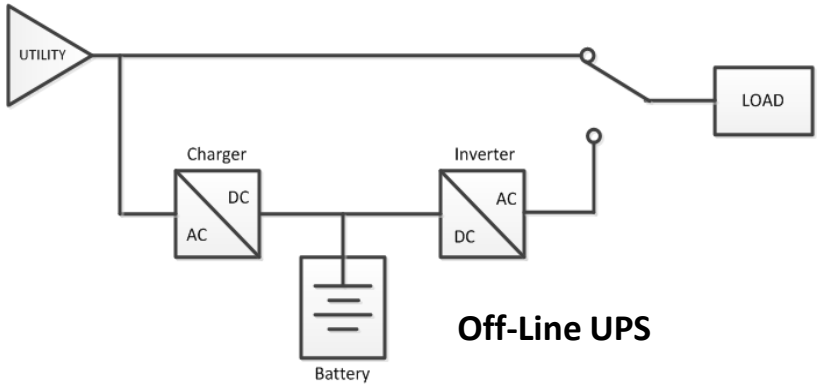
On-Line (Double conversion) UPS

- Load always powered thru UPS
- Seamless transition when utility power is lost
- Highest reliability

Use for critical or sensitive loads



On-Line UPS



Off-Line UPS

Off-Line UPS (most common)

- Load is powered from utility until utility power is lost
- NON-seamless transition when utility power is lost

Use for non-critical loads and loads not controlled by *u-processors*

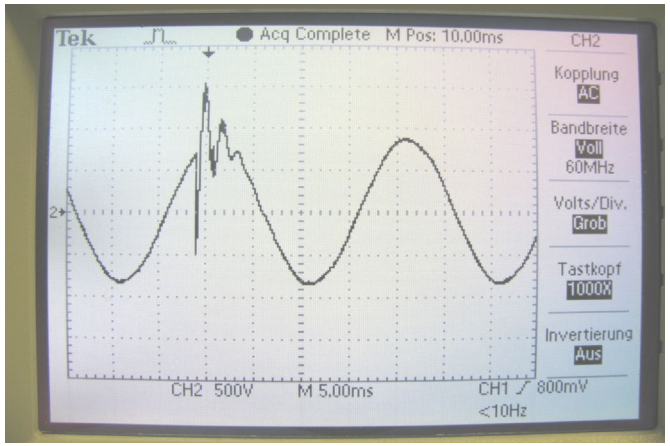
4) Best PQ Practices Transients

- Use lightning arrestor at service entrance
- Use TVSS at main panel and at downstream panels
  - Cascaded voltage and energy ratings
- Use 3% or 5% AC line reactor at each drive
  - Small drives are most susceptible to nuisance tripping
- Maintain proper low impedance ground
  - Multi strand conductor
  - Braided conductor
  - Grounding grid
  - Single point grounding

Best Practices for Transients Caused by PF Capacitor Switching

Utility capacitor switching transients are common

- **May cause up to 200% voltage impulse**
- **May cause up to 200% current surge**



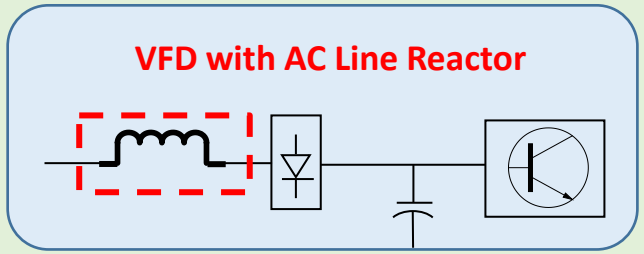
Capacitor switching transients often originate on utility system.

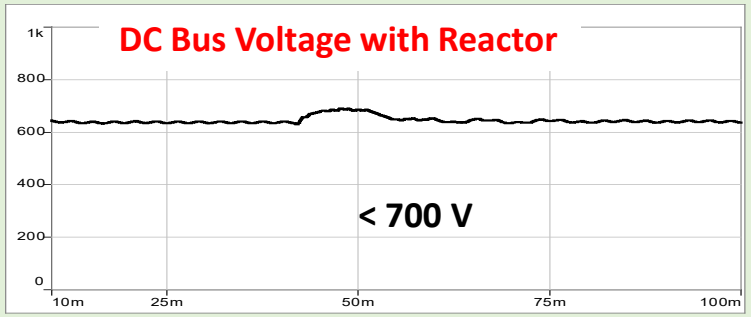
Transients may also be caused by YOUR PF capacitor switching.

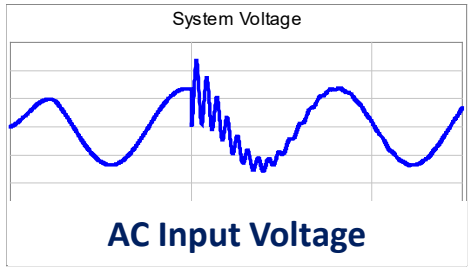
These transients can also be up to 2x peak voltage.

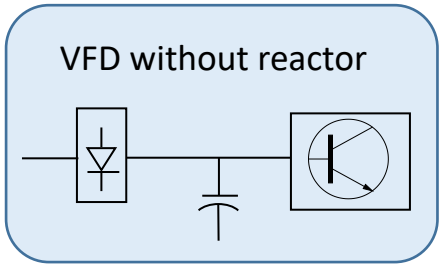
4.1) Capacitor Switching Transients

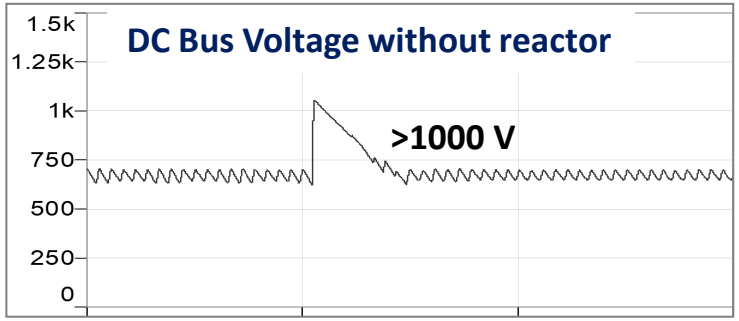
- **PREVENT: Use capacitor switching methods that minimize transients**
  - *Series reactor*
  - *Thyristor switches (zero cross)*
  - *Contactors w/ pre-insertion resistors*
- **SOLVE: Use 5% AC line reactor ahead of each VFD**





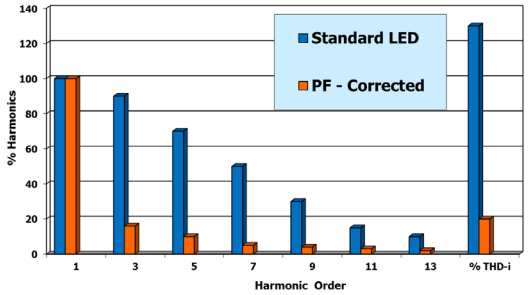






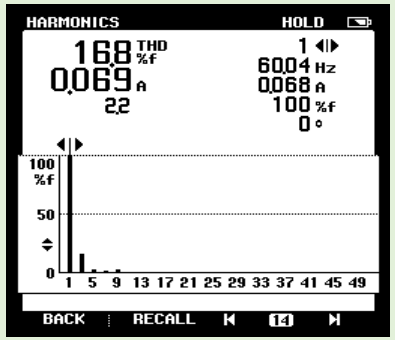
5) Best PQ Practices for LED lighting

- Review data sheets (PF, THD, max voltage) before making a selection
- Select PF Corrected (≥ 95%) lamps
  - lower harmonic distortion
  - higher total power factor
- Reduce pre-existing THD-v for max. lamp life
- Protect all Power Factor capacitors from harmonics
  - LED harmonics will add to previous THD levels
- Assure adequate lamp/driver ventilation
- Note: Elevated peak voltage will reduce lamp life
  - Reduce harmonic voltage distortion (THD-v)

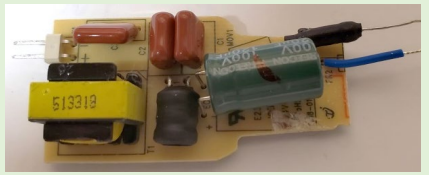


LED Lamp Harmonics

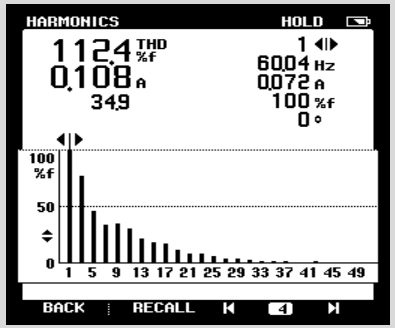
Can be 10% to 140% THD-i



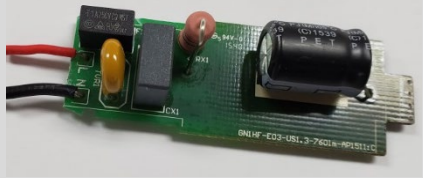
Low THD



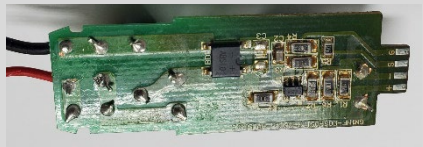
PF Corrected driver



High THD



Standard driver

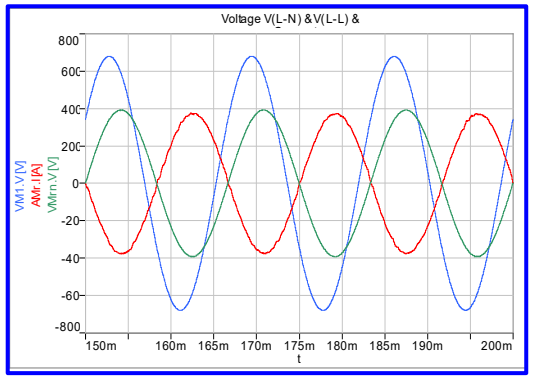


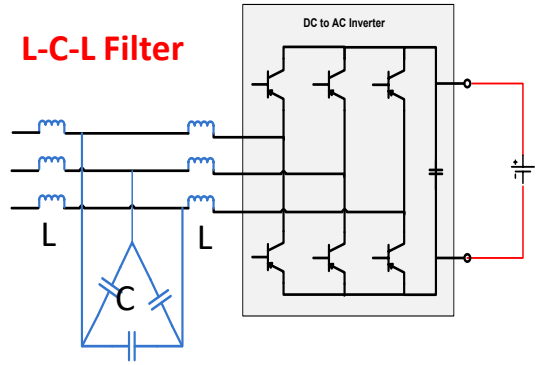
6) Best Practices for Renewable Energy Sources

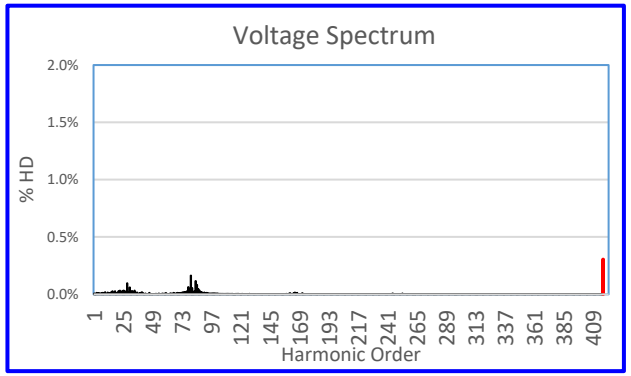
- **Select inverters with good filtering (<3% THD)**
  - L-C-L filters are generally best
  - But…can be cheapened by using lesser component values
- **Select inverters based upon load factors:**
  - Need to convert kW to kVA
  - Need to base kVA on peak current, PF, and %THD-i
- **R.E. inverters cause supra-harmonics**
  - May cause failures of small capacitors (EMI + PFC)
  - Higher switching frequency is generally lower THD
  - Higher switching frequency is easier to filter
- **Use shielded conductors (VFD cable) for power wiring**
- **R.E. inverters can reduce kW at your meter, but may also reduce your Power Factor**
  - Use over-size inverter programmed to inject leading kVARs
  - Use larger PFC system
  - Locate PFC power sensing above inverter connection

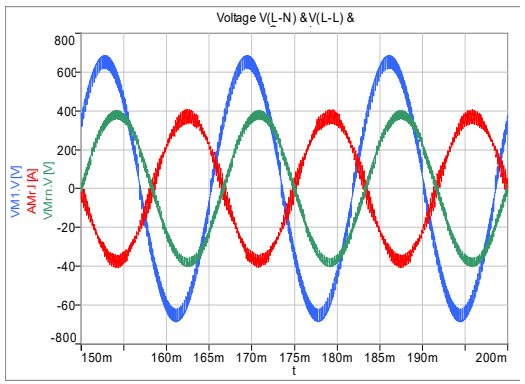
6.1) R.E. Inverter PQ Best Practices

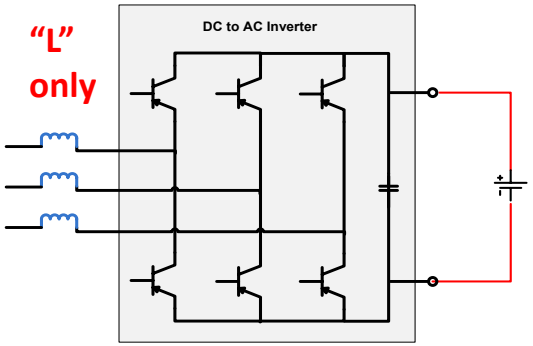
Select inverters with lowest Supra-harmonics
Use inverter with L-C-L filter

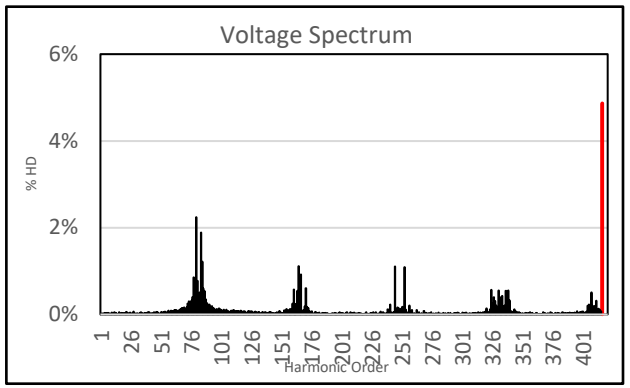












Power Quality Specialists

Educational Opportunities

Seminars Available	DSPS No.	DSPS Credit
Introduction to Power Quality	18431	4 hrs
Power Factor	17409	4 hrs
Fundamental of harmonics	17383	4 hrs
Harmonic Distortion & Solutions	20095	8 hrs
PQ for Motor Control Applications	18902	4 hrs
PQ for Energy Efficiency Retrofits	20980	4 hrs
Power Quality Troubleshooting	21617	4 hrs
PQ for Combined Utility & Renewable Power	22804	4 hrs
PQ for Energy Eff retrofits & Renewable Energy Systems	23154	4 hrs
Power Factor Short course	961898	2 hrs
PQ troubleshooting short course	961899	2 hrs
Best Practices for Electrical Power Quality	962316	1 hr

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