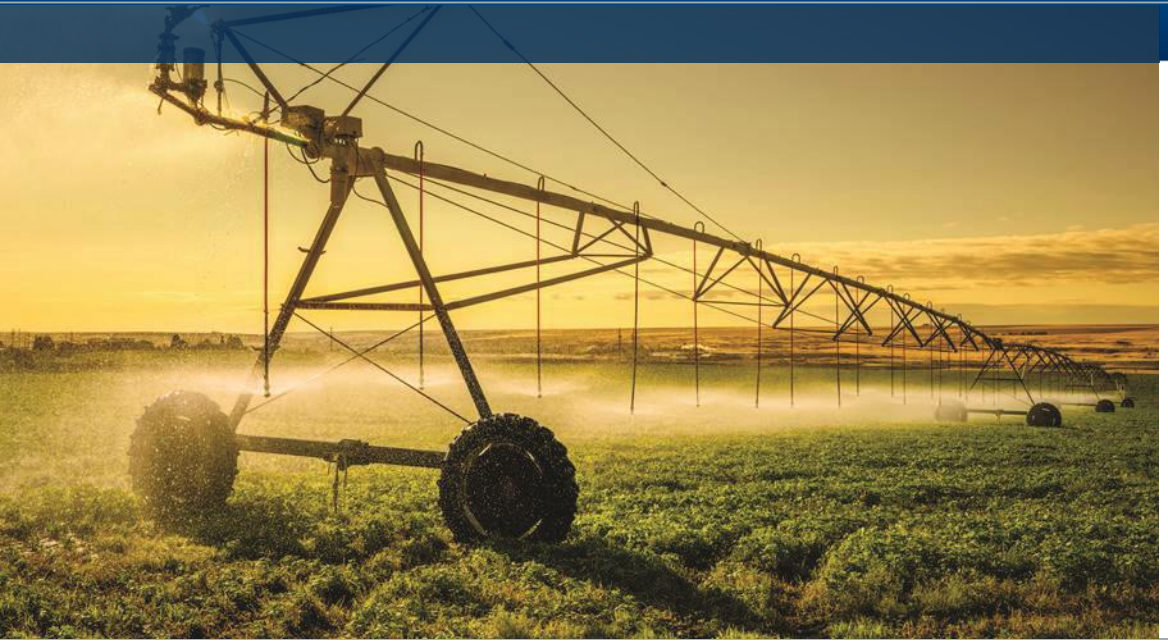
Harmonics - Effects on Pump Drive Applications

NGWA Ground Water Week 2023



IT'S PERSONAL

YASKAWA

Speaker Greg Weichman | **Date** December 05, 2023

PRESENTATION AGENDA

- What are Harmonics?
- Why are Harmonics a Concern?
- What causes Harmonics?
- IEEE 519
- Harmonic Solutions

What are HARMONICS?

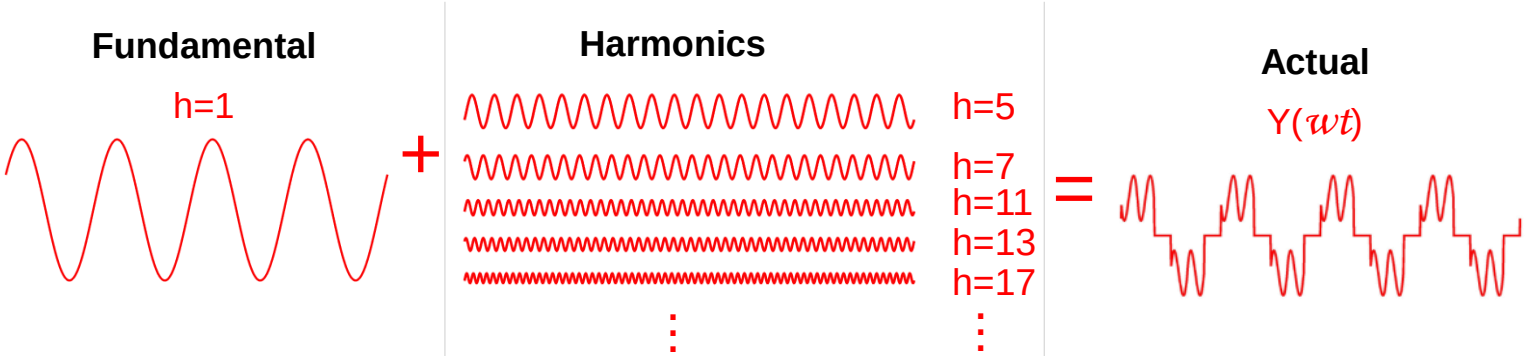
WHAT ARE HARMONICS?

Fourier Series

Any **periodic** waveform can be expressed as an infinite sum of sine waves in **integral** multiples called "**harmonics**".

$$Y(\omega t) = \sum_{h=1}^{\infty} \left[c_h \sin\left(h\omega t + \phi_h \right) \right]$$

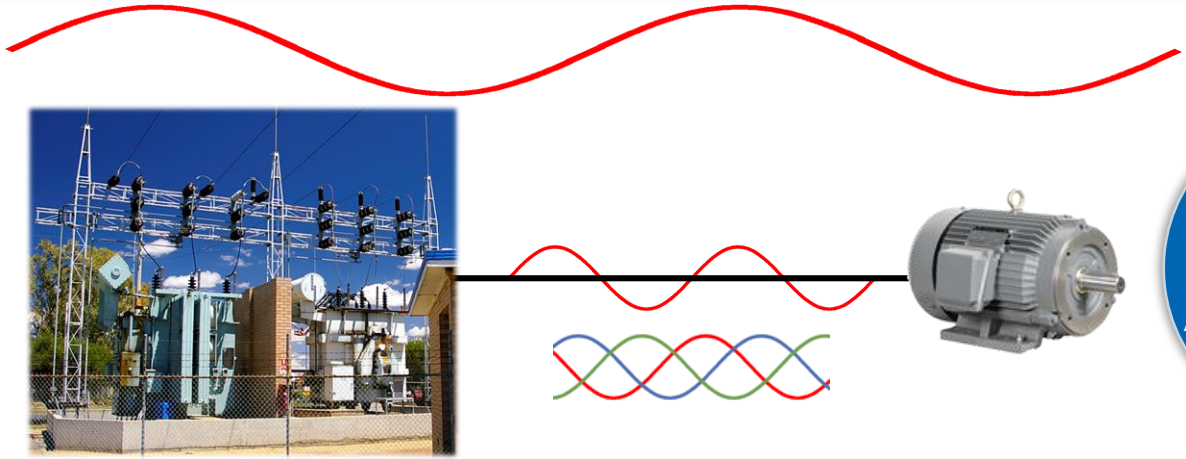
Jean Baptiste Joseph Fourier
(21 March 1768 – 16 May 1830)



Math Used to Find a Waveform's Components

DRIVES & HARMONICS

BEFORE DRIVES…
EVERYTHING WAS SINUSOIDAL



MOTORS RAN DIRECTLY ACROSS-THE-LINE

SUPPLY LINE
- Provides sinewave **voltage** which the motor likes

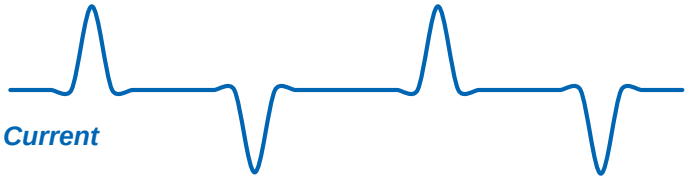
MOTOR
- Draws sinewave **current** which the supply likes.

WHAT ARE HARMONICS?

Voltage is typically supplied as a sine wave.

Supply Voltage

Current Waveform ≠ Voltage Waveform
Current waveform is non-linear.



Non-linear Current

Harmonics occur whenever the current waveform is distorted.
Distortion → 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
  - Reduced Maintenance on Mechanical Couplings

BENEFITS OF DRIVES

ACROSS THE LINE

1 Pump Across the Line

100% Speed → 100% Flow

= 100% Power

MOTOR RUN BY A DRIVE

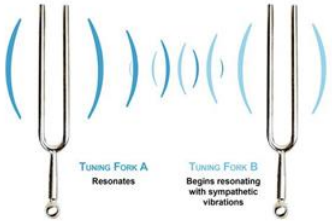
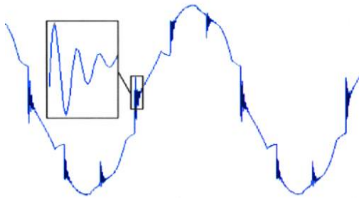
70% speed → 49% Torque

Total Power = 34%

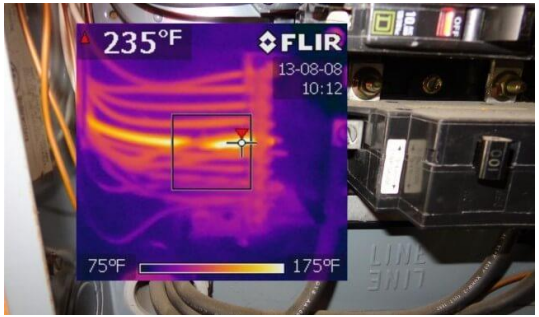
66% Power Reduction

HARMONICS, Why the Concern?

WHY THE CONCERN?

CAUSE		EFFECT
Harmonic currents create heat (power loss)		**Power losses in transformers, wiring and other components on the power line**
Unchecked harmonics may lead to resonance with line inductance & capacitance		**Resonance creates poor reliability, premature failure, and greater cost in maintenance and parts**
Excessive harmonics distorts input voltage		**Electrical equipment may operate erratically, fault, or even prematurely fail**

WHY CARE?



Additional Cooling required due to added heating

LOWER EFFICIENCY
HIGHER OPERATING COSTS

Oversizing of transformers and other equipment

HIGHER STARTUP
REPLACEMENT COSTS

Charges or penalties from high harmonics, low power factor

COSTLY POST INSTALL
CORRECTIVE ACTIONS

IEEE 519 Guidelines

IEEE 519

From IEEE 519, 1.2 Purpose:

“This standard is to be used for guidance in the design of power systems with non-linear loads.”

Reduce electrical interference between electrical equipment (i.e., LOWER harmonics).

IEEE 519

HARMONIC VOLTAGE LIMITS

5.1 Voltage distortion limits

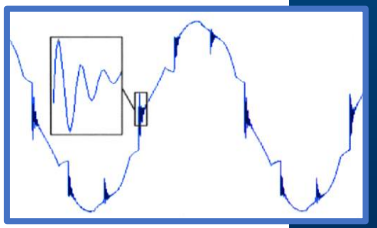
At the PCC, system owners or operators shall limit line-to-neutral voltage harmonics as follows:

— Daily 99th percentile very short time (3 s) values shall be less than 1.5 times the values given in Table 1.

— Weekly 95th percentile short time (10 min) values shall be less than the values given in Table 1.

Table 1—Voltage distortion limits

Bus voltage V at PCC	Individual harmonic (%) h ≤ 50	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]



CURRENT DISTORTION LIMITS

All values shall be in percent of the maximum demand load current, I_L and shall be established at the PCC. Table 2 applies to harmonic currents whose frequencies are integer multiples of the power frequency.

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[b]						
I_{SC}/I_L	$2 \le h < 11$[a]	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	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

Most aggressive level.

Very common. Adding reactor could be enough.

IEEE 519

PCC EXCERPT

"The limits given in this document are based on assumptions that are technically justifiable at the PCC between the system owner/operator and user. These assumptions, and therefore the limits in this document, are not necessarily valid at any other point in the power system. For this reason, the limits given in this document are not intended to be used for the evaluation of equipment.

Limits Apply Only at the PCC, NOT:

- Specific Equipment
- Locations Within User's Facility

HARMONIC SOLUTIONS

YASKAWA

REDUCING VFD HARMONICS

VFD Harmonics Mitigation

- DC Reactor (DC Link Choke)
  - Maintains Current Draw
- Multi-pulse Rectifiers
  - Draws Current More Often
- Active Front End
  - Forces Current Draw by Boosting DC Bus

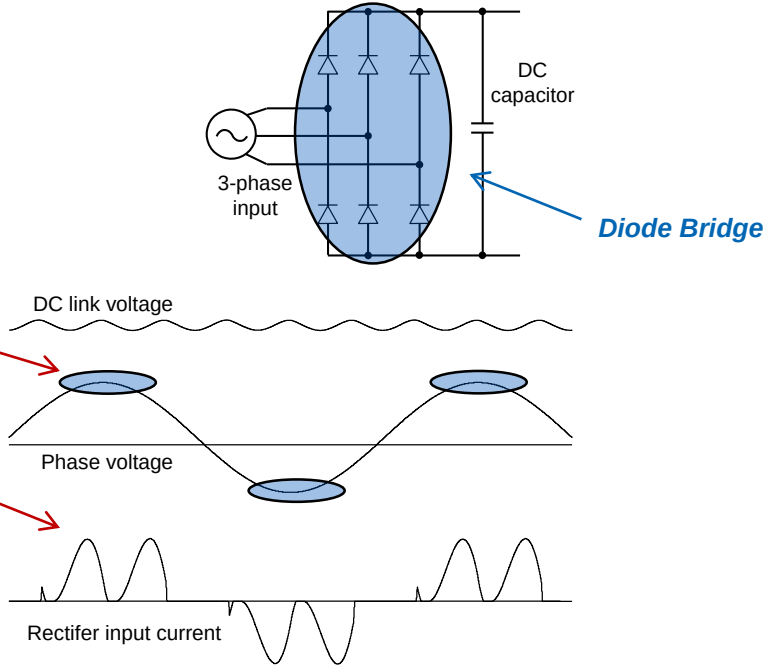
Low-harmonics VFD Design

- AC-to-AC Design Creates Sinusoidal Current

6-PULSE / STANDARD DRIVES

Goal: Charge the DC Bus

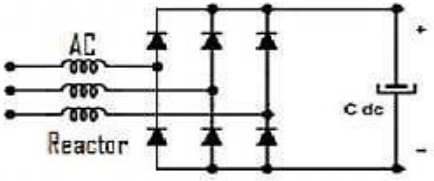
- Charges DC Bus: AC > DC
- Only Occurs at Peaks of AC Waveform
- Result is Non-Linear Current
- Input iTHD = 80%+



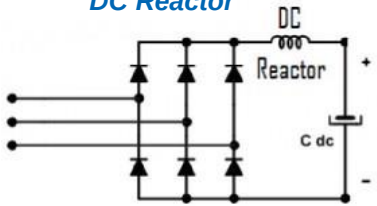
VFD WITH INDUCTOR

- Two Inductor Connection Types
- Inductors Suppress Change
  - $V = L \frac{di(t)}{dt}$
- Current Holds Back at Start
- Current Will Continue to Flow Once Started
- Input iTHD: 30-40%

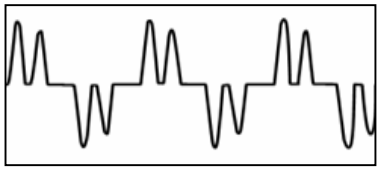
AC Reactor



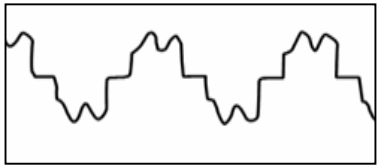
DC Reactor



Standard



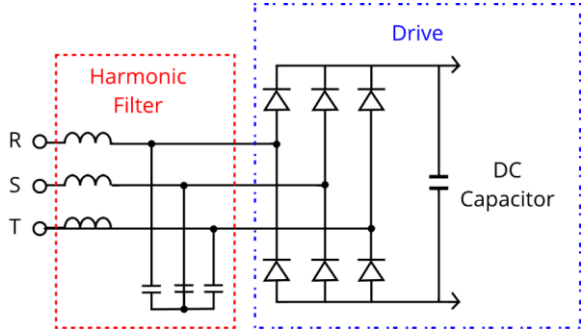
W/Reactor



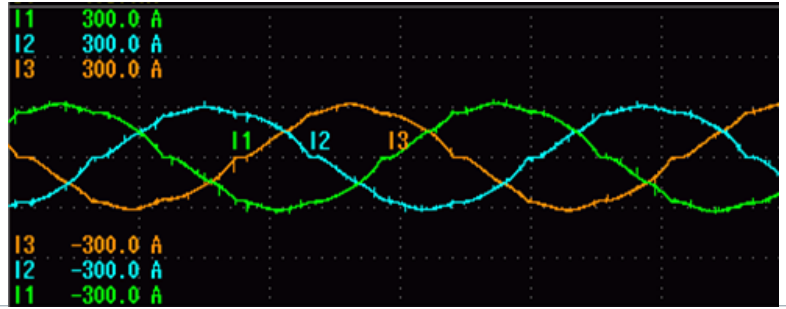
HARMONICS SOLUTIONS

HARMONIC FILTERS

- Shift Power Burden to Filter
- Provides Isolation From Source
- Constantly Draws Current From Line
- Harmonics Between Filter and Drive
- Input iTHD: ~5%
- Negatives:
  - Lower Efficiency
  - Not Reliable
  - Causes OV Faults



Input Current



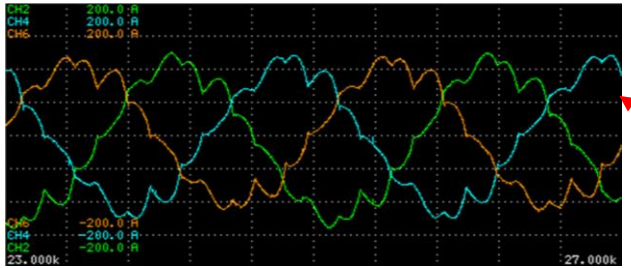
12-PULSE

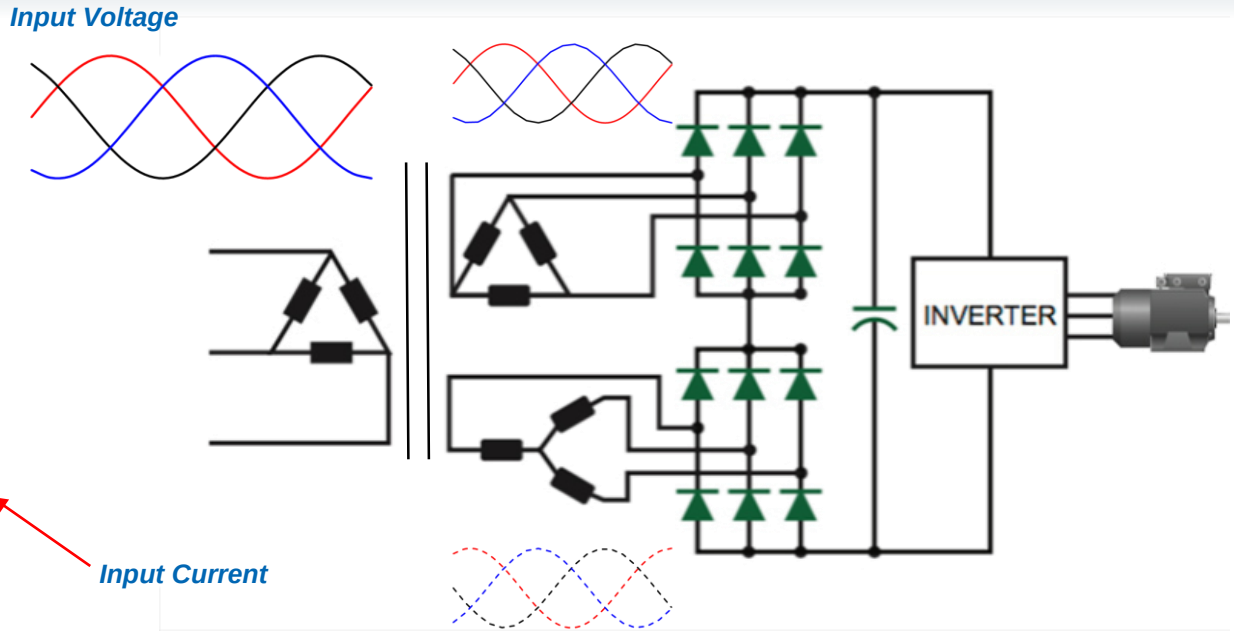
Add Transformer

- Phase Shift to Voltage
- 2 Sets of 3-Phase Voltage

Extra Set of Diodes

- Conducts Each Set of 3-Phase Power





ACTIVE FRONT END (AFE)

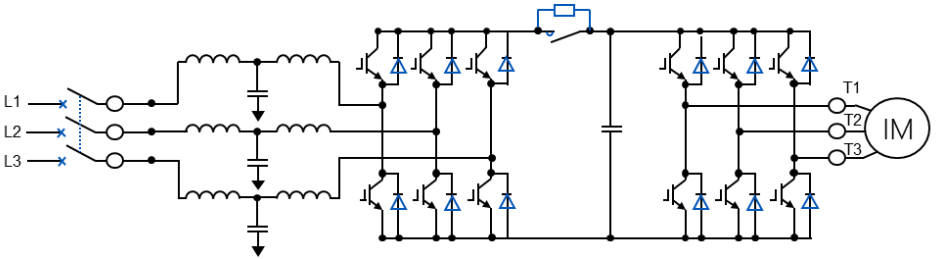
Input Switches Constantly ON/OFF

- Changes How Drive Sees Voltage
- Current Can't Just Stop
- Flows Through Different Phase

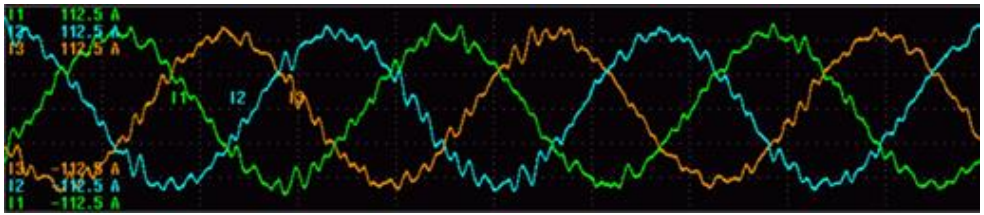
Results

- Boosted Voltage on Bus
- Continuous Current Draw
- Input iTHD: ≤ 5%

All-in-One Active Front End



Input Current



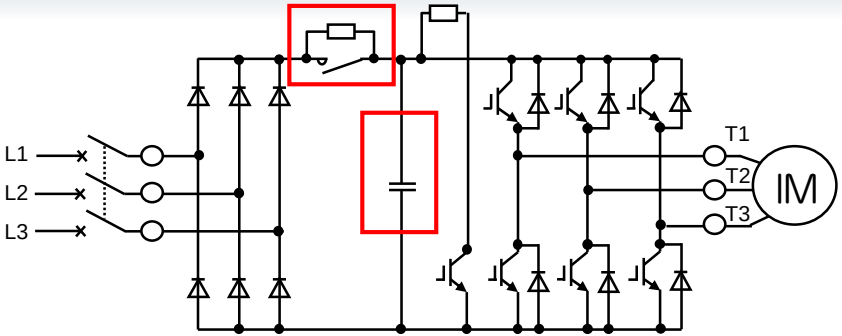
Matrix Drive vs. Conventional Drive

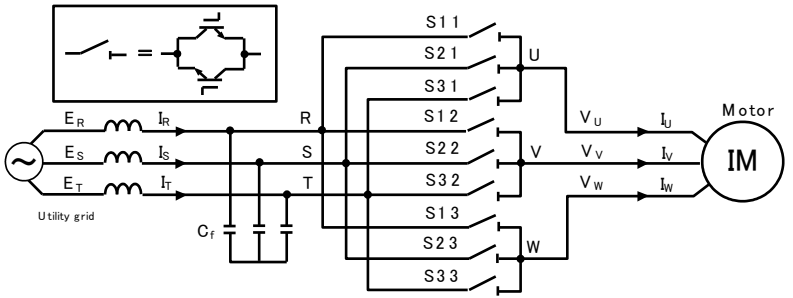
Conventional Drives

- Large Amounts of Capacitance
- Pre-Charge Contactor

Matrix Drives

- AC to AC = No Large Capacitors
- No Large Caps = No Pre-Charge Circuit
- Input iTHD: ≤ 5%
- Lowest harmonic levels at reduced speeds

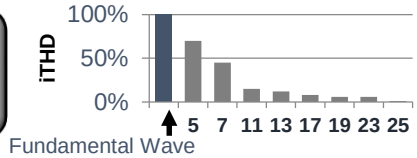
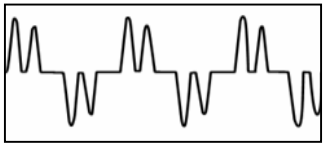
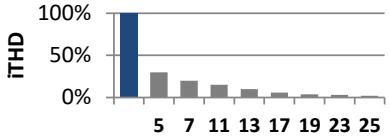
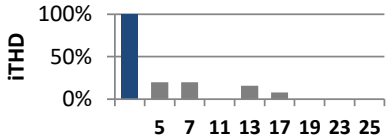
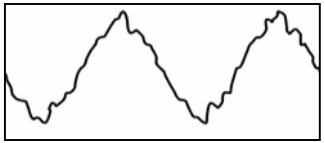
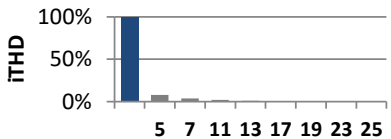
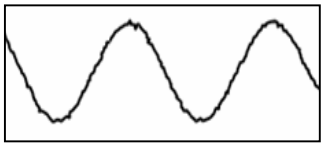




HARMONICS PERFORMANCE

COMPARISON DETAILS

Rated Power Operation

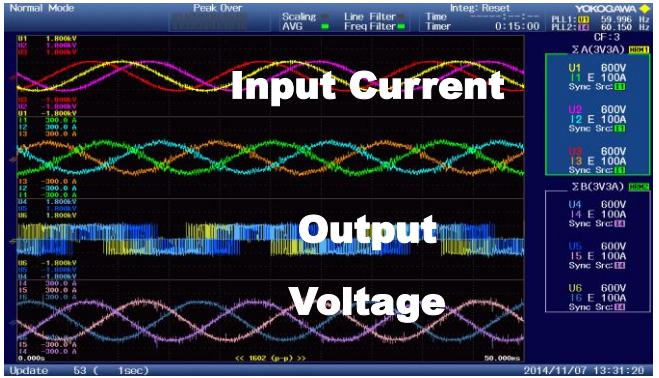
	Current Harmonics	Current Waveform	Current Distortion	True Power Factor
VFD			88%	0.75
VFD			33%	0.90
VFD			6 to 12%	0.95
MATRIX/ AFE			**3 to 5%**	**0.98**

LOWEST HARMONIC SOLUTIONS

Matrix/AFE Drive

- Two types of drives with best harmonic mitigation
- Simple installation – 3 wires in / 3 wires out
- Both drives achieve IEEE 519
- Both drives get to 5% or lower harmonic distortion
- No additional components adding size or points of failure

Consult your local drive representative for more information



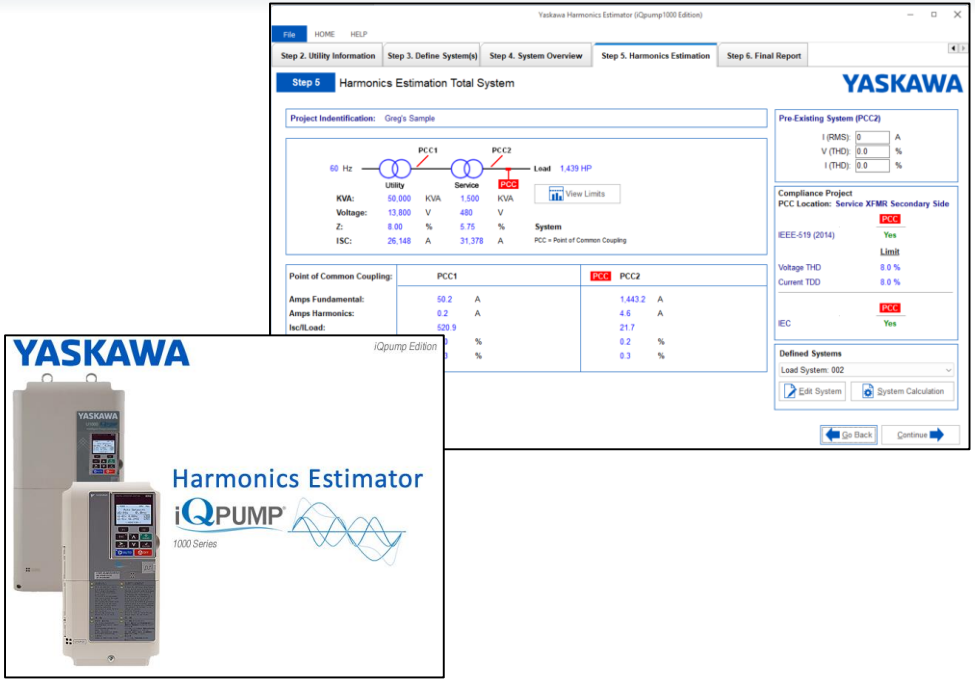
WE CAN HELP

Summary

- This doesn’t need to be scary
- Manufacturers are here to guide you
- Manufacturers have made this number crunching easy

We make the complicated simple

Visit us at booth 633



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IT'S PERSONAL