Power Quality and Harmonics

Wayne Walcott: MTE Application engineering Manager
August, 2015
Discussion Topics

PQ & Harmonics – Wayne Walcott

- What are harmonics? 3phase and single
- What problems do they cause?
- Understanding (IEEE-519) and the New 2014 version?
- National smart Grid & Power quality directive
- Metering ieee1449-2010
- What affects the THD & TDD?
- What about PF?
- How can the harmonics be reduced?
- Review of harmonic mitigation methods
- Look inside the MTE AP harmonic filter
- System harmonic calculation tools
Major PQ contribution: 
Power conversion AC/DC nonlinear loads

- 54% of power grid issues are from nonlinear loads primarily
  
  *VFD’s motor drives.*

- Lighting florescent, battery charging, servers, UPS and dimmers see growing use.

- Induction Arc furnaces, welders and induction heat treating place an added financial burden on utilities and stress the grid.

- Utilities make VA power and typically bill for watts, but that’s changing!
Common power issues related to PQ

- Process or shutdown impacting production
- False sensor data or communication
- Mysterious drive faults
- Transformer and or cable heating
- PF correction problems
- Power provider requires compliance to IEEE519
- High PF penalty charges from utility
- Planned expansion limited by facility capacity
**Power Quality Cost**

In a 2001 study, it was determined US commercial and industrial businesses were losing over $45 billion per year due to power interruptions.¹

$15 to $24 billion in losses

Were attributed to power quality problems.

¹ From the Electric Power Research Institute (EPRI), *The Cost of Power Disturbances to Industrial & Digital Economy Companies*, copyright 2001
7 - Types of PQ Problems

IEEE519 PQ Definitions

1. Transients
2. Interruptions
3. Sag (Undervoltage)
4. Swell (Overvoltage)
5. Waveform Distortion
6. Voltage Fluctuations
7. Frequency Variations
MTE Complete Solutions

Matrix® AP

Line Reactors

Utilities Power

Harmonic Filters

VFD

SineWave Filters

dV/dt Filters

Load Reactors

Load Side

Motor Protection

Motor
Harmonics

Wayne Walcott, Application Engineering Manager
Introduction to Power System Harmonics

- Harmonics are a mathematical way of describing distortion to a voltage or current waveform. The term harmonic refers to a component of a waveform that occurs at an integer multiple of the fundamental frequency.

- Fourier theory tells us that any repetitive waveform can be defined in terms of summing sinusoidal waveforms which are integer multiples (or harmonics) of the fundamental frequency.
Harmonics from an Oscope perspective

**Causes of harmonics:** A non-linear load is any load which draws current which is not proportional to the voltage applied, such as:

- Variable Frequency Drives
- Controls for arc welders, furnaces, ovens
- Any AC to DC rectifiers
- Un-interruptible power supplies
Harmonics creation from AC to DC conversion

- Power supply input with full wave bridge
Single phase Harmonics results

- This is a third harmonic example caused by typical single phase bridge rectifier supplies.
3 phase six pulse bridge bus supply

- Non-sinusoidal currents are drawn from the supply
- Pulsating power from the supply source
Classic 3 phase six pulse bridge bus supply current
What problems do they cause?

- Increased Utility current requirement
  - Inability to expand or utilize equipment
- Component overheating
  - Distribution transformers & wires
- Nuisance tripping causing lost productivity
  - Sensitive equipment
- Equipment malfunction
  - Due to multiple or loss of zero crossing
- Noise transfer to other loads
  - Possibly even other utility customers
- Incorrect meter readings, relays malfunction
  - Maintenance time
- Communication or Telephone Interference problems
- Excitation of Power System Resonance's creating over-voltage's
- Voltage Flat Topping Problem
Current Harmonics

Create “by Ohms Law”

Voltage Harmonics
Transformer has impedance

utility transformer

2500kVA
5.75% Z
480V/sec

Load

Load Current

Drive

AC

AC
Large transformer: 1500kVA, 75hp 1% THVD
Under sized transformer: 75kVA, 75hp 7.2% THVD
Purpose of The IEEE519 and Global standards

To provide a clean source of electrical energy to the world population so that consumer and industry can prosper side by side
IEEE519 – 1992 original standard

- IEEE 519 was created to limit the harmonics on supply networks (they cause losses, affect other users)
- IEEE 519 limits the DEMAND distortion (TDD) and VOLTAGE distortion (THVD) at the POINT OF COMMON COUPLING (PCC)
- The PCC is defined as the point where the user connects to the supply
- The VFD input current distortion (THID) does not necessarily need to be <5% to meet IEEE 519 at the PCC.
2014 standard has changed IEEE519-2014

- The point of common coupling is specifically defined as the point of connection to the utility usually upstream of the considered installation.

- Total demand distortion “TDD” is now the critical base which determines how the harmonics % are limited. New standard removes wording that was open to interpretation.

- A statistical method of assessing the measurement of and recorded harmonic data based on time reference sampling without instrumentation details.

- Revisited voltage limits established a max of 8% THVD

- The current distortion limits remained the same and only for harmonics less than 50th.

- Recommendations for increasing harmonic current limits brings active & passive filters to equality with 12 & 18 pulse drives.
What value should be compared against the limit?
Harmonic measurements

- **From IEEE519-2014 4.2** Very short time harmonic measurements are assessed over a 3 second interval based on an aggregation of 15 consecutive 12 (10)cycle windows for 60 (50)Hz power systems. Individual frequency components are aggregated on an RMS calculation shown: **3 s “very short” value:**
  
  $$F_{n,vs} = 2\sqrt{\frac{1}{15} \sum_{i=1}^{15} F_{n,i}^2}$$

- **F** is either volts or amps

- **From IEEE519-2014 4.3** Short time harmonic measurements are assessed over a 10 minute interval based on aggregation of 200 consecutive very short time values for a specific frequency component. The 200 values are aggregated based on and RMS calculation as shown.
  
  $$F_{n,sh} = 2\sqrt{\frac{1}{200} \sum_{i=1}^{200} F_{(n,vs),i}^2}$$
Weekly Statistical Indices

95th or 99th percentile Value to be compared against limit
Percentile-Based Current Limits

- Daily 99th percentile very short time (3 s) harmonic currents should be less than 2.0 times the values given in Table ...
- Weekly 99th percentile short time (10 min) harmonic currents should be less than 1.5 times the values given in Table ...
- Weekly 95th percentile short time (10 min) harmonic currents should be less than the values given in Table ...
IEEE 519-2014 standards

Table 1—Voltage distortion limits

<table>
<thead>
<tr>
<th>Bus voltage $V$ at PCC</th>
<th>Individual harmonic (%)</th>
<th>Total harmonic distortion THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V \leq 1.0 \text{ kV}$</td>
<td>5.0</td>
<td>8.0</td>
</tr>
<tr>
<td>$1 \text{ kV} &lt; V \leq 69 \text{ kV}$</td>
<td>3.0</td>
<td>5.0</td>
</tr>
<tr>
<td>$69 \text{ kV} &lt; V \leq 161 \text{ kV}$</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>$161 \text{ kV} &lt; V$</td>
<td>1.0</td>
<td>$1.5^1$</td>
</tr>
</tbody>
</table>

*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 standards

Table 2—Current distortion limits for systems rated 120 V through 69 kV

<table>
<thead>
<tr>
<th>Individual harmonic order (odd harmonics)⁴, ⁵</th>
<th>3 ≤ h &lt; 11</th>
<th>11 ≤ h &lt; 17</th>
<th>17 ≤ h &lt; 23</th>
<th>23 ≤ h &lt; 35</th>
<th>35 ≤ h ≤ 50</th>
<th>TDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{sc}/I_L$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 20⁶</td>
<td>4.0</td>
<td>2.0</td>
<td>1.5</td>
<td>0.6</td>
<td>0.3</td>
<td>5.0</td>
</tr>
<tr>
<td>20 &lt; 50</td>
<td>7.0</td>
<td>3.5</td>
<td>2.5</td>
<td>1.0</td>
<td>0.5</td>
<td>8.0</td>
</tr>
<tr>
<td>50 &lt; 100</td>
<td>10.0</td>
<td>4.5</td>
<td>4.0</td>
<td>1.5</td>
<td>0.7</td>
<td>12.0</td>
</tr>
<tr>
<td>100 &lt; 1000</td>
<td>12.0</td>
<td>5.5</td>
<td>5.0</td>
<td>2.0</td>
<td>1.0</td>
<td>15.0</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>15.0</td>
<td>7.0</td>
<td>6.0</td>
<td>2.5</td>
<td>1.4</td>
<td>20.0</td>
</tr>
</tbody>
</table>

⁴Even harmonics are limited to 25% of the odd harmonic limits above.

⁵Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

⁶All 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.
THID: Total Harmonic (I) current Distortion

- A measurement of the harmonic performance of a product
- Each individual harmonic current \( (I_n) \) can be represented as a percentage of the fundamental \( I_1 \):
  - e.g. 5th harmonic current = \( (I_5/I_1) \times 100\% \)
- As each harmonic current can be out of phase with other harmonic currents, to produce a total sum of the harmonic currents, they have to be added vectorially (take the square root of the sum of the square of each ratio for each relevant harmonic!):

\[
THID = \sqrt{\sum_{n=2}^{n_{\text{max}}} \left( \frac{I(n)}{I(1)} \right)^2 \times 100\%}
\]
**THID vs. TDD**

- **TDD(I) = Total Current Demand Distortion**
- Calculated harmonic current distortion against the full load (demand) level of the electrical system

\[
TDD = \sqrt{\sum_{h=2}^{\infty} \frac{I_h^2}{I_L}} \times 100\%
\]

- The greater the amount of Linear load, the less of an issue the current distortion becomes. Conversely as the linear load decreases distortion becomes more of a factor.
- Looks at the full capacity of the system
  - If non-linear loads are a small % of the full system current demand, the TDD is less
Harmonics and the Smart Grid

- Smart Grid supports co-generation, automatic monitoring, diagnosing and repair functions
- The installation of Advanced Metering Infrastructure (AMI) is the bridge to the construction of smart grids.
- IEEE std 1459-2000 & 2010 defines a methodology to measure power with the presence of sinusoidal and non-sinusoidal harmonic voltage and currents.
- Utility's want to bill customers for actual costs of producing power “VA” not just watts
The Good Old Mechanical
Watthour Electric Meter

PQ and the Smart Grid

New Advanced Electronic
Smart Meter

Reads only fundamental sine wave power

Reads and captures EVERYTHING
New Metering of power systems.
IEEE 1459-2010

This standard is meant to serve the user who wants to measure and design instrumentation for energy and power quantification.

Structure:

Single phase, sinusoidal quantities:

Single phase, nonsinusoidal quantities:

Three phase, nonsinusoidal and non balanced quantities:
Smart meters

Automated Meter Reading (AMR) → Advanced Metering Infrastructure (AMI)

- AMR 1
- AMR 2
- AMR 3
- Standard meter

- Meter communication
- Meter data management
- Meter data repository

- Billing
- Load Forecasting
- Load Management
- Outage Management
- Consumer Demand-side Management
- Demand response

Power quality. Solved.
What is Unified Power?

The Fluke Unified Power measurement system expresses power and energy measurements that directly quantify the waste energy in electrical systems using a combination of classical methods, IEEE 1459-2010, and the Polytechnic University of Valencia’s mathematical calculations. Unified Power measures harmonics and imbalance waste in kilowatts. By factoring in the cost of each kilowatt hour, it’s possible to calculate the cost of waste energy over a week, a month, or a year.
Why $mart meters

- The main issue is equity in billing in the presence of large harmonic content in both the voltage and current waveforms in the power grid. The power triangle only works for sinusoidal waveforms and is no longer valid. Measuring real consumed power (watts) and reactive power (VARs) separately is a historical crutch which started out because the original meters could only measure real power.

\[ a^2 + b^2 = c^2 \]
Smart Meter technology

- The CENTRON Polyphase meter is a solid-state meter which uses the Hall Effect (one per phase) to measure metered current and voltage dividers (one per phase) to measure metered voltage as indicated in block diagram below.
FFT sampling

- The metrology performs the direct sampling of the voltage and current waveforms and the raw processing of these samples to compute all the energy quantities.
- The meter uses a dedicated microprocessor and an analog-to-digital (A/D) converter. Low level signals proportional to the service voltages and currents are connected to the analog inputs of the A/D converters. These converters, which are contained in one package, individually sample the signals and send the digital results to the microprocessor 1,920 times per second. The microprocessor takes these samples, applies precision calibration corrections and computes all the quantities required for the specific meter configuration.
- The analog-to-digital converter samples each phase voltage and current signal 32 times per line cycle and sends the digital values immediately to the microprocessor. This amounts to 32 samples per cycle at 60 Hz. Each time a new set of digital samples are received by the microprocessor, it calculates all of the selected metrological quantities.
Measured Harmonics

- At 32 samples a cycle, harmonics to the 15th are measured. The high rate of the sampling enables the CENTRON Polyphase meter to measure energy quantities accurately under high harmonic distortion conditions. The sampling continues uninterrupted as long as the meter is powered up. All other processing is done in the background between samples. From the continuous train of digital samples on each of the six channels, current, voltage, active energy, reactive energy, and apparent energy quantities are computed.

\[
V_{\text{RMS}} = \sqrt{\frac{1}{N} \sum_{\Delta \rightarrow N} V_\Delta^2}
\]

\[
I_{\text{RMS}} = \sqrt{\frac{1}{N} \sum_{\Delta \rightarrow N} I_\Delta^2}
\]

Where \( N \) is the number of samples per second.

\[
W = V_{\text{INST}} \times I_{\text{INST}}
\]

\[
VAR = V_i \times I_{\text{INST}} \quad (V_i \text{ is } 90^\circ \text{ from } V)
\]

\[
VA = V_{\text{RMS}} \times I_{\text{RMS}}
\]
Smart meter Power calculations

- **Watt-hour (Wh) Measurement**: Watt-hours are measured by multiplying the instantaneous value of the voltage on each phase times the instantaneous value of the current on the same phase.

- **VARhour (Varh) Measurement**: Varhour measurement is accomplished by multiplying the current sample by a previous voltage sample. The meter corrects for the phase difference between 90 degrees and the actual amount of phase error that is generated by the buffered samples. The meter metrology places the reactive energy into one of four quadrant registers based on the result of the accumulator after two cycles have been completed.

- **Volt-ampere-hour (VAh) Measurement**: The CENTRON Polyphase meter measures either Vectorial or RMS volt-amperes using arithmetic phase summation. The arithmetic method of measurement ensures that the resulting VAh value contains as much of the harmonic information as possible. Volt-ampere values are calculated by multiplying the RMS voltage value times the coincident RMS current value.

- **Qhour (Qh) Measurement**: The CENTRON Polyphase meter calculates Qh from watthour and varhour values according to the following general formula. The Qh measurement parallels the inherent characteristics of the electromechanical Qh meter.

\[
Qh = \frac{1}{2} Wh + \frac{\sqrt{3}}{2} Varh
\]
GE KV2c meter statement from their brochure

...With modern loads, measuring energy and power factor isn’t enough. The kV2c family of meters will simultaneously measure all of the components of service cost (real & reactive – with and without harmonics, distortion, and vector apparent power).
Harmonic development and reduction

- Sum of % THID x % of load = % TDD at PCC

THID

<table>
<thead>
<tr>
<th>Load</th>
<th>THID</th>
<th>% of Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load #1</td>
<td>30%</td>
<td>25%</td>
</tr>
<tr>
<td>Load #2</td>
<td>30%</td>
<td>25%</td>
</tr>
<tr>
<td>Load #3</td>
<td>30%</td>
<td>25%</td>
</tr>
<tr>
<td>Load #4</td>
<td>30%</td>
<td>25%</td>
</tr>
</tbody>
</table>
Harmonics are summed and cancel

I(TDD) is measured at each metering point

Goal is to keep the V(THD) at PCC1 ≤ 5%,

Customer A

Customer B

Customer C
Example

I(TDD) limits are met at each metering point:

At PCC1: V(THD) = 3.6%

Customer A: 300hp 6-p drives, 600hp linear load

Customer B: 80hp unbuf drives, 700kW linear load

Customer C: 1000hp 12-p drives

Utility transformer:
- 2500kVA
- 5.75% Z
- 480V sec

Connections:
- 241Arms
- 2960Arms
- 113Arms
- 981Arms
- 101Arms
- 926Arms
- 72Arms
- 1053Arms
# Customer example

<table>
<thead>
<tr>
<th>Line #</th>
<th>Drive Type</th>
<th>HP</th>
<th>Average</th>
<th>Tested</th>
<th>Motor Rating</th>
<th>THID/5th</th>
<th>P.F.</th>
<th>KVA/KVAR</th>
<th>KW</th>
<th>contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>THID corrected</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pre THID</td>
<td>filtered</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line #1</td>
<td>DC</td>
<td>75</td>
<td>60</td>
<td>61</td>
<td>123</td>
<td>34.4/31.5</td>
<td>34.4</td>
<td>37</td>
<td>52.9/49.15R</td>
<td>19.74</td>
</tr>
<tr>
<td>Line #2</td>
<td>DC</td>
<td>100</td>
<td>90</td>
<td>102</td>
<td>158</td>
<td>34.6/31.8</td>
<td>34.6</td>
<td>5</td>
<td>82.6/76.4R</td>
<td>31.4</td>
</tr>
<tr>
<td>Line #3</td>
<td>DC</td>
<td>200</td>
<td>200</td>
<td>167</td>
<td>293</td>
<td>32.1/28.0</td>
<td>32.1</td>
<td>5</td>
<td>131.4/124.3R</td>
<td>42.6</td>
</tr>
<tr>
<td>Line #4</td>
<td>DC</td>
<td>200</td>
<td>240</td>
<td>217</td>
<td>320</td>
<td>34.0/29.3</td>
<td>34.0</td>
<td>5</td>
<td>170.0/151.5R</td>
<td>77.2</td>
</tr>
<tr>
<td>Line #5</td>
<td>DC</td>
<td>100</td>
<td>80</td>
<td>82.6</td>
<td>148</td>
<td>36.1/32.3</td>
<td>36.1</td>
<td>5</td>
<td>66.6/62.02R</td>
<td>24.4</td>
</tr>
<tr>
<td>Line #6</td>
<td>DC</td>
<td>125</td>
<td>100</td>
<td>109.7</td>
<td>220</td>
<td>33.1/31.6</td>
<td>33.1</td>
<td>5</td>
<td>87.97/71.95R</td>
<td>50.6</td>
</tr>
<tr>
<td>Line #7</td>
<td>DC</td>
<td>125</td>
<td>150</td>
<td>136</td>
<td>202</td>
<td>36.5/33.4</td>
<td>36.5</td>
<td>5</td>
<td>108.9/107.4R</td>
<td>18.3</td>
</tr>
<tr>
<td>Line #7</td>
<td>AC (blower)</td>
<td>15</td>
<td>10</td>
<td>3.3</td>
<td>17.5</td>
<td>96.3/70.8</td>
<td>96.3</td>
<td>41</td>
<td>2.63/1.86R</td>
<td>1.85</td>
</tr>
</tbody>
</table>

Linear load 850 hp

Transformer 1500kva

ISC/load 17

TDD <5%
**Einstein explains Power Factor (PF)**

\[
\text{Power Factor} = \frac{\text{Real Power (kW)}}{\text{Apparent Power (kVA)}} = \frac{kW}{\sqrt{(kW)^2 + (kVAR)^2}}
\]

\[
1 / \sqrt{1 + \text{THD}^2}
\]

“Most of the fundamental ideas of science are essentially simple… If you can’t explain it simply, you don’t understand it well enough!”

– Albert Einstein
Displacement Power Factor

\[ PF(\text{disp}) = \frac{I_{\text{real}}}{I_{\text{fund}}} \]

\[ I_{\text{fund}} = \sqrt{I_{\text{real}}^2 + I_{\text{react}}^2} \]

I_{\text{real}} \quad \text{(In phase with line voltage)}

I_{\text{fund}}

I_{\text{react}}
Real and Reactive Current
Distortion Power Factor

\[ I(\text{THD}) = \frac{I_{\text{harm}}}{I_{\text{fund}}} \]

\[ \text{PF(dist)} = \frac{I_{\text{fund}}}{I_{\text{total}}} = \sqrt{\frac{1}{1+\text{THD}^2}} \]

\[ I_{\text{total}} = \sqrt{I_{\text{fund}}^2 + I_{\text{harm}}^2} \]
Total power or current is now a 3D vector diagram

\[ S = \sqrt{P^2 + Q^2 + D^2} \]
Total Current = Real + Reactive + Harmonic
How can we reduce the harmonic current?

- DC link choke within the drive
- Line reactor
- Passive filter
- Active filter
- Multi-pulse
  - 12 pulse
  - 18 pulse
- Active rectifier / converter
Drive w/o DC Link Choke

- Common configuration for drives <= 5hp
- Sensitive to line voltage transients
- High peak line currents
- Typical I(THD) of 80 to 120%
Drive with DC Link Choke

- Less sensitive to line transients
- Typical $I_{THD}$ of 35%
Line Reactor

- Typical values are 3% and 5% impedance
- Big help for drives without DC link choke
- Typical $I_{THD}$ of 25%
Multi-Pulse

Transformer

Drive
DC Link Choke

Motor Load

Power quality.
Solved.
18 Pulse

Advantages

- Cost effective >100HP
- No resonance issues
- Higher DC bus voltage
  - Less ripple
  - Higher nominal voltage
- Can feed primary of isolation transformer with MV

Disadvantages

- Requires Transformer
  - Auto-transformer is smaller and less expensive than isolation transformer
- Likely larger than a Passive filter
- Less efficient that Passive filter
- Higher cost than passive filter
- Much More Complex
- Requires special DC input drive
- May require special pre-charge circuit
18-Pulse Auto-Transformer Converter

Supply Transformer | Line Reactor | Auto-Transformer | 18 Diode Bridge
Multi-Pulse Front-End

- 12 or 18 pulse Diode bridge converter
- Common DC bus drives
- Auto or Isolation Transformers
Passive Harmonic Filter

Transformed transformer

Drive

DC Link

Choke

Passive Filter

Motor Load

hp

AC

DC

M

Power quality. Solved.

mtecorp.com
75 Hp harmonic simulation drive no filter

Input P-P & Drive input volts

Phase current to phase voltage

Bus voltage

Shunt current at L11

Input current and load current

mtecorp.com

Power quality.
Solved.
75 Hp harmonic simulation with filter
MTE Matrix® AP

Wayne Walcott
2010 Research leads to US and international patents for the MTE AP

The technical challenge:
Find a new technology for passive filters that
- offers consistent harmonic performance over load
- is compatible with generator systems
- reduces leading power factor
- Won’t cause resonance with utility systems
What we came up with
Adaptive Passive technology!
Initiated a Provisional Patent on a new reactor technology that will allow us to have consistent performance over load (like Matrix D) and generator compatibility (like Matrix G) filters!
A Deeper Look Into New Adaptive Passive Filter Technology
FAP Construction

- **Ferrite + Gap = FAP**
- Ferrite material with a high Curie temperature
- Material typically is only used as a complete core on components operating at 1 MHz or more.
Adaptive Passive Construction

In a standard matrix “G” the conventional air gap material is replaced with the new FAPS to create the adaptive passive technology.
Adaptive Passive Inductance

Normal versus Adaptive Inductance versus Current

- Adaptive Inductor
- Curie Temperature Transition
- Typical Inductor

Percent Rated Inductance vs Percent Load
Technology Comparison

Step Gap Swing Choke
- The inductance change is very non-linear making it unsuitable for AC filters.
- The saturated part of the core can have excessive heating and audible noise.
- No optimally flat inductance characteristic possible.

Adaptive Passive
- The inductance change can be linear.
- ONLY the FAPs saturate. Insignificant noise and heat generation from FAPs.
- Easy to construct
- Moderate tooling cost
- Easy to adapt existing designs.
Matrix G with AP technology results


- Series G
- Series D
- Series G with Adaptive Passive Technology

Percent Load

%THID

0 2 4 6 8 10 12 14

0 20 40 60 80 100 120

mtecorp.com
Matrix® AP Advantages

- MTE’s patented Adaptive Passive Technology adapts impedance in response to changing loads.
- Achieves superior harmonic mitigation and better THID performance over a wider load range.
- AP changes inductance and is less likely to resonate with utility systems.
- Lower kVAR, generator compatible.
- AP has much higher inductance and percent impedance at light loads and offers better drive transient protection.
- High efficiency throughout the load range.
- Standard three year warranty.
Matrix AP Loaded

Matrix AP 636 Amp Harmonics 25% -100% loading

Harmonic number

% THD

Drive @ 25%
Filtered @ 25%
Drive @ 50%
Filtered @ 50%
Drive @ 75%
Filtered @ 75%
Drive @ 100%
Filter @ 100%
Matrix® AP Marketing Collateral: See Nate

- Two page sell sheet (PSP)
- Product selector (PSL)
- Technical Reference Manual (TRM)
- Website
Application Profiles – Mitigating Harmonics

Better Harmonic Performance at Light Loads Results in Less Overall Distortion on the Power Grid

Matrix® AP Harmonic Filters provided the optimum solution for reciprocating pump operators in the Bakken oil fields.

Oil reciprocating pumps may be a large cost driver to offset the weight of the pump and which can be several hundreds feet long. This produces a major and drive load profile that is optimized with a frequency from 0 to 60 cycles per minute. During one of these cycles, the load varies from 0% to 100% or more for short bursts, with an average load of about 40% to 60% during the loaded portion of the cycle. In the oil fields, these reciprocating pumps may be the major load on the power grid and sometimes can be the only single or many similar loads. The cumulative effect of perhaps hundreds of these types of loads on the power grid results in higher background harmonic voltage distortion for the entire grid in that region.

The challenge:

Conventional harmonic filters are designed to perform between 40% and 100% load. In oil fields, the cumulative effect of lightly loaded drives and filters results in background voltage distortion of 10% or more.

The solution:

MTE worked closely with a large energy company to test the Matrix® AP Harmonic Filter against a competitor’s filter in several well sites. The Matrix AP Filter with its patent pending adaptive passive technology, provides superior harmonic reduction over a very wide operating load range, achieving less than 5% total harmonic current distortion THDI at 45% load.

With the Matrix AP Harmonic Filter, the overall voltage distortion was reduced by much as 50% compared to the competitor.

Reducing Harmonic on Large Power Supply Systems

Matrix® AP Harmonic Filters are used to reduce harmonics on high power induction heaters.

An OEM that manufactures large power supply systems for megawatt has harmonic issues that are caused by the motors. These power supplies have a 5400-cycle frequency, which can be 4,000 cycles. Reciprocating filters provide a solution to generate power for heating and hardening. These large distortions cause significant distortion on the power network. The effect of harmonic frequencies can cause severe damage to neighboring power consumers, creating disturbances in various electronics such as computers, televisions, telephones, and motors.

The challenge:

A variable harmonic filter capable of several thousand watts is not readily available and to custom design a filter at this power level would not be practical. The harmonic noise for these power supplies can affect the power grid and cause a steady undulationcoupling of the electric utility company to shut down the heat treating factory.

The solution:

MTE worked closely with the OEM to develop a solution by providing harmonic filters. In Matrix AP Filters are used in a custom enclosure to achieve the desired current rating. The Matrix AP Filter with its patent pending adaptive passive technology, provides superior harmonic reduction even at very wide operating load range. Less than 5% total harmonic current distortion THDI achievable at 40% load.

Working with the OEM, MTE developed methods for product work to harden and maintain the integrity of the filter, meeting the required current rating.
Achieve Superior Product Performance and Reliability!

For an oil producer, Matrix® AP Harmonic Filters with 6-pulse drives proved to be a higher performance, lower cost harmonic mitigation solution when compared to multi-pulse drives.

The challenge:
A large global oil producer was looking for a competitive edge. They wanted to work by lowering the total cost of ownership for the end product.

Specifications called for multi-pulse drives that are not as effective under light loads and are sensitive to voltage imbalances. This can lead to performance problems, overheating, mechanical failures, and shortened equipment life.

Furthermore, a multi-pulse solution has lower overall power system efficiency.

The solution:
MTE worked closely with the drive manufacturer to deploy a solution to optimize the entire system.

Test data provided by MTE demonstrated that the Matrix AP Harmonic Filter with 6-pulse drive produced superior performance and improved efficiency when compared to 18-pulse and Active Front End (AFE) drives.

The 6-pulse drive combined with MTE’s Matrix AP Harmonic Filter:
- Power loss approximately 10% less compared to 18-pulse drives.
- Harmonic performance under balanced load conditions: 3% lower THD at 250% and 5% lower THD at 300%.
- Power Factor: Better than the performance at loads 300% and above.

The Matrix AP Harmonic Filter exhibited a reduced harmonic signature in all load conditions, significantly outperforming the 18-pulse and AFE drives in the 300% and above load conditions.

The result:
- Improved reliability
- Lower initial capital expenditure and overall operating costs

Harmonic Mitigation to Variable Frequency Drives: 6-Pulse Drive with MTE Matrix AP Harmonic Filter vs. 18-Pulse Drive

Abstract:
The proliferation of variable frequency drives (VFDs) has increased attention to harmonics effects caused by drives. A standard 6-pulse drive has no harmonics with the fundamental frequency. This condition occurs when the output waveform is identical to the input waveform. However, typical passive harmonic filters are designed with 12-pulse or 18-pulse drive systems. A 6-pulse drive with a Matrix AP Harmonic Filter has no harmonic currents at the system. The Matrix AP harmonic filter mitigates the harmonic content of the drive system, providing a cleaner output waveform.

November 23, 2023
Trevor Stedman, Solutions Engineer

Harmonic Mitigation to Variable Frequency Drives: 18-Pulse Drive with Matrix AP Harmonic Filter vs. Active Front End (AFE) Drive

Abstract:
The proliferation of variable frequency drives (VFDs) has increased attention to harmonics effects caused by drives. A standard 18-pulse drive has no harmonics with the fundamental frequency. This condition occurs when the output waveform is identical to the input waveform. However, typical passive harmonic filters are designed with 12-pulse or 18-pulse drive systems. A 18-pulse drive with a Matrix AP Harmonic Filter has no harmonic currents at the system. The Matrix AP harmonic filter mitigates the harmonic content of the drive system, providing a cleaner output waveform.

December 15, 2023
Alexei T. Galvez, Solutions Engineer
Questions
Thank You