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Power Quality and Harmonics

Wayne Walcott: MTE Application engineering Manager

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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

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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

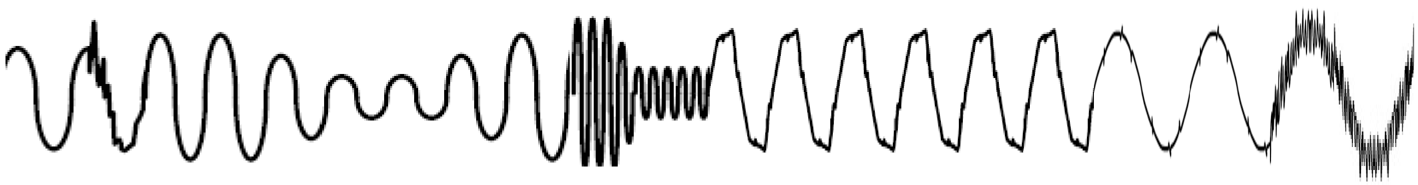
- Process or shutdown impacting production
- False sensor data or communication
- Mysterious drive faults
- Transformer and or cable heating
- PF correction problems
- Power provider requires compliance to IEEE519
- High PF penalty charges from utility
- Planned expansion limited by facility capacity

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*

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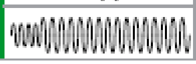
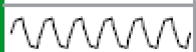
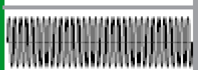
7 - Types of PQ Problems

IEEE519 PQ Definitions

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

Disturbance category	Wave form	Effects	Possible causes	Possible solutions
1. Transient				
Impulsive		Loss of data, possible damage, system halts	Lightning, ESD, switching impulses, utility fault clearing	TVSS, maintain humidity between 35 – 50%
Oscillatory		Loss of data, possible damage	Switching of inductive/capacitive loads	TVSS, UPS, reactors/ chokes, zero crossing switch
2. Interruptions				
Interruption		Loss of data possible, damage shutdown	Switching, utility faults, circuit breaker tripping, component failures	UPS
3. Sag/ undervoltage				
Sag		System halts, loss of data, shutdown	Startup loads, faults	Power conditioner, UPS
Undervoltage		System halts, loss of data, shutdown	Utility faults, load changes	Power conditioner, UPS
4. Swell/ overvoltage				
Swell		Nuisance tripping, equipment damage/reduced life	Load changes, utility faults	Power conditioner, UPS, ferroresonant "control" transformers
Overvoltage		Equipment damage/reduced life	Load changes, utility faults	Power conditioner, UPS, ferroresonant "control" transformers
5. Waveform distortion				
DC offset		Transformers heated, ground fault current, nuisance tripping	Faulty rectifiers, power supplies	Troubleshoot and replace defective equipment
Harmonics		Transformers heated, system halts	Electronic loads (non-linear loads)	Reconfigure distribution, install k-factor transformers, use PFC power supplies
Interharmonics		Light flicker, heating, communication interference	Control signals, faulty equipment, cycloconverters, frequency converters, induction motors, arcing devices	Power conditioner, filters, UPS
Notching		System halts, data loss	Variable speed drives, arc welders, light dimmers	Reconfigure distribution, relocate sensitive loads, install filters, UPS
Noise		System halts, data loss	Transmitters (radio), faulty equipment, ineffective grounding, proximity to EMI/RFI source	Remove transmitters, reconfigure grounding, moving away from EMI/RFI source, increase shielding filters, isolation transformer
Voltage fluctuations		System halts, data loss	Transmitters (radio), faulty equipment, ineffective grounding, proximity to EMI/RFI source	Reconfigure distribution, relocate sensitive loads, power conditioner, UPS
Power frequency variations		System halts, light flicker	Intermittent operation of load equipment	Reconfigure distribution, relocate sensitive loads, power conditioner, UPS

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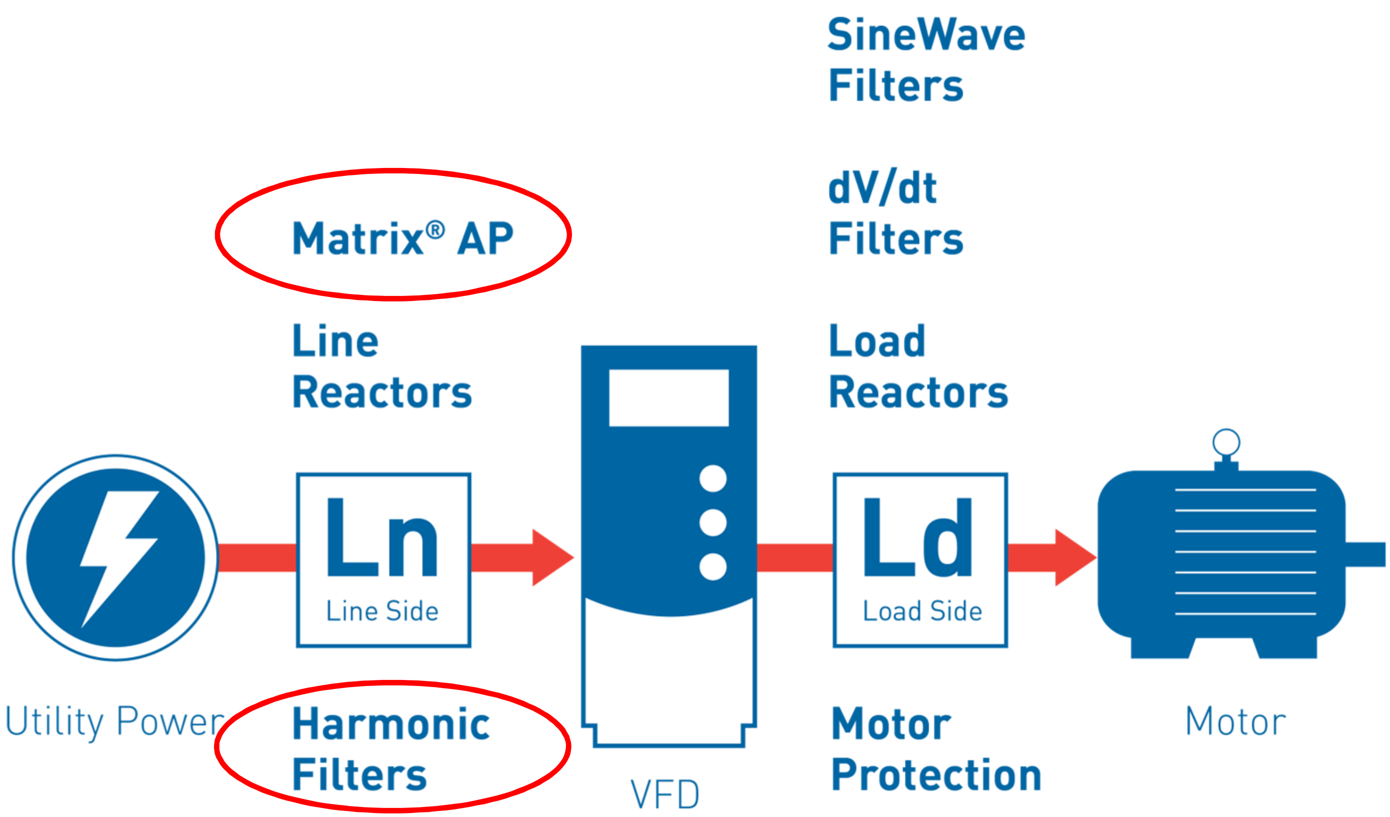
MTE Complete Solutions



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Harmonics

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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.

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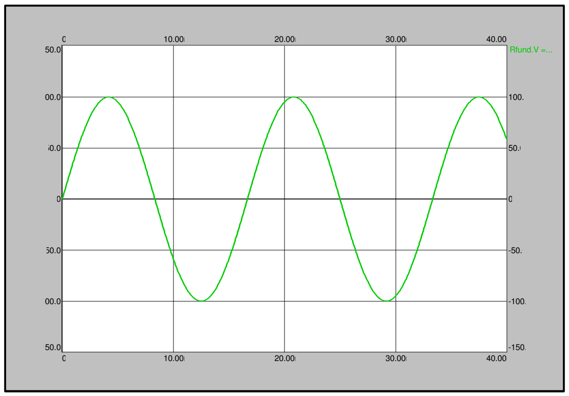
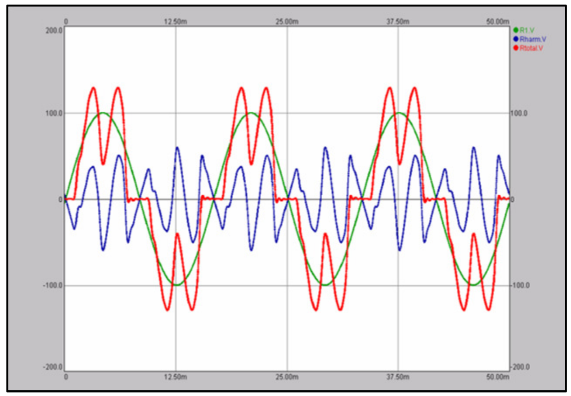
Harmonics from an Oscope perspective

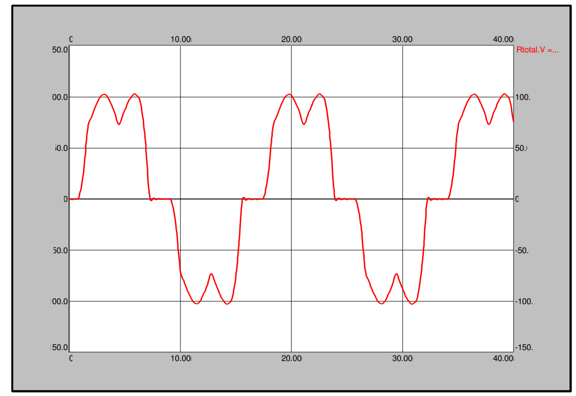
Fundamental



Sum harmonics & fundamental



Distorted waveform



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

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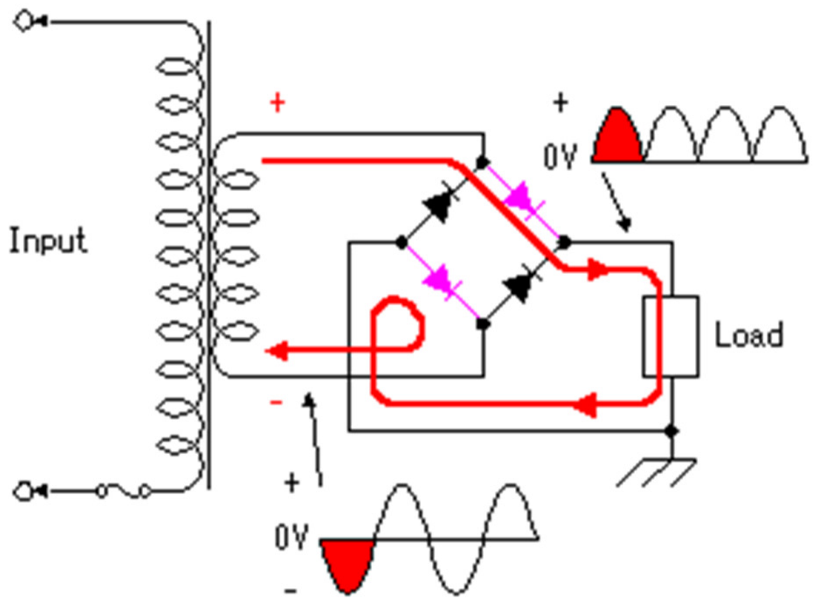
Harmonics creation from AC to DC conversion

- Power supply input with full wave bridge



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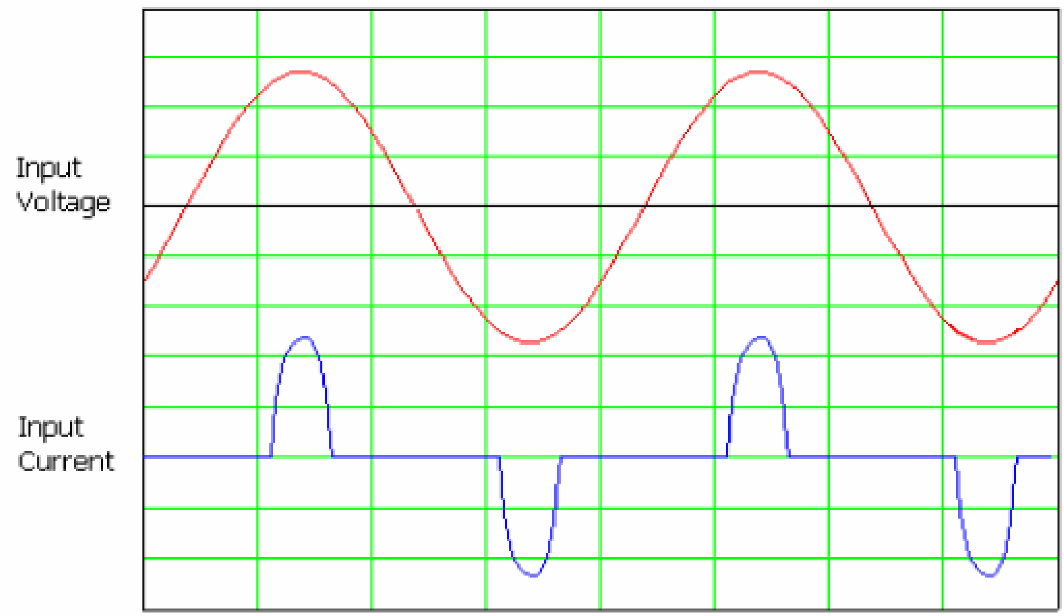
Single phase Harmonics results

- This is a third harmonic example caused by typical single phase bridge rectifier supplies.



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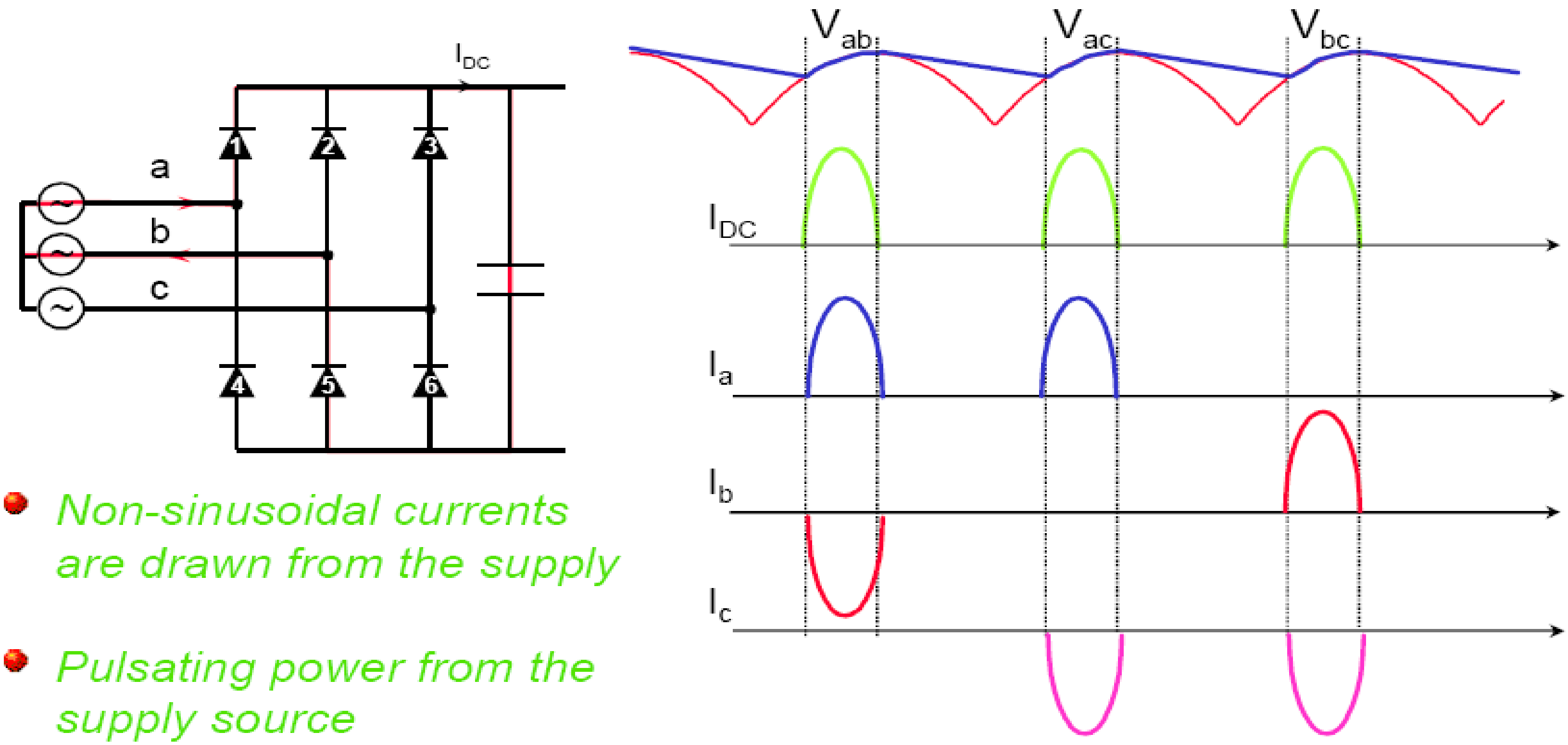
3 phase six pulse bridge bus supply



- *Non-sinusoidal currents are drawn from the supply*
- *Pulsating power from the supply source*

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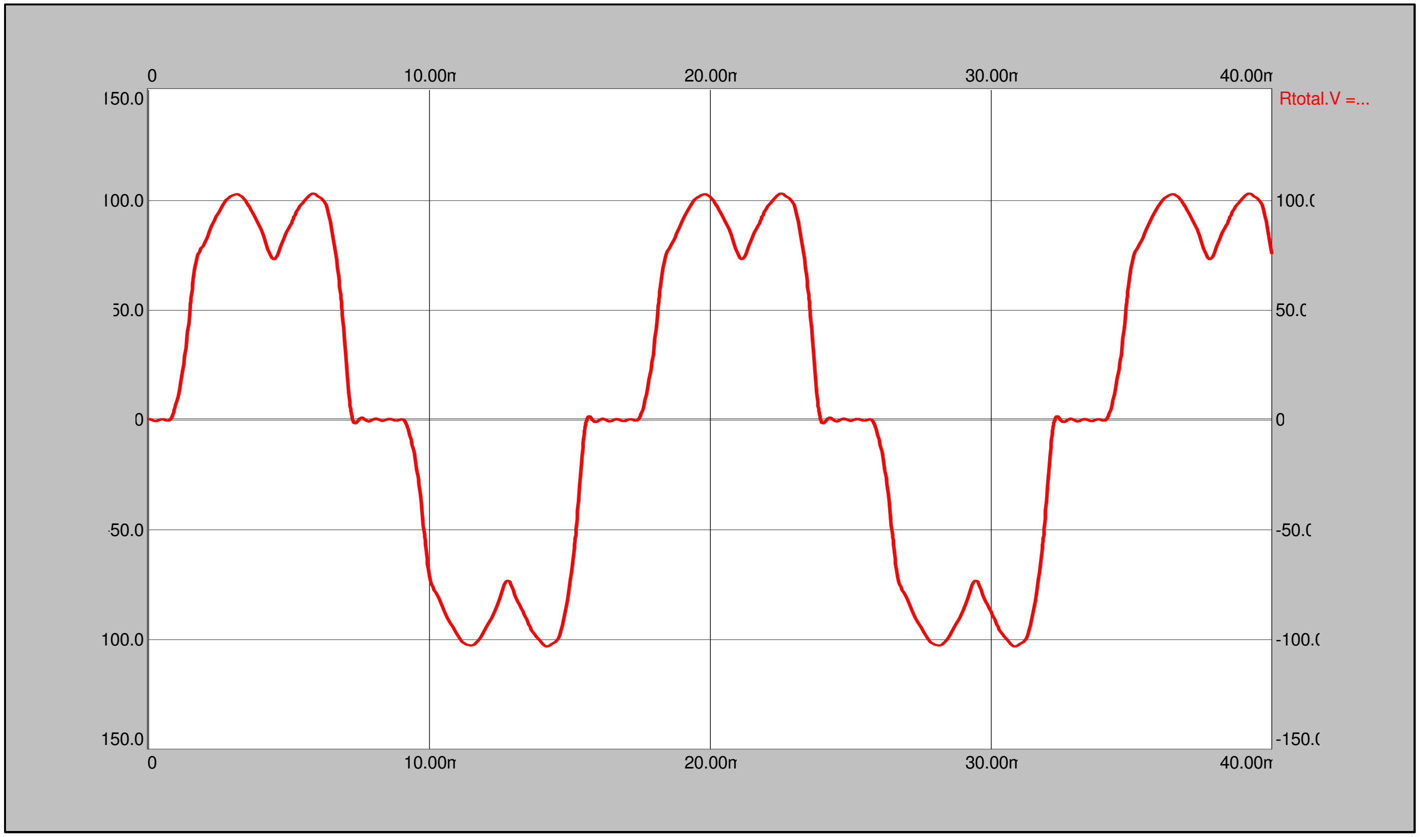
Classic 3 phase six pulse bridge bus supply current



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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

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Current Harmonics

Create **“by Ohms Law”**

Voltage Harmonics

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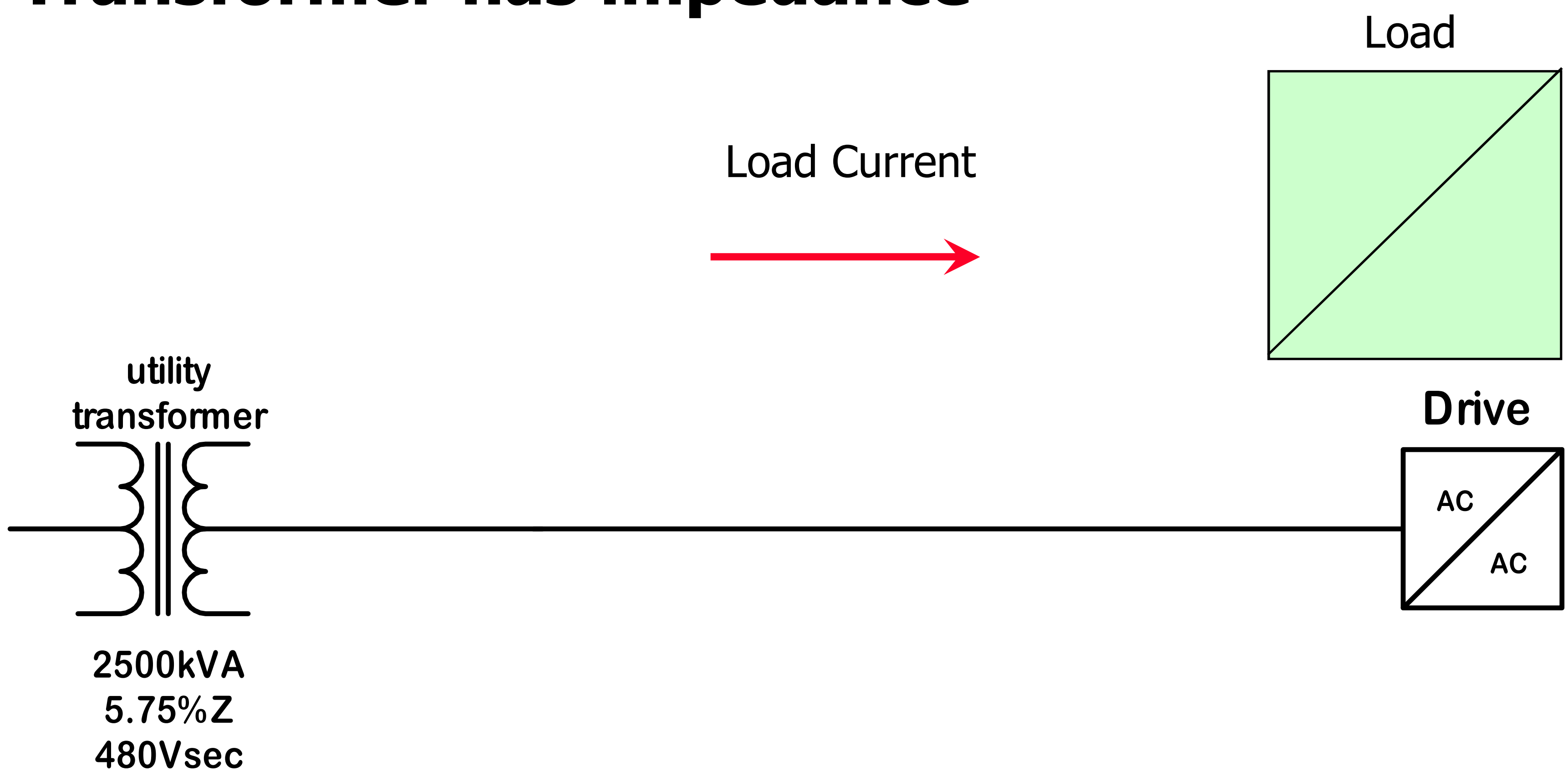
Transformer has impedance



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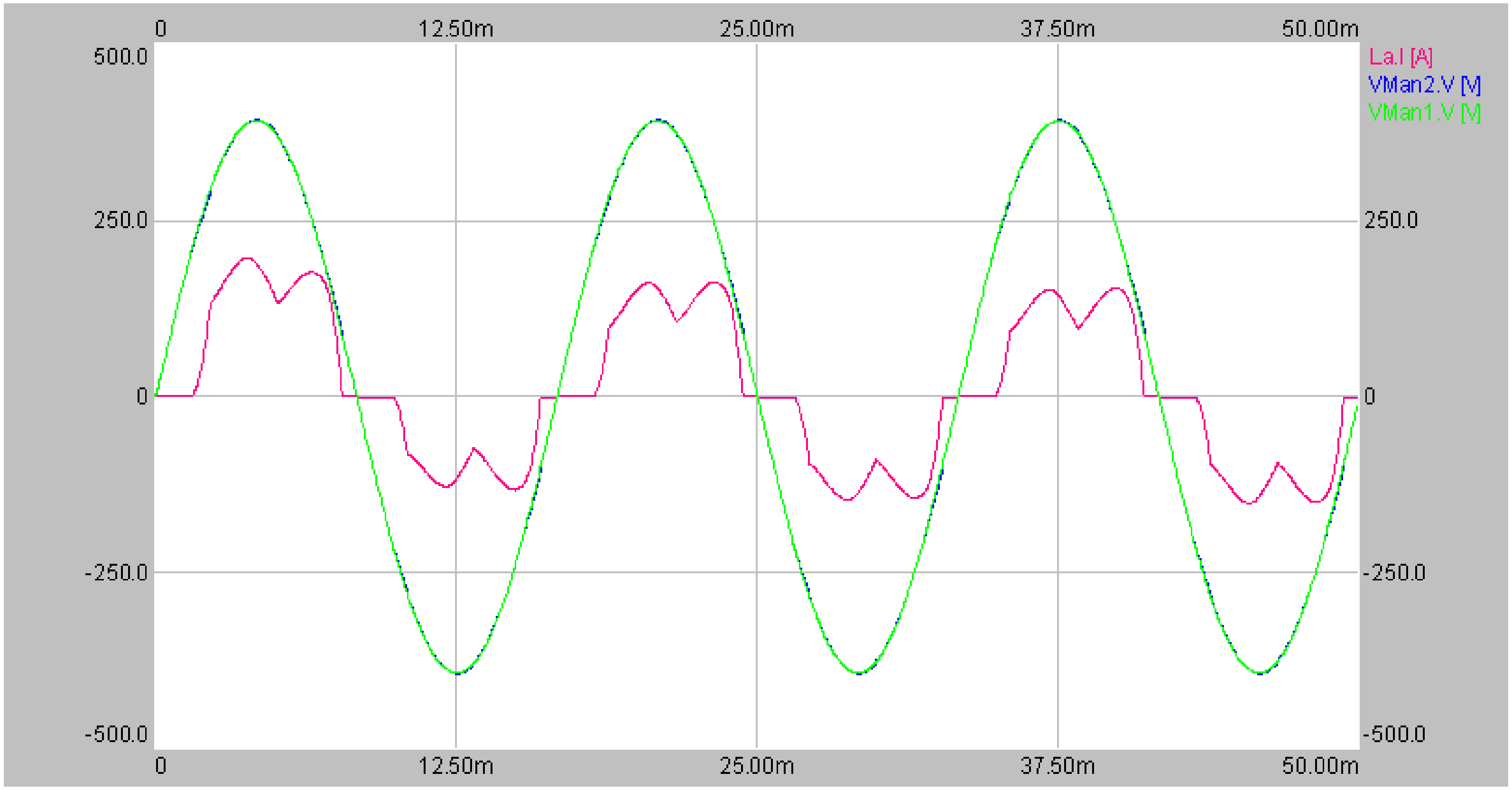
Large transformer: 1500kVA, 75hp 1% THVD



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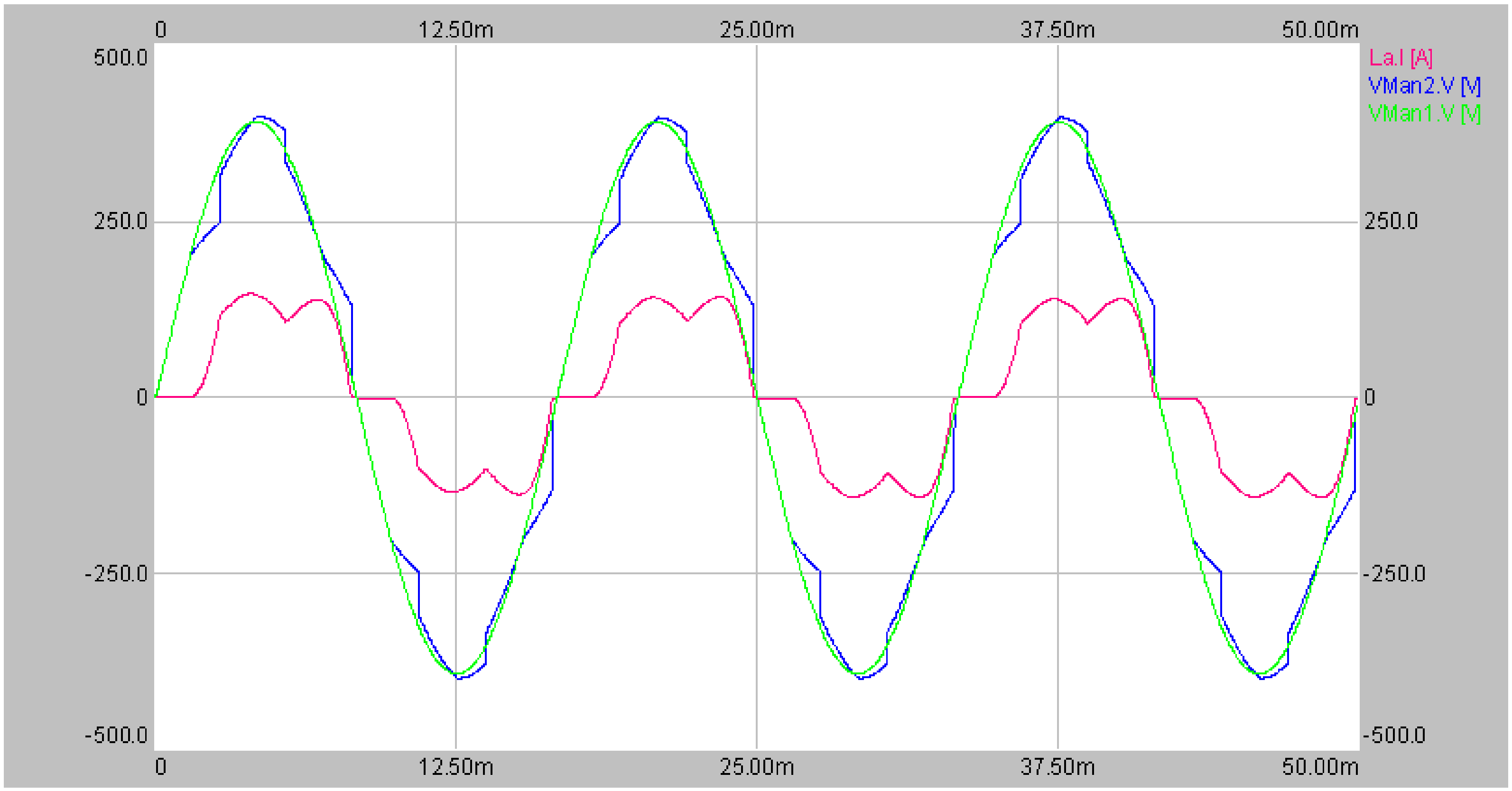
Under sized transformer: 75kVA, 75hp 7.2% THVD



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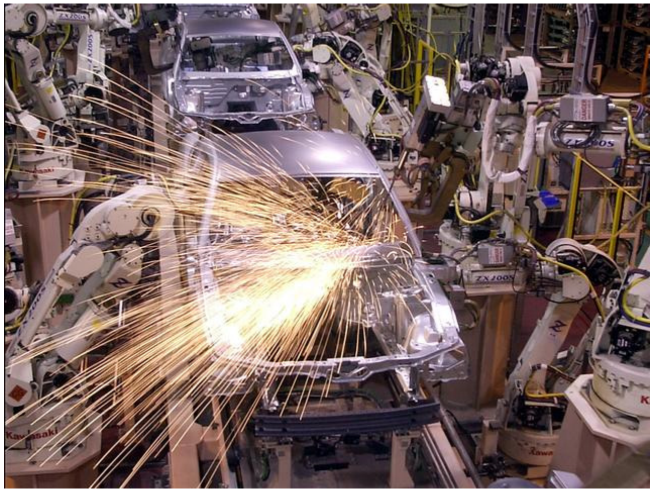
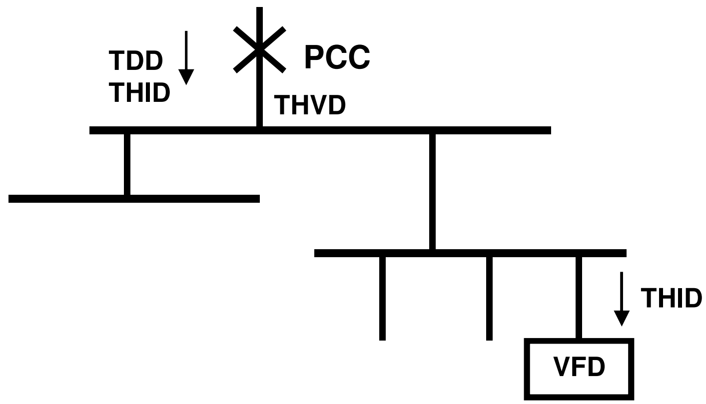
Purpose of The IEEE519 and Global standards

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.



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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 50^{th}.
- Recommendations for increasing harmonic current limits brings active & passive filters to equality with 12 & 18 pulse drives.

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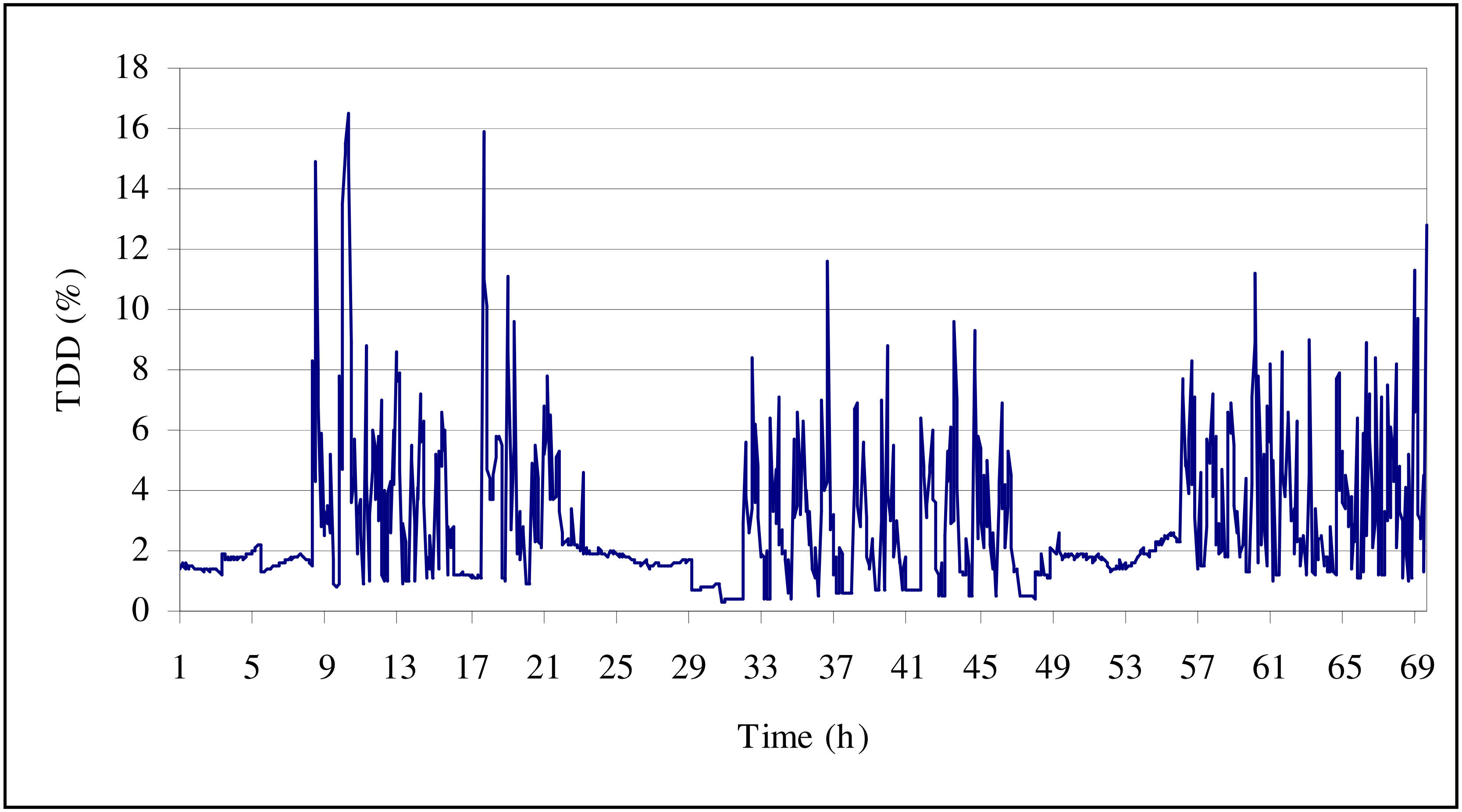
Assessment of Limit Compliance



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*** is either volts or amps $F_{n,vs} = \sqrt[2]{\frac{1}{15}\sum_{i=1}^{15} F_{n,i}^2}$
- ***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.

$$F_{n,sh} = \sqrt[2]{\frac{1}{200}\sum_{i=1}^{200} F_{(n,vs),i}^2}$$

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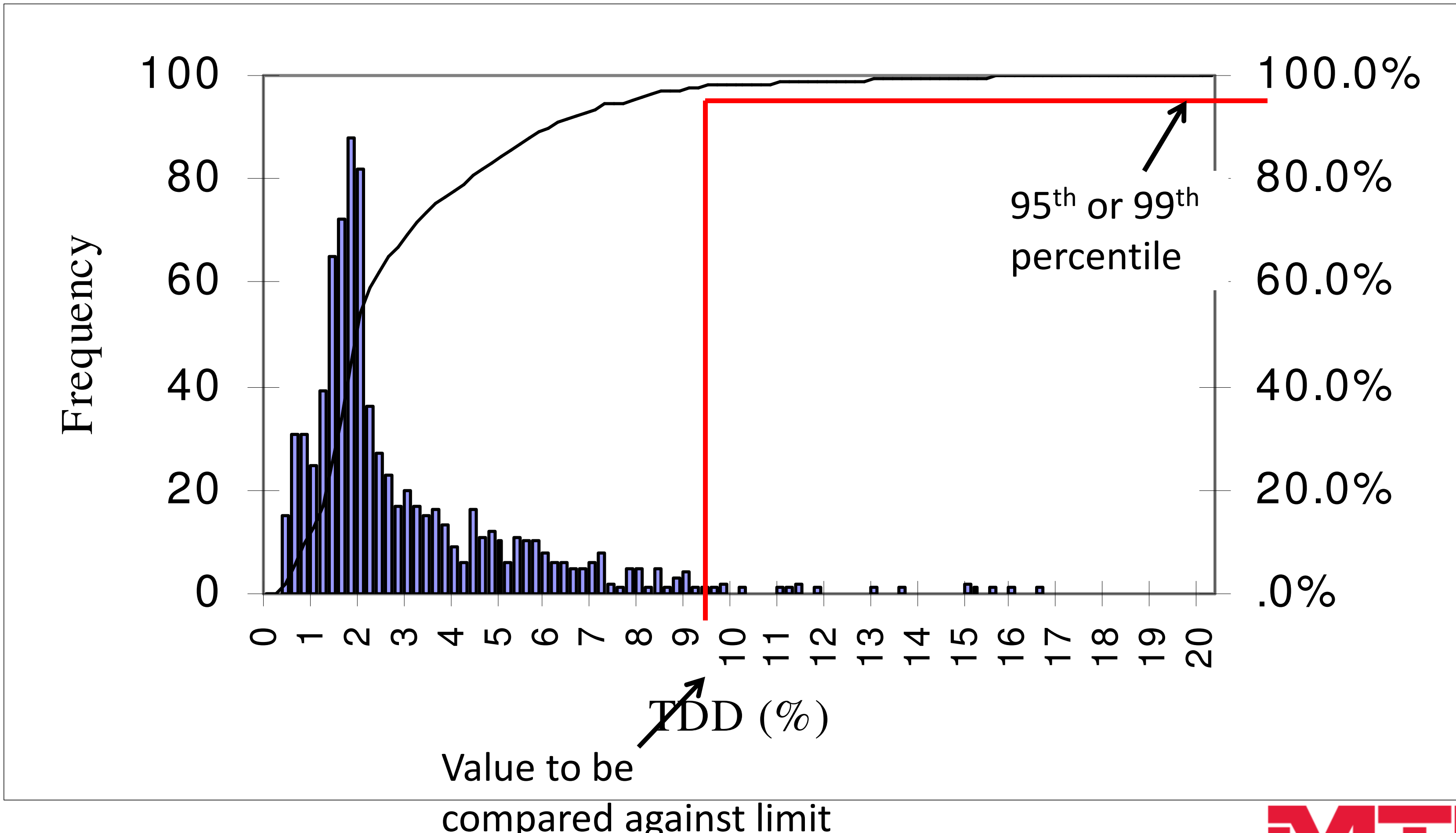
Weekly Statistical Indices



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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 …

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IEEE 519-2014 standards

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.

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IEEE 519-2014 standards

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

[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

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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. 5^{th} 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 vectoraillly (take the square root of the sum of the square of each ratio for each relevant harmonic!):

$$THID = \sqrt{\sum_{n=2}^{n_{max}} \left(\frac{I_{(n)}}{I_{(1)}}\right)^2} \cdot 100\%$$

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THID vs. TDD

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

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

I_L → Full load of the system

- 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

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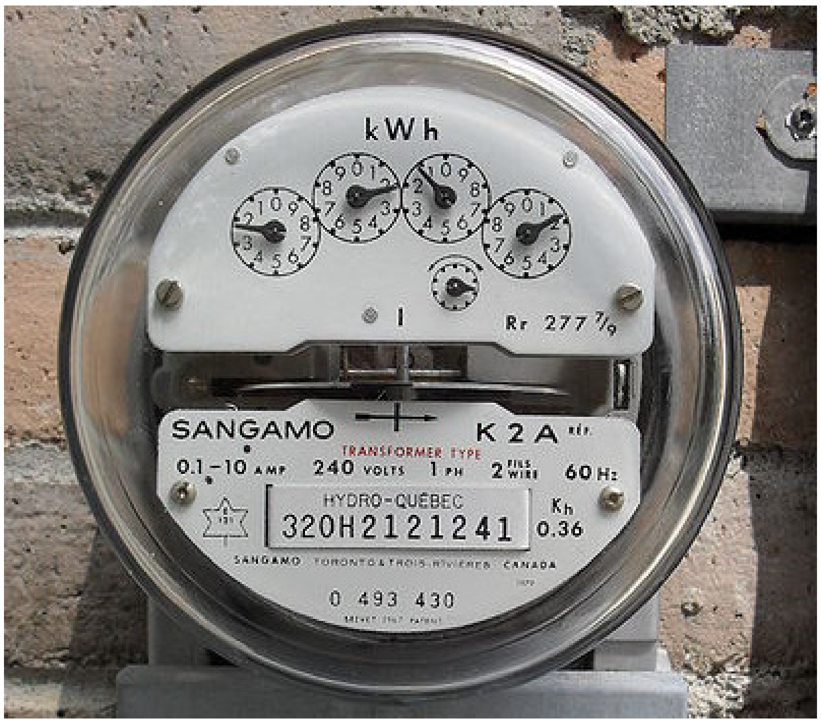
The Good Old Mechanical

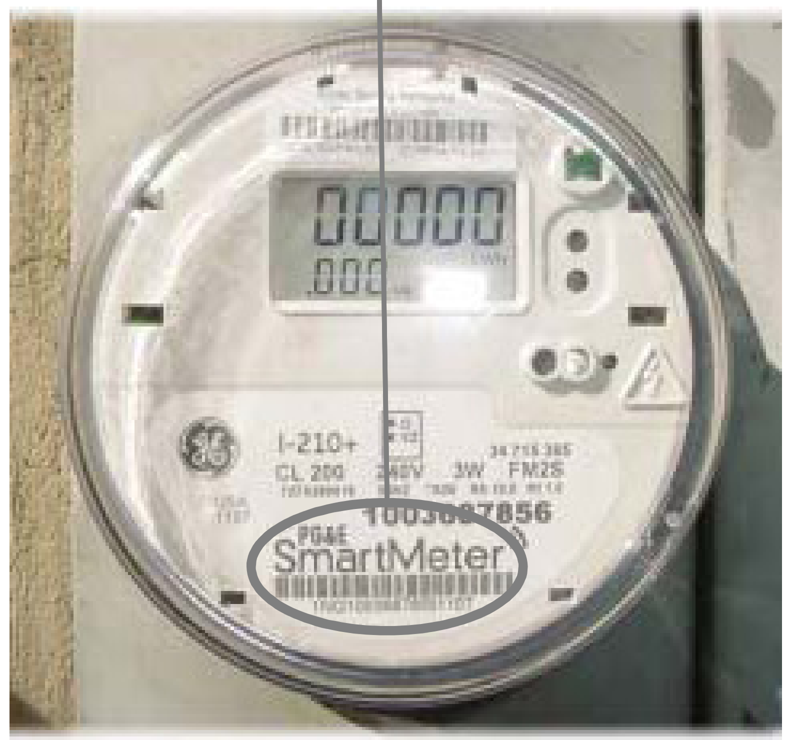
Watthour Electric Meter

PQ and the Smart Grid

New Advanced Electronic

Smart Meter





Reads only fundamental sine wave power

Reads and captures EVERYTHING

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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:

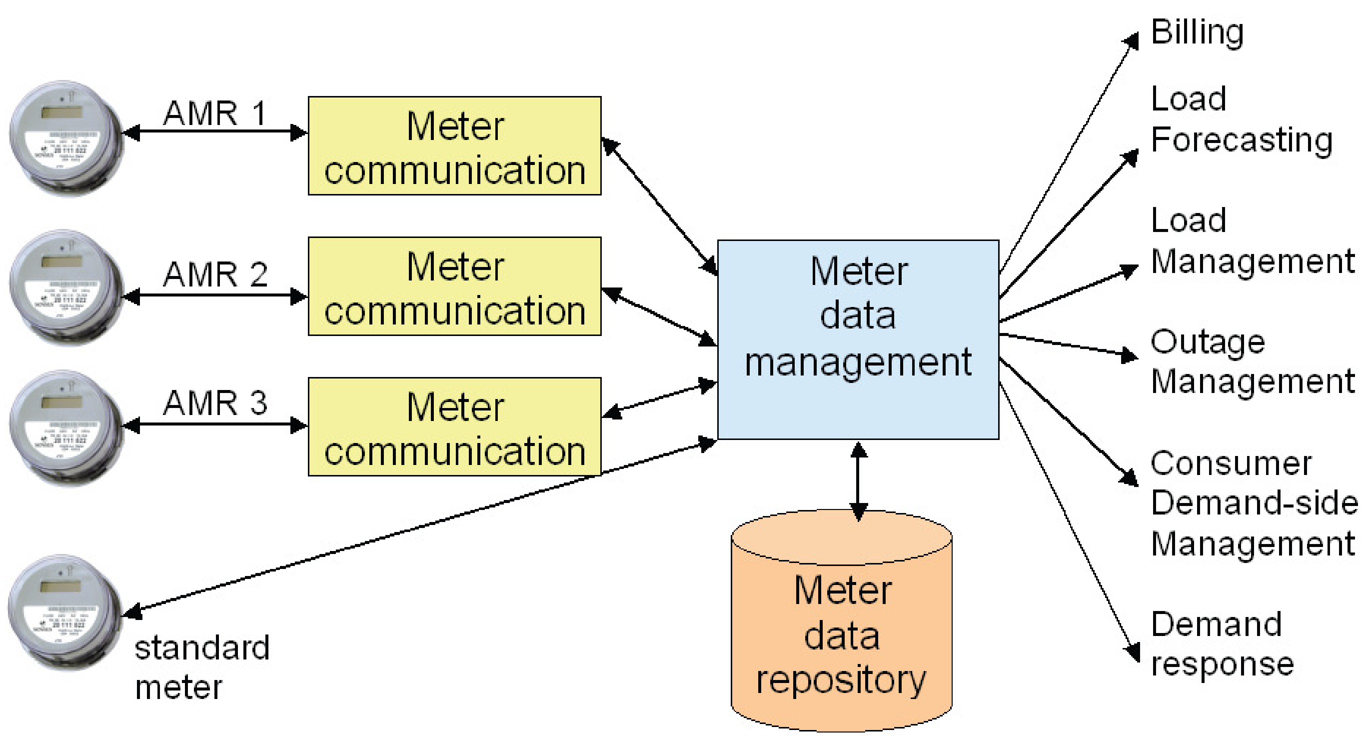
Single phase, sinusoidal quantities:

Single phase, nonsinusoidal quantities:

Three phase, nonsinusoidal and non balanced quantities:

Smart meters

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



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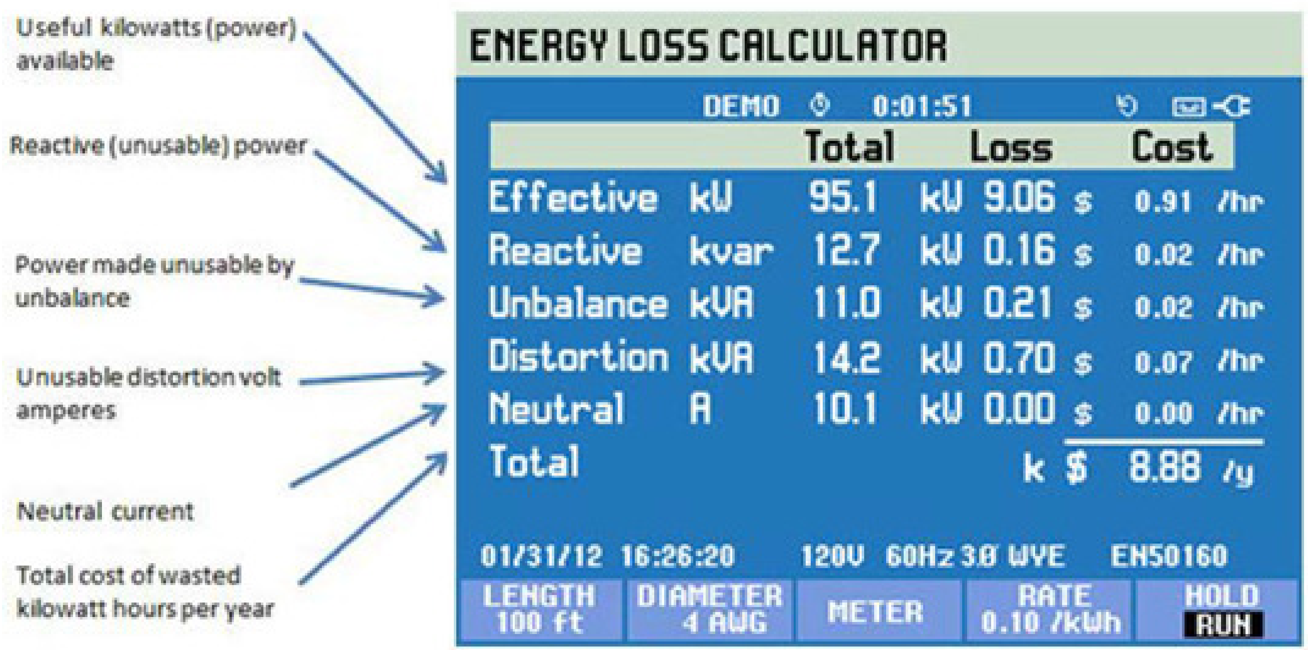
What is Unified Power?

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.



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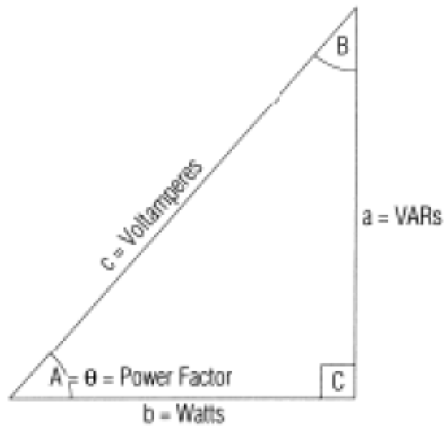
Why $mart meters

- 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.



$$a^2 + b^2 = c^2$$

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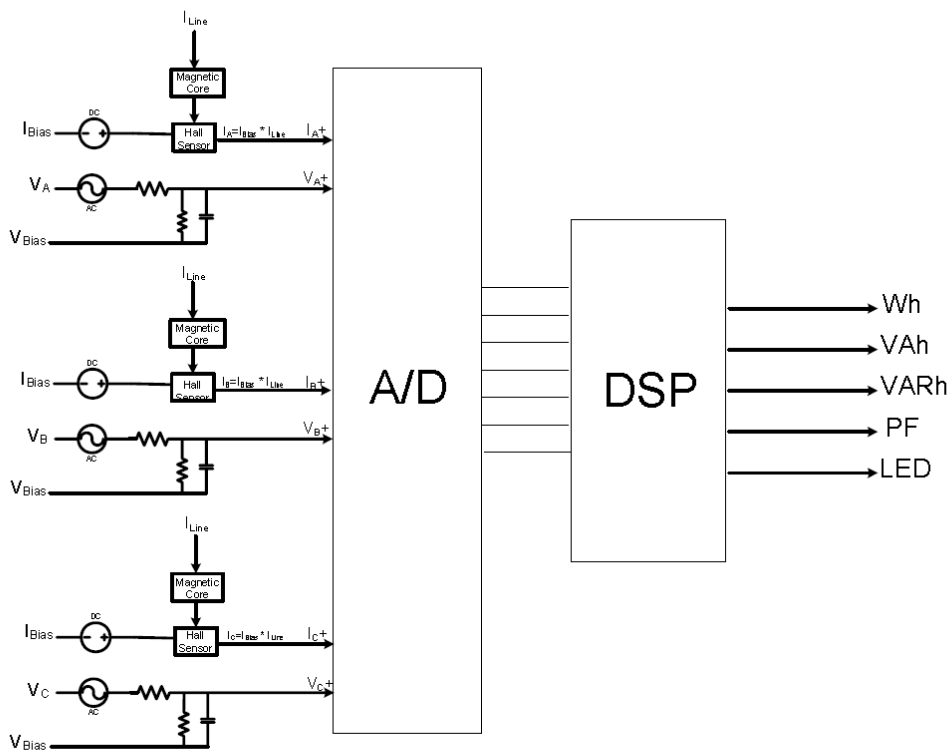
Smart Meter technology

- 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.



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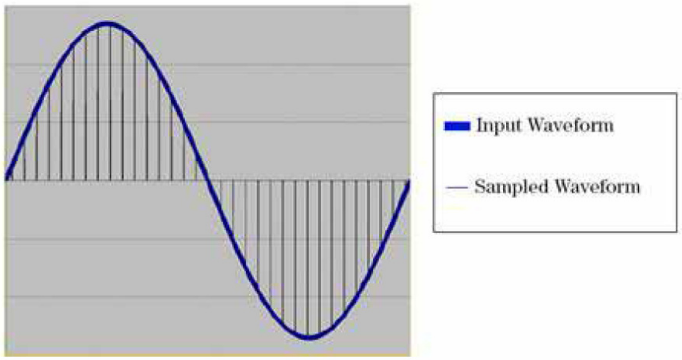
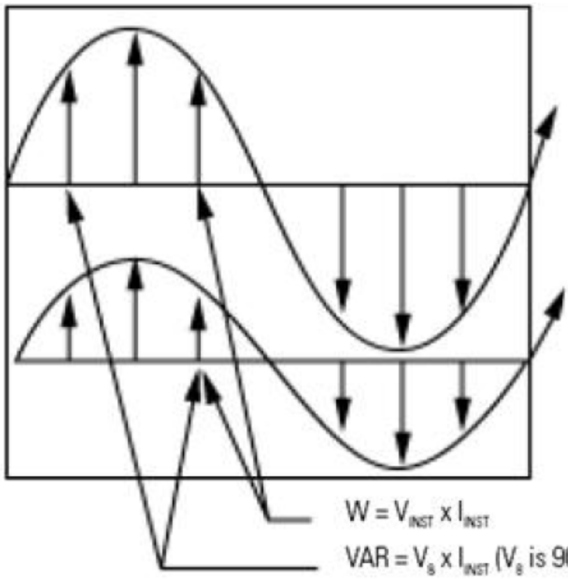
FFT sampling

- 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.



$$V_{RMS} = \sqrt{\frac{1}{N} \sum_{\Delta \to N} V_N^2}$$

$$I_{RMS} = \sqrt{\frac{1}{N} \sum_{\Delta \to N} I_N^2}$$

Where N is the number of samples per second

Smart meter Power calculations

- **Watthour (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 multipling 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-amperehour (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.

$$Qh = \frac{1}{2}Wh + \frac{\sqrt{3}}{2}Varh$$

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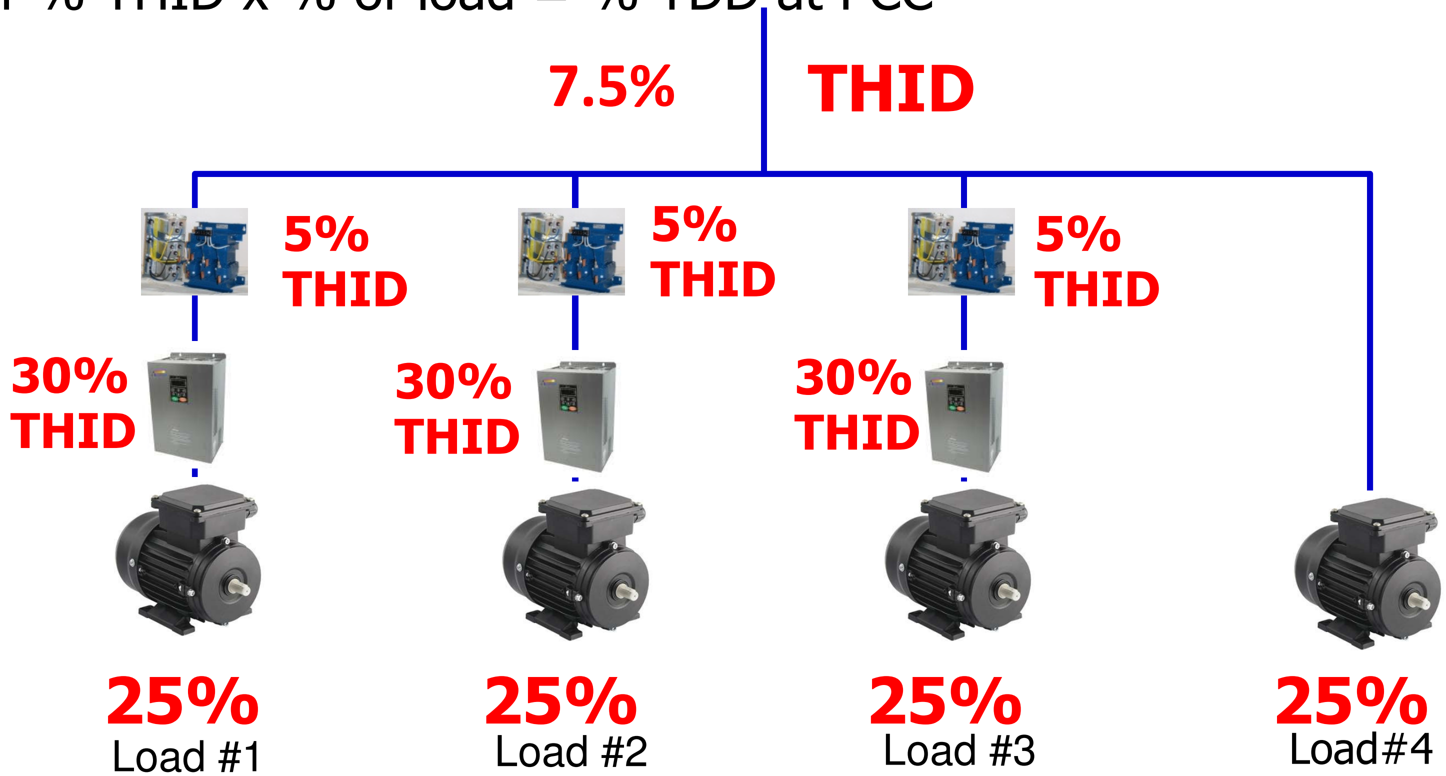
GE KV2c meter statement from their brochure

…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



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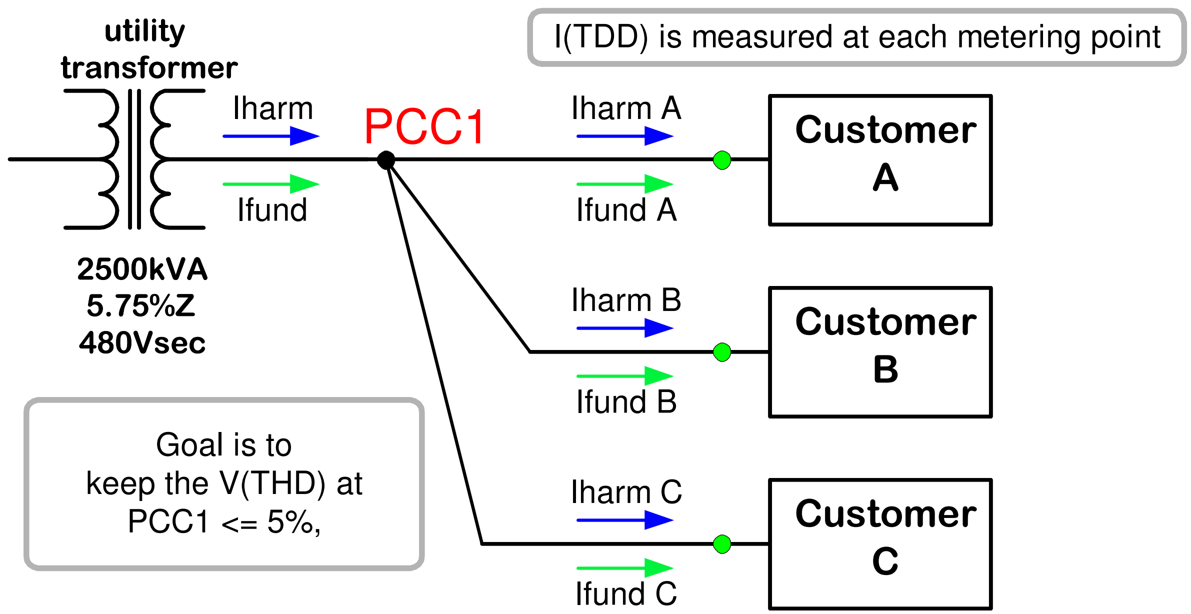
Harmonics are summed and cancel



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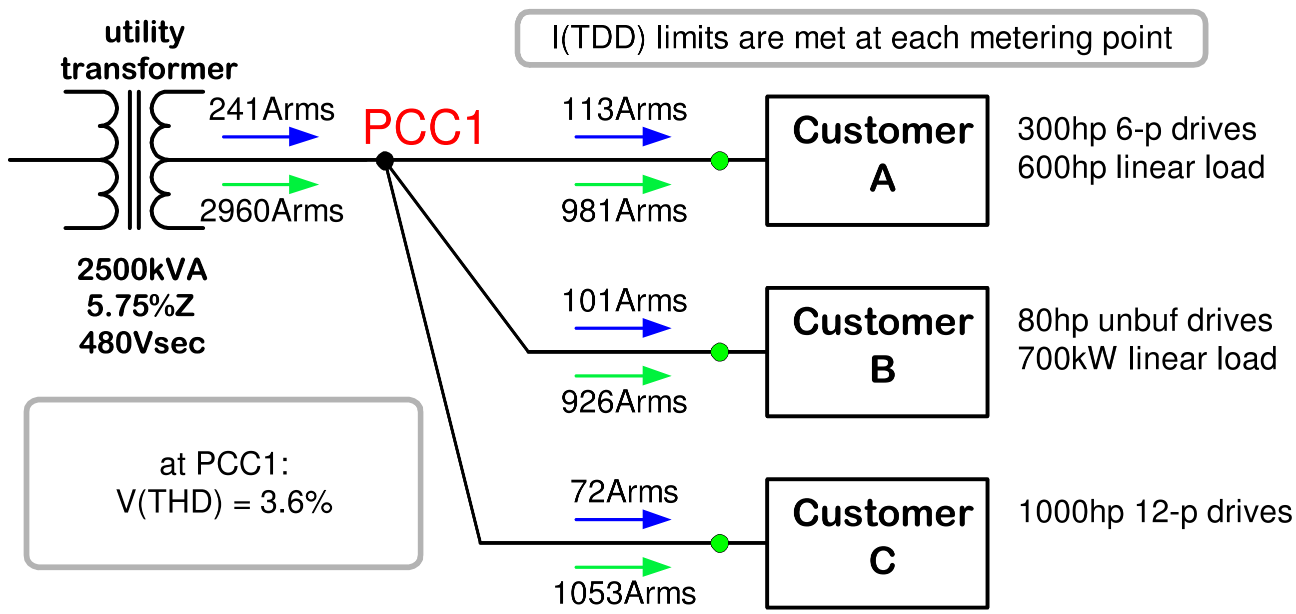
Example



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Customer example

Line #	Drive Type	HP	Average AC Amps	Tested AC Amps	Motor Rating FLA	THID/5th	origional	THID corrected	P.F.	KVA/KVAR	KW		contribution pre THID	contribution filtered			
Line #1	DC	75	60	61	123	34.4/31.5	34.4	34.4	37	52.9/49.15R	19.74		2.8	2.8		filter selection	filter list $
Line #2	DC	100	90	102	158	34.6/31.8	34.6	5	38	82.6/76.4R	31.4		3.6	0.5		MAPG0128D	$5,250
Line #3	DC	200	200	167	293	32.1/28.0	32.1	5	32	131.4/124.3R	42.6		6.1	1		MAPG0240D	$6,750
		* MTE-RLW															
Line #3	AC (blower)	20	12	14	25	75.1/62.8	75.1	75.1	75	11.6/7.7R	8.7		1.2	1.2			
Line #4	DC	200	240	217	320	34.0/29.3	34.0	5	45	170.0/151.5R	77.2		7.1	1		MAPG0240D	$6,750
		*MTE-RLW															
Line #4	AC (blower)	15	9	4.9	27	104/79.4	104	104	67	3.99/2.97R	2.67		1.8	1.8			
Line #5	DC	100	80	82.6	148	36.1/32.3	36.1	5	37	66.64/62.02R	24.4		3.5	0.5		MAPG0128D	$5,250
Line #6	DC	125	100	109.7	220	33.1/31.6	33.1	5	58	87.97/71.95R	50.6		4.7	0.7		MAPG0165D	$5,821
Line #7	DC	125	150	136	202	36.5/33.4	36.5	5	27	108.9/107.4R	18.3		4.8	0.7		MAPG0165D	$5,821
Line #7	AC (blower)	15	10	3.3	17.5	96.3/70.8	96.3	96.3	41	2.63/1.86R	1.85		1.1	1.1			
				897.5	1533.5								36.7	11.3			
linear load		850 hp															
										origional TDD	15%		projected total TDD		4.6		
transformer		1500kva															
ISC/load		17															
tdd		<5%															

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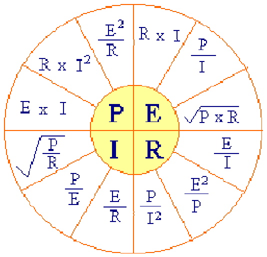
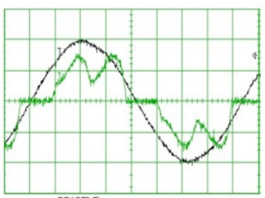
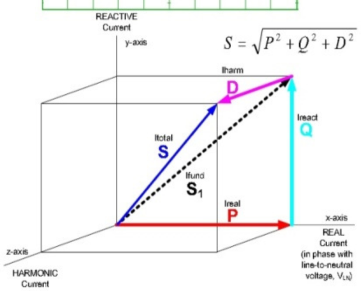
Power quality. Solved.

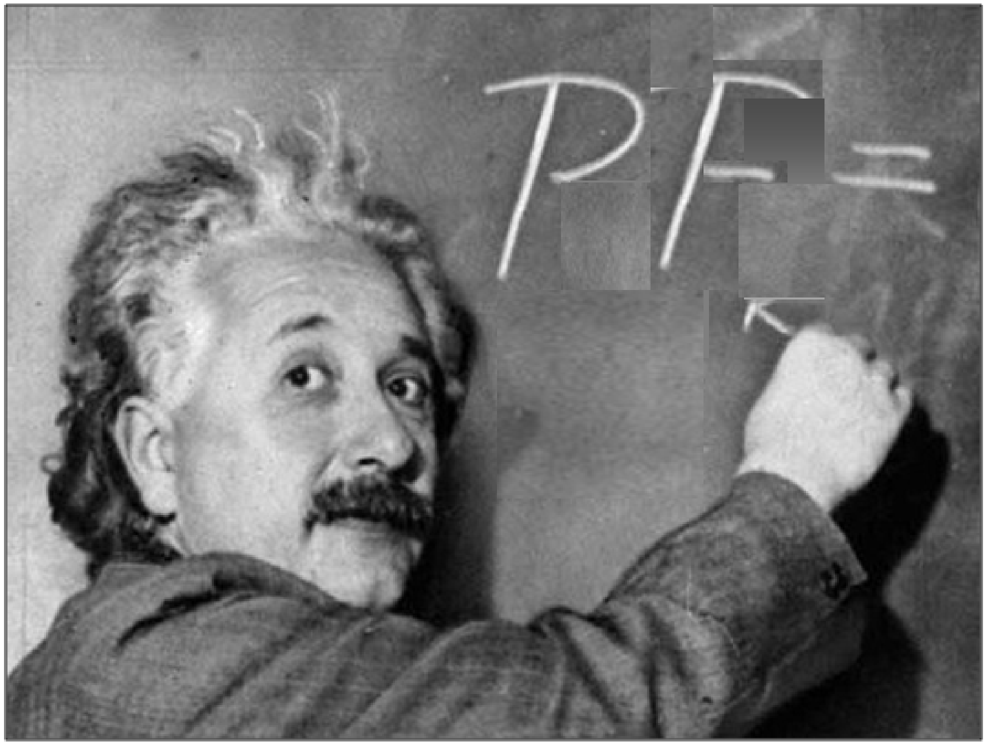
$$\text{Power Factor} = \frac{\text{Real Power (kW)}}{\text{Apparent Power (kVA)}} = \frac{\text{kW}}{\sqrt{(\text{kW})^2 + (\text{kVAr})^2}}$$

Einstein explains Power Factor (PF)

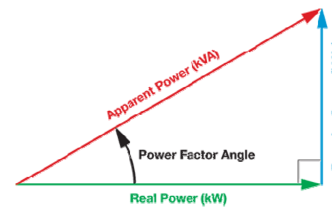








$$1/\sqrt{1 + \text{THD}^2}$$



"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***

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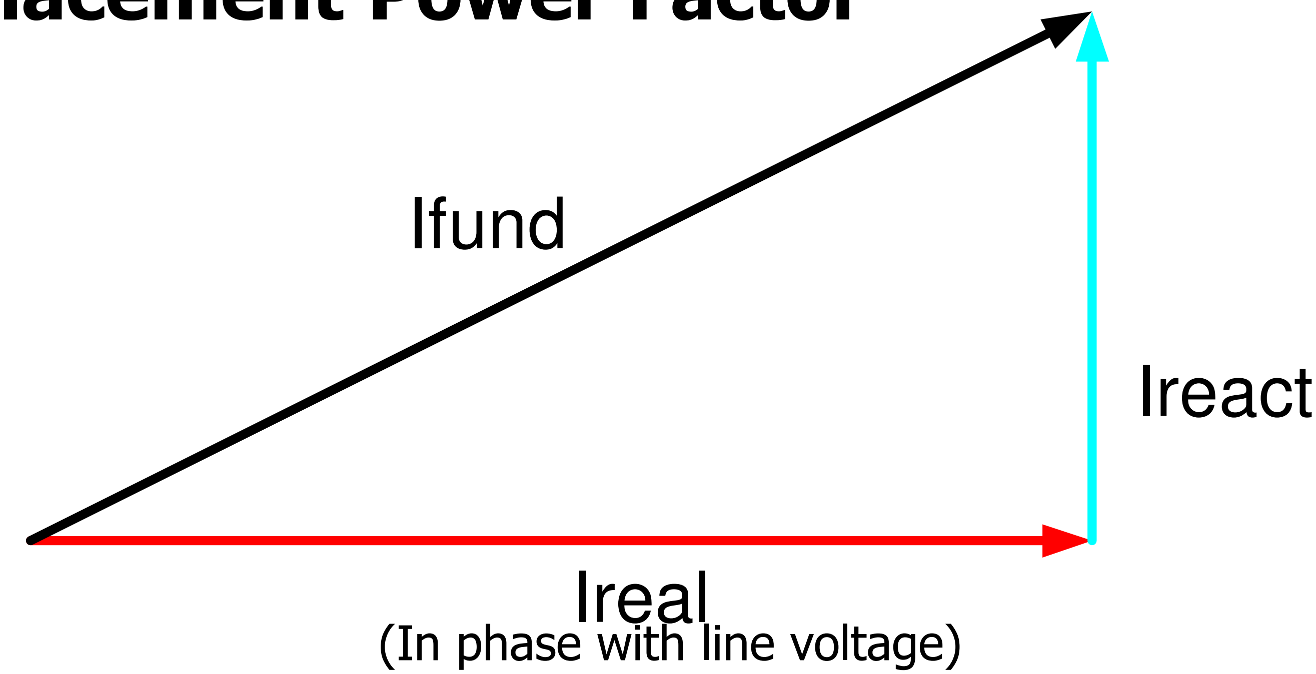
Displacement Power Factor

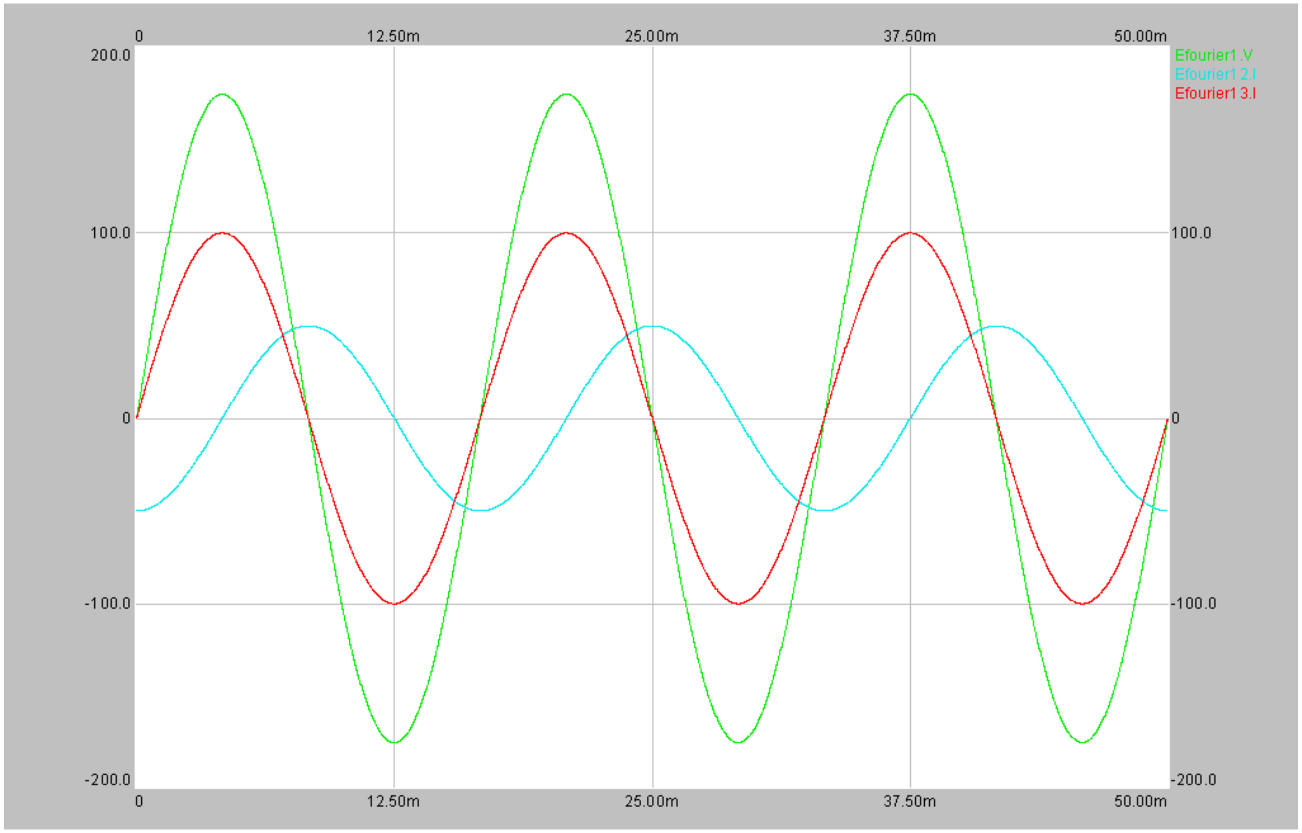


PF(disp) = Ireal / Ifund

$$Ifund = sqrt(Ireal^2 + Ireact^2)$$

Power quality. Solved.

Real and Reactive Current



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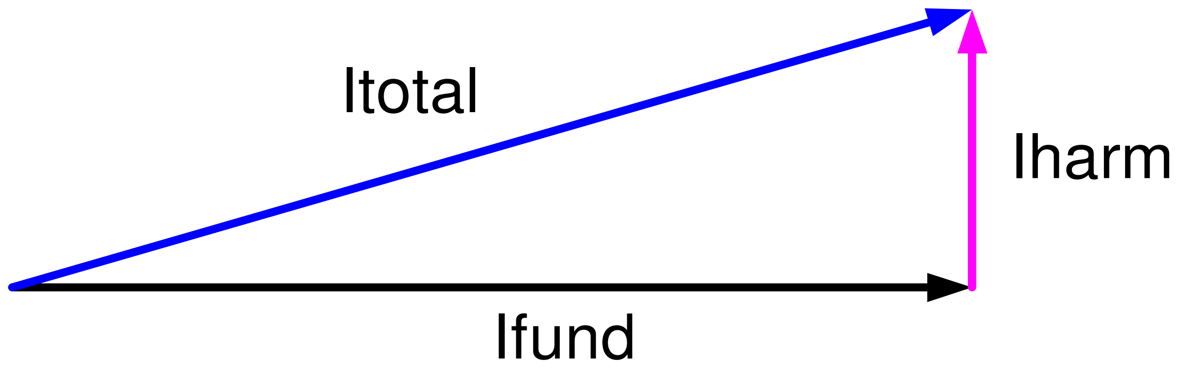
Distortion Power Factor



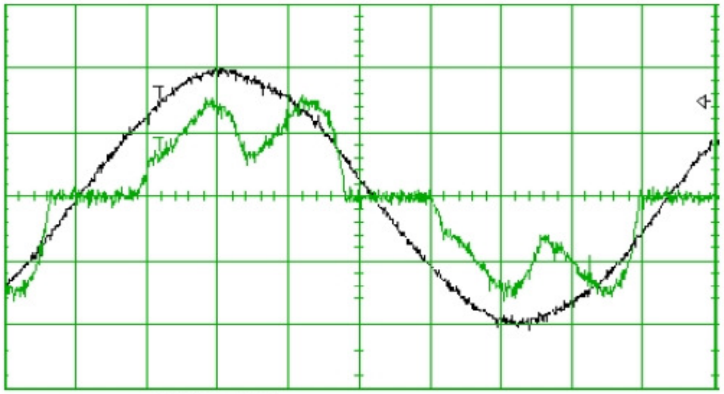
I(THD) = Iharm / Ifund

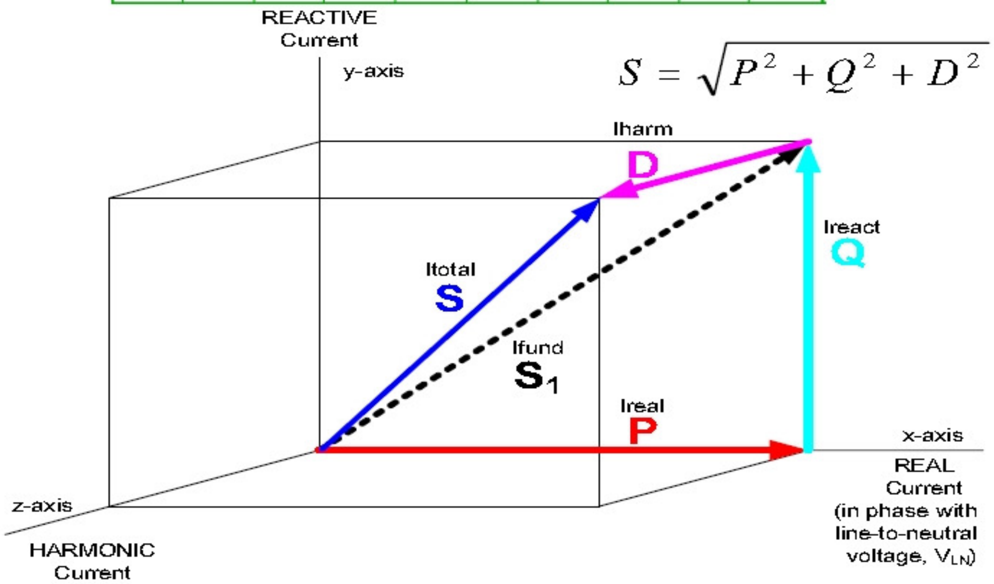
PF(dist) = Ifund / Itotal
= sqrt(1/(1+THD^2))

$$1/\sqrt{1+\mathrm{THD}^2}$$

Itotal = sqrt(Ifund^2 + Iharm^2)

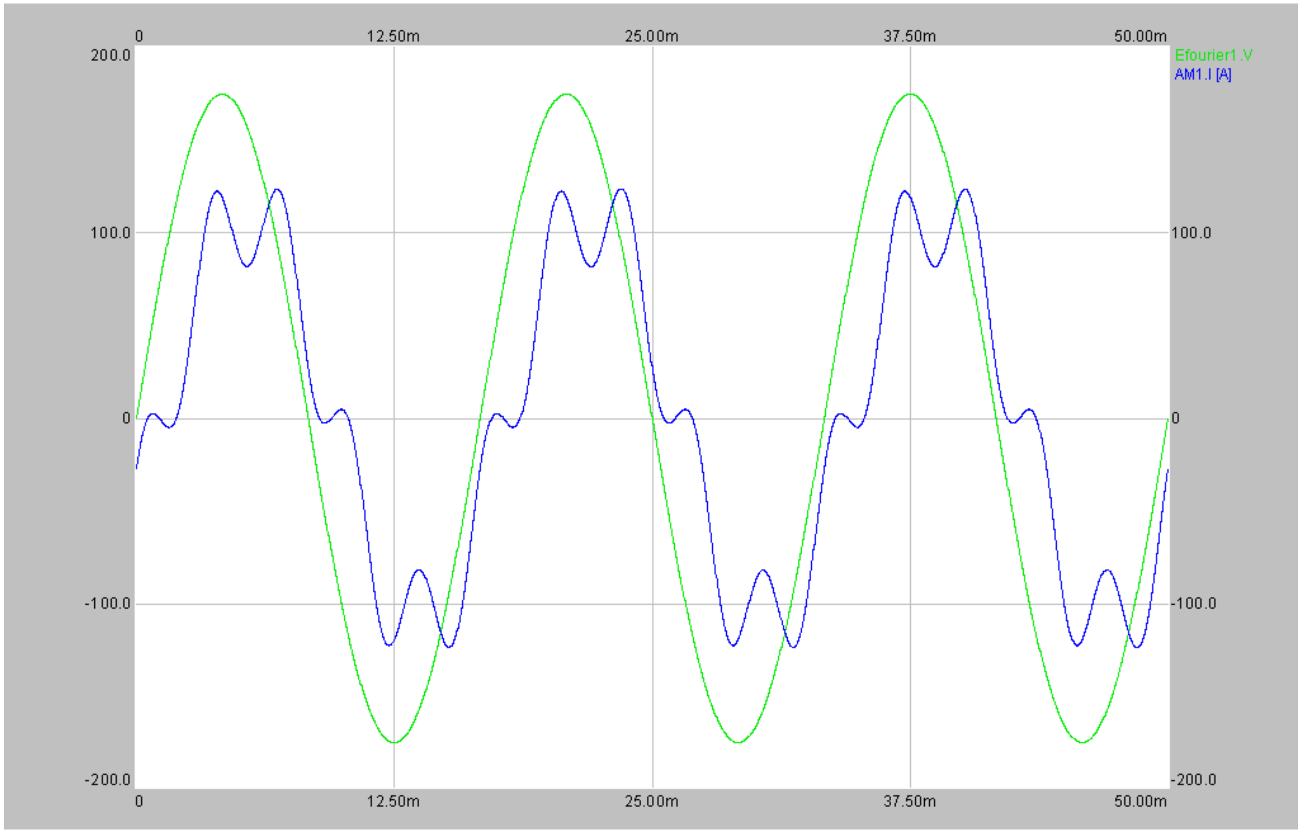
Total power or current is now a 3D vector diagram





Power quality. Solved.

Total Current = Real + Reactive + Harmonic



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Power quality. Solved.

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

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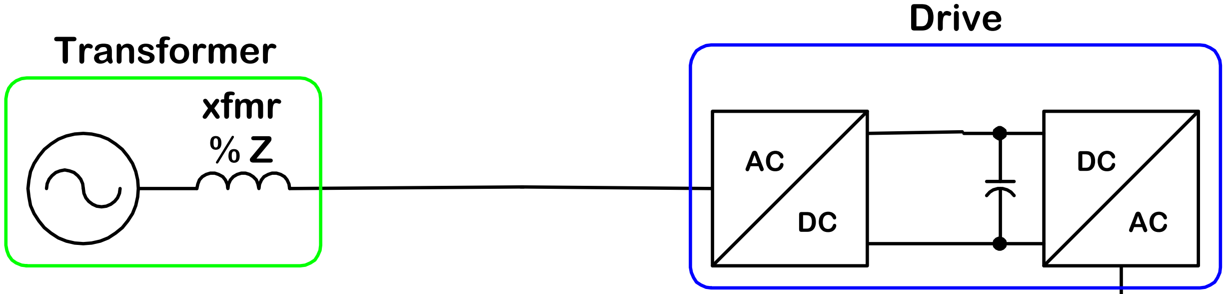
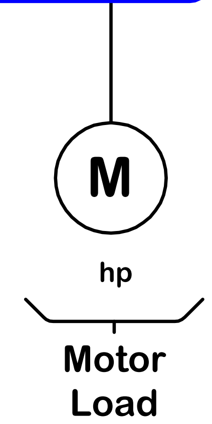
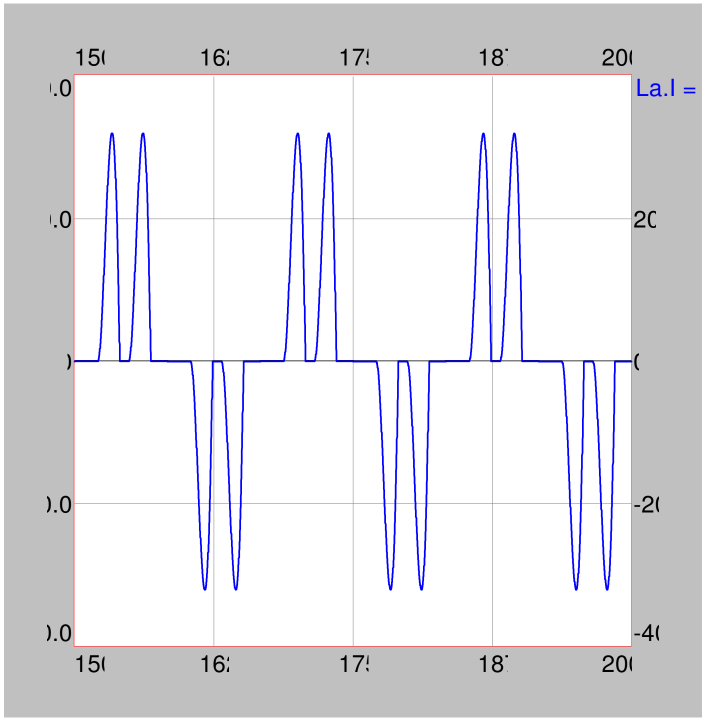
Power quality. Solved.

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%

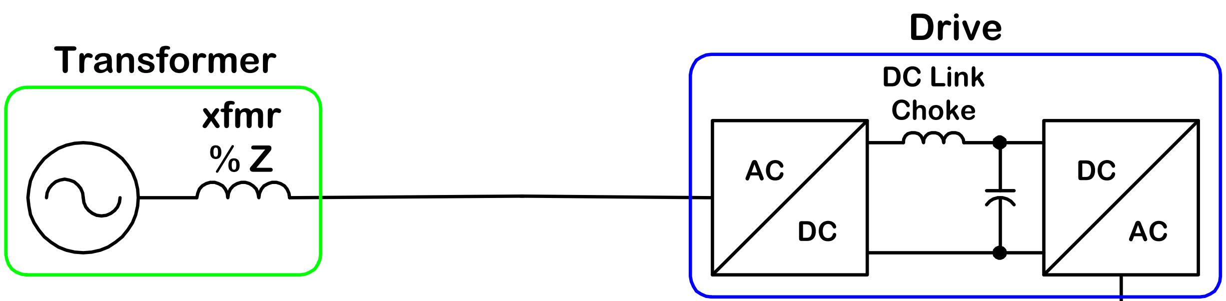


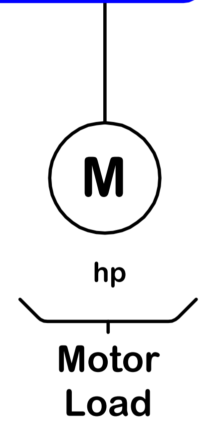




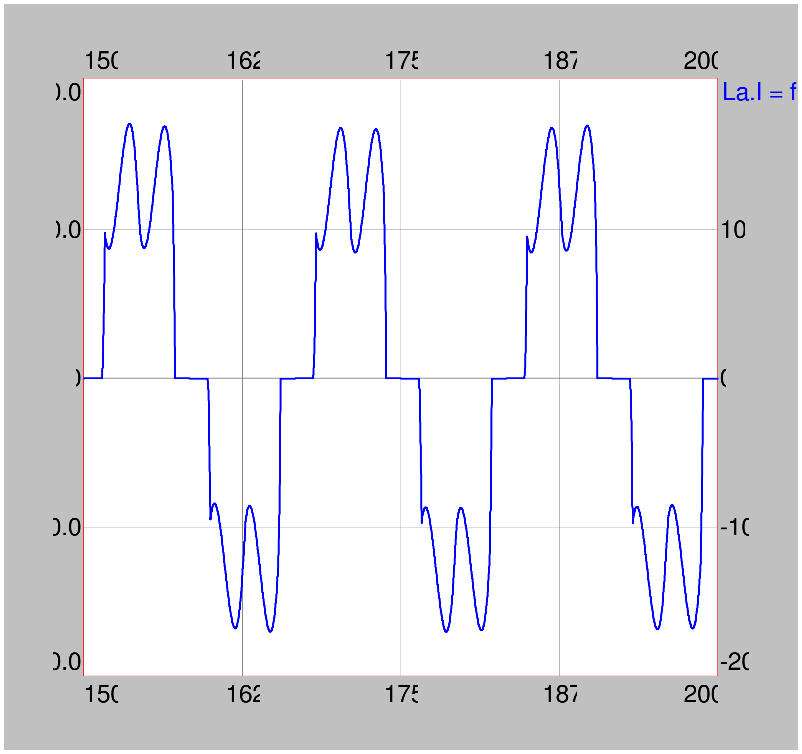
Power quality. Solved.

Drive with DC Link Choke





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



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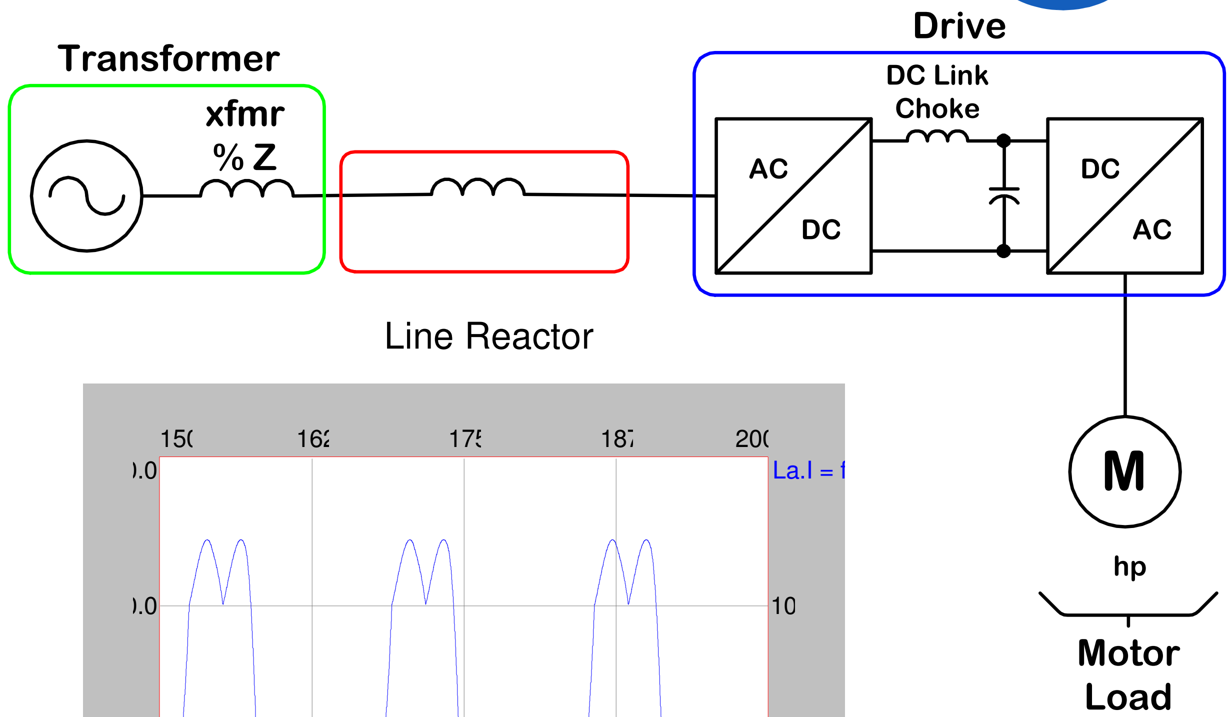
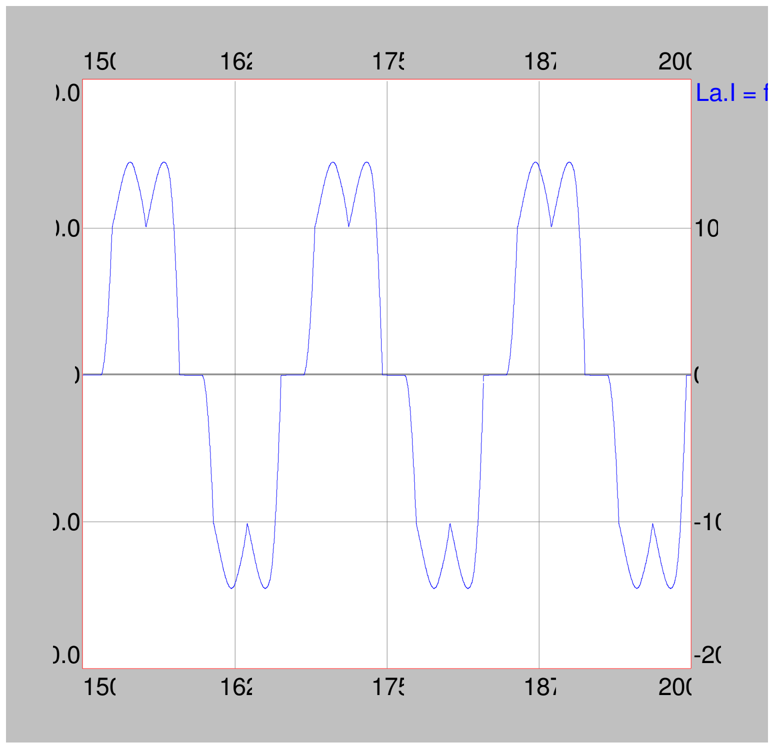
Line Reactor

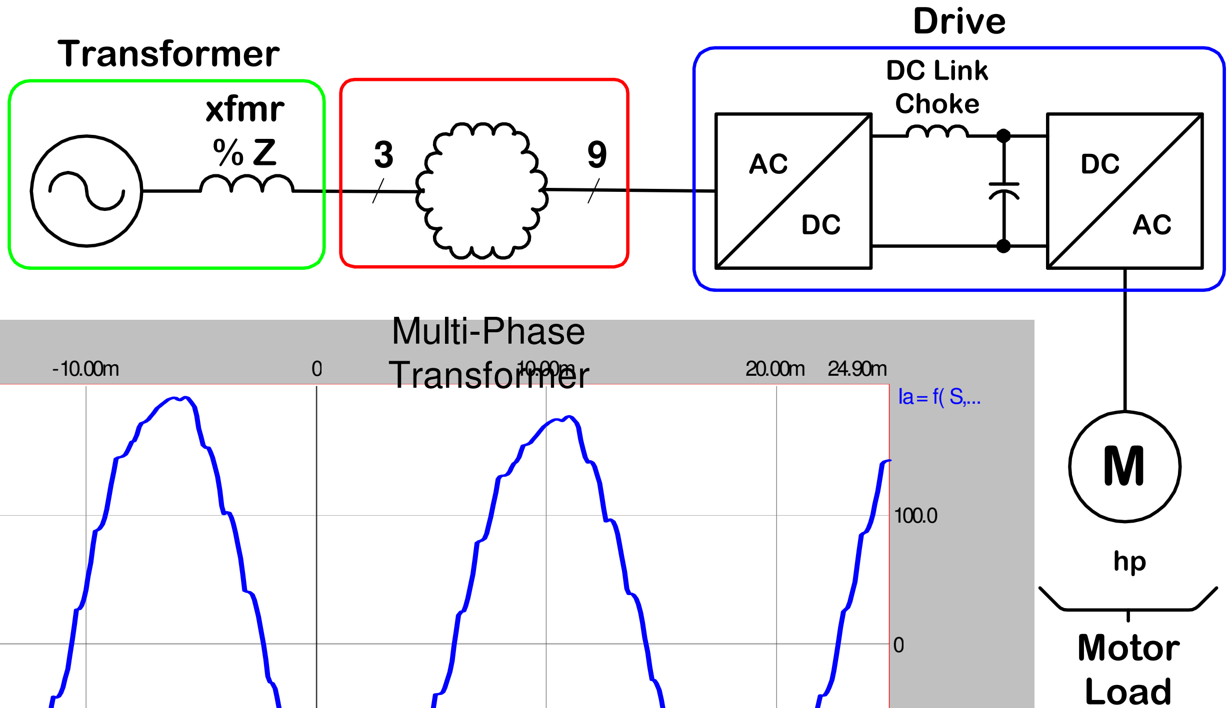


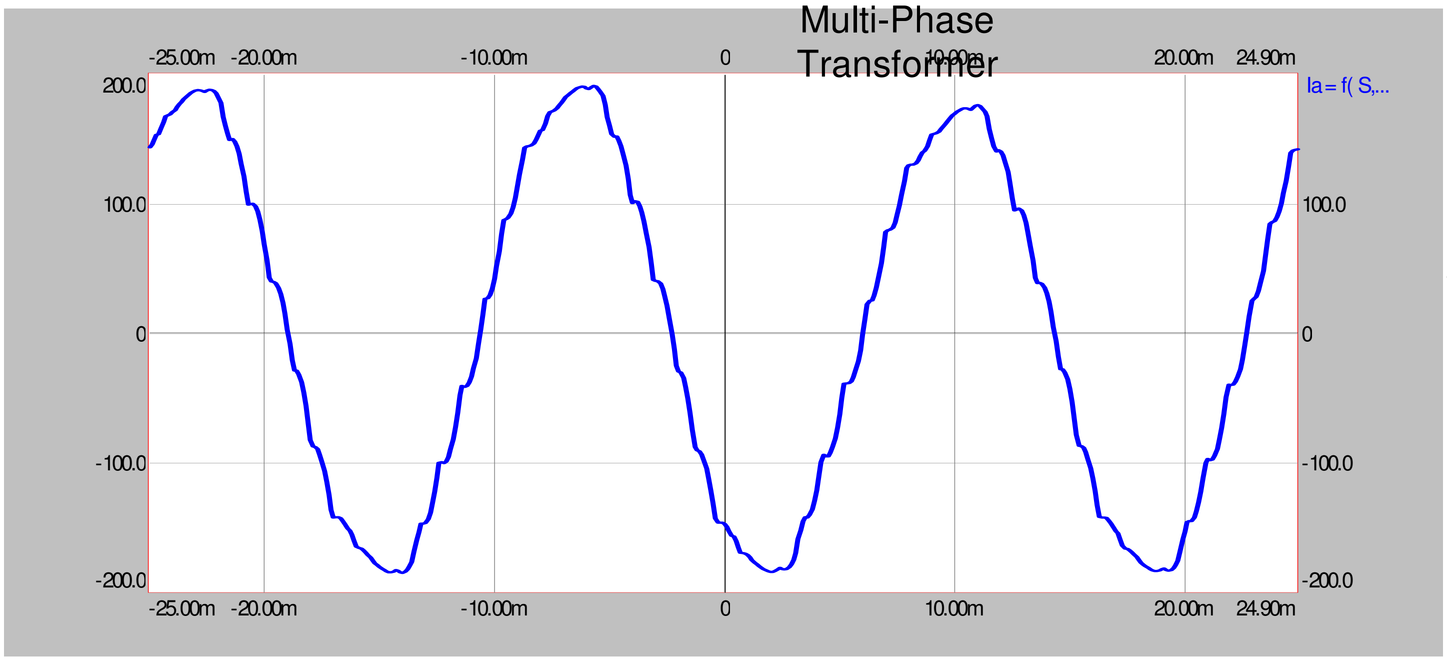


- Typical values are 3% and 5% impedance
- Big help for drives without DC link choke
- Typical I_{THD} of 25%

Power quality. Solved.

Multi-Pulse





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

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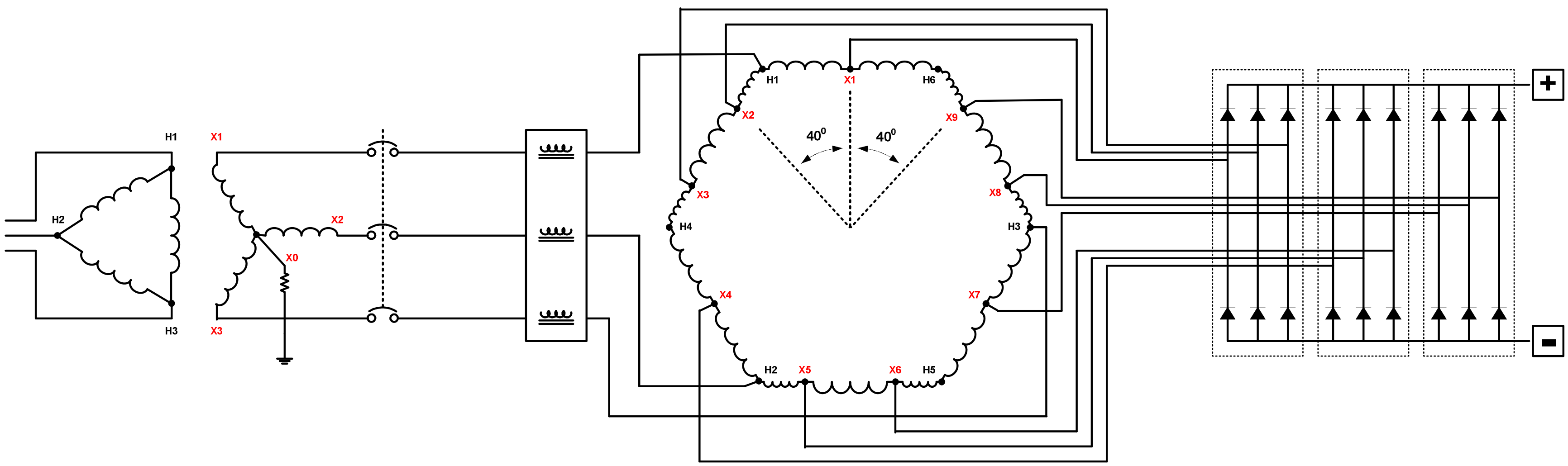
Power quality. Solved.

Supply Transformer | Line Reactor | Auto-Transformer | 18 Diode Bridge

18-Pulse Auto-Transformer Converter



Autotransformer

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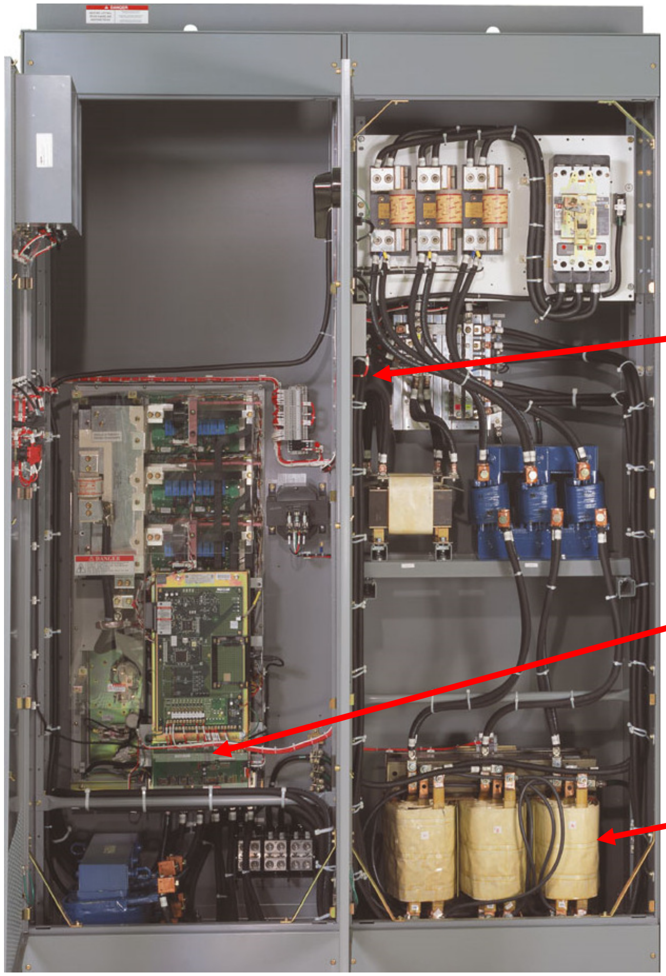
Power quality. Solved.

Multi-Pulse Front-End



12 or 18 pulse Diode bridge converter

Common DC bus drives

Auto or Isolation Transformers

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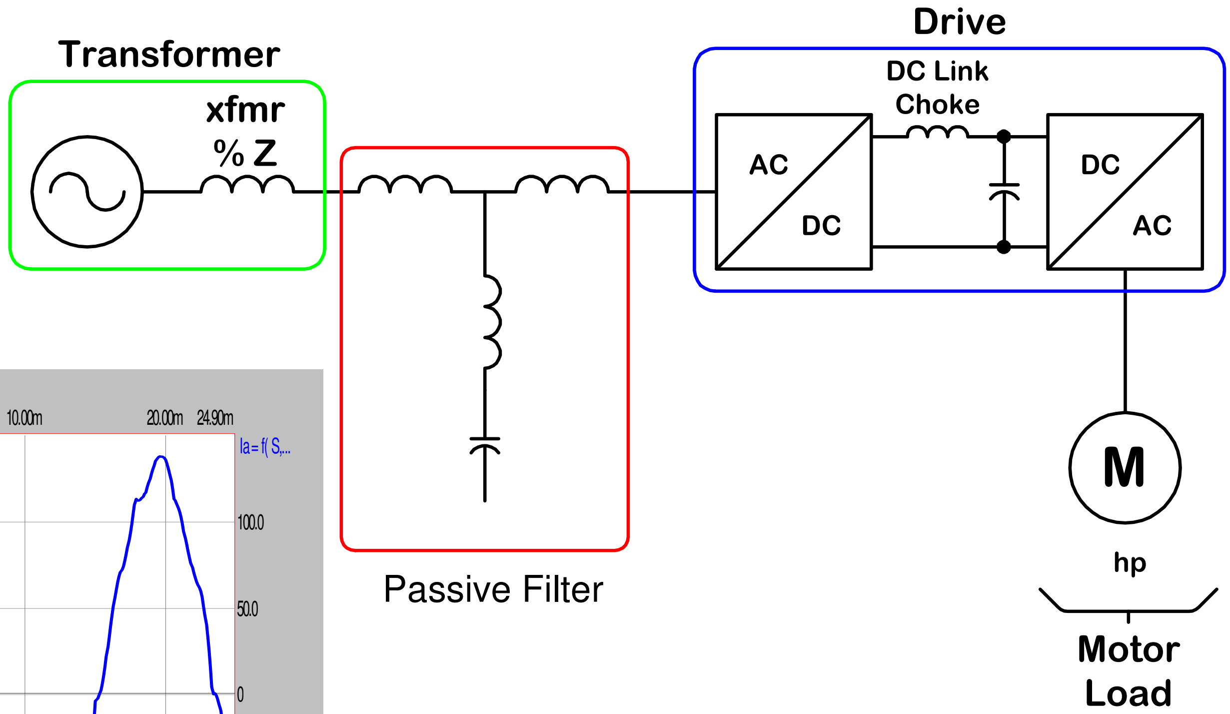
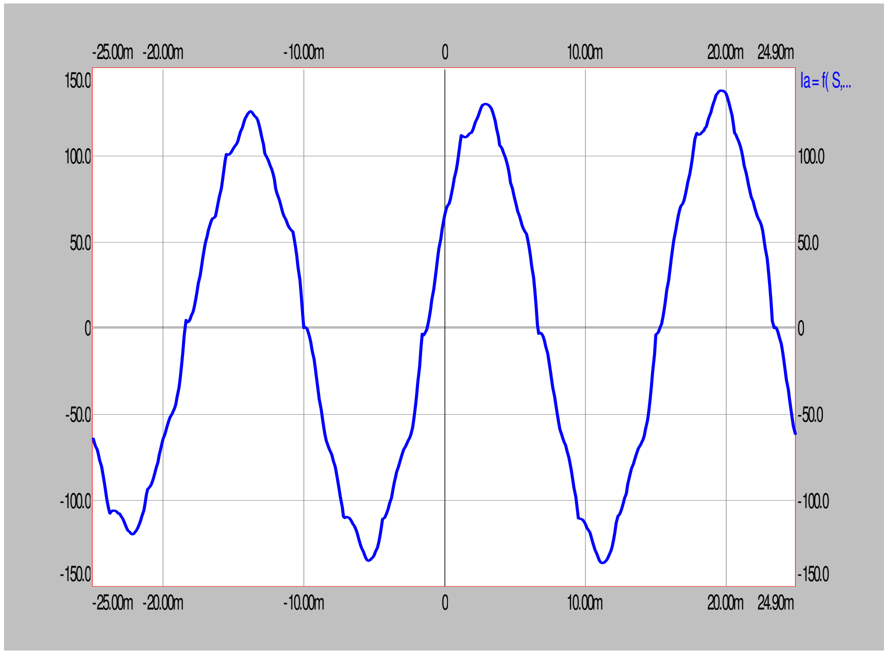
Power quality. Solved.

Passive Harmonic Filter





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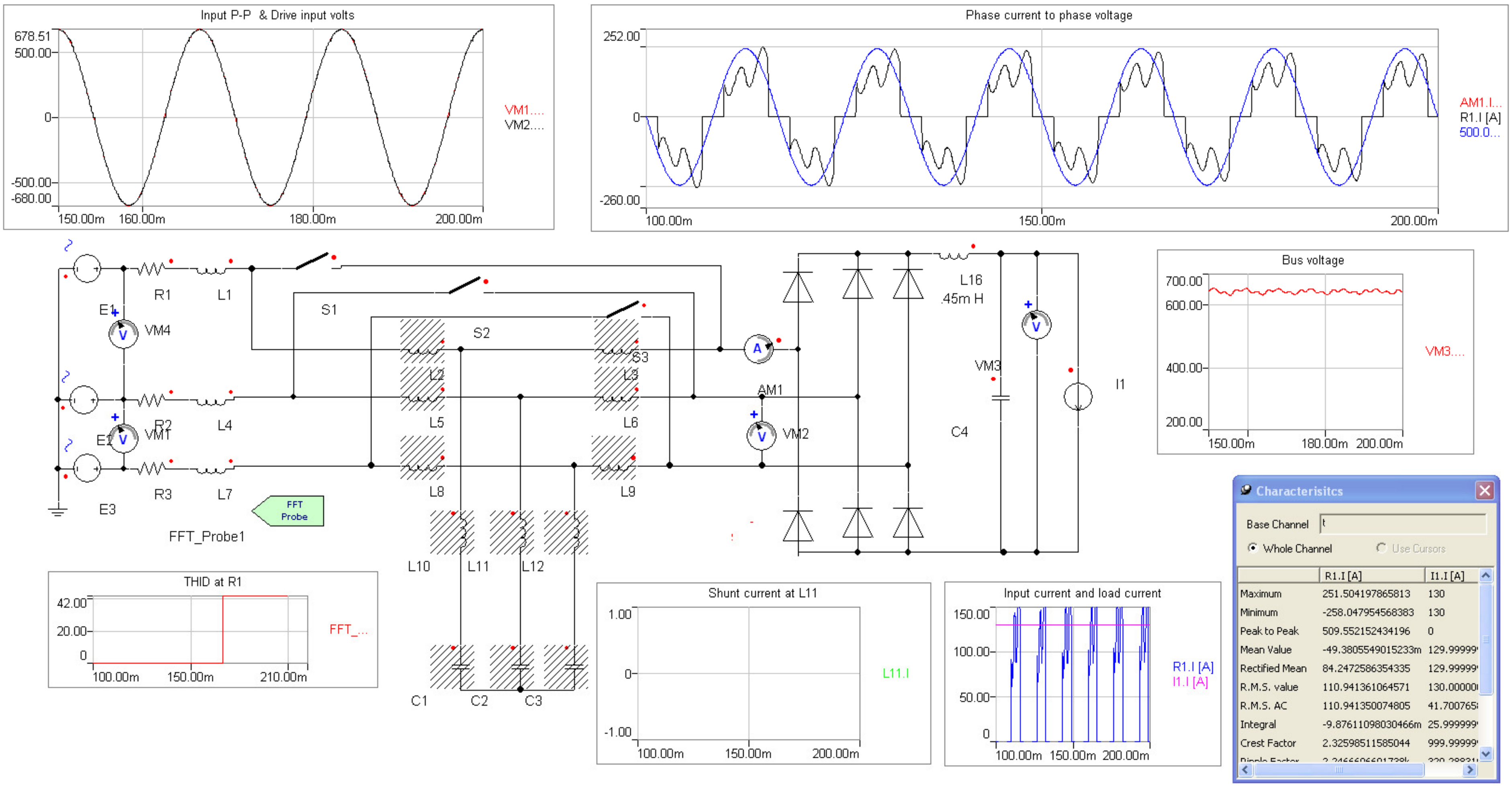
Power quality. Solved.

75 Hp harmonic simulation drive no filter



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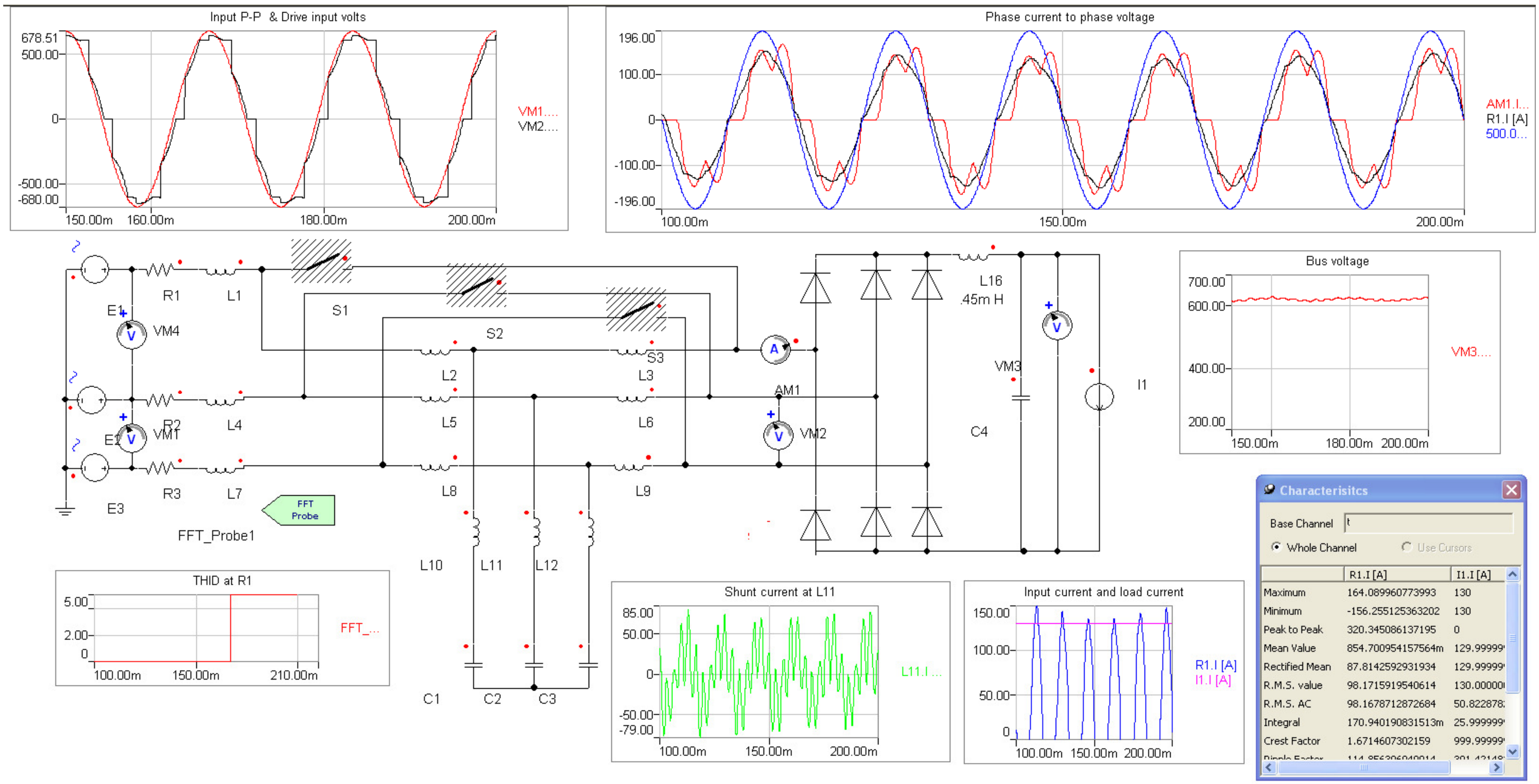
Power quality. Solved.

75 Hp harmonic simulation with filter



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Power quality. Solved.

MTE Matrix® AP

Wayne Walcott

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

The technical challenge:

Find a new technology for passive filters that

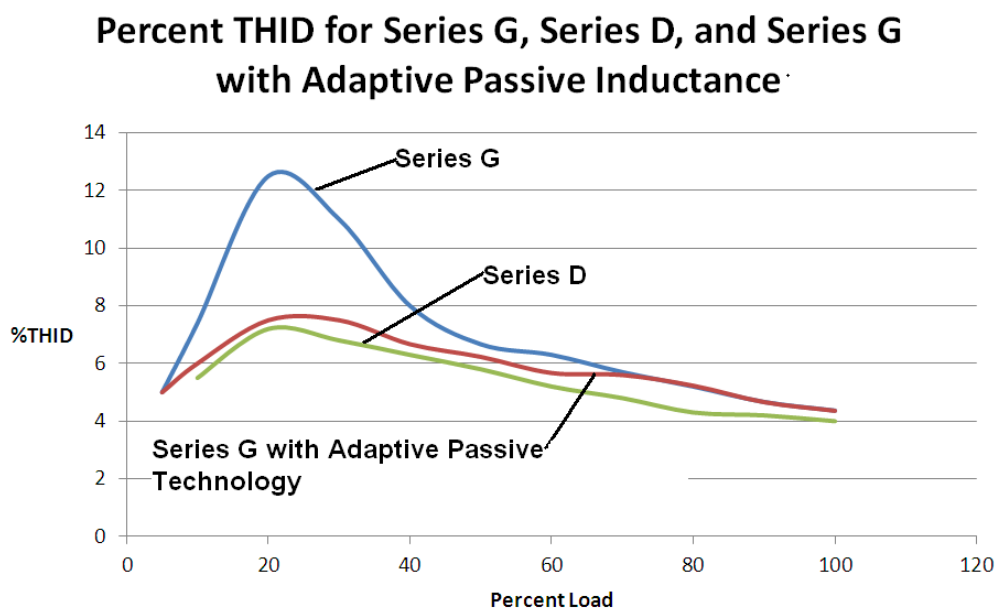
- offers consistent harmonic performance over load
- is compatible with generator systems
- reduces leading power factor
- Won't cause resonance with utility systems

Power quality. Solved.

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!



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Power quality. Solved.

A Deeper Look Into New Adaptive Passive Filter Technology

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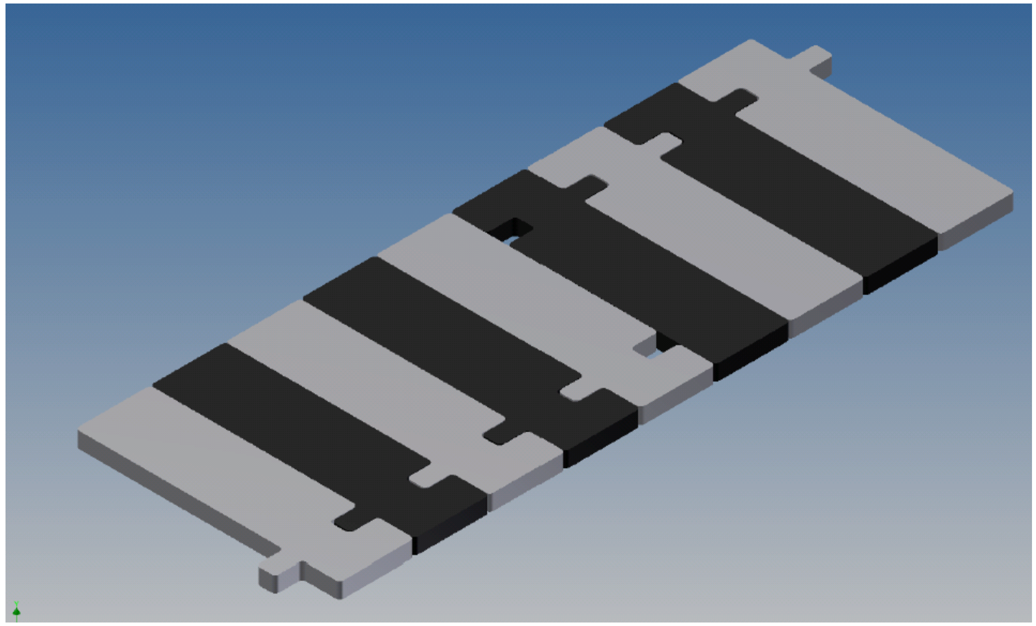
Power quality. Solved.

FAP Construction



- **F**errite + G**ap** = **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.

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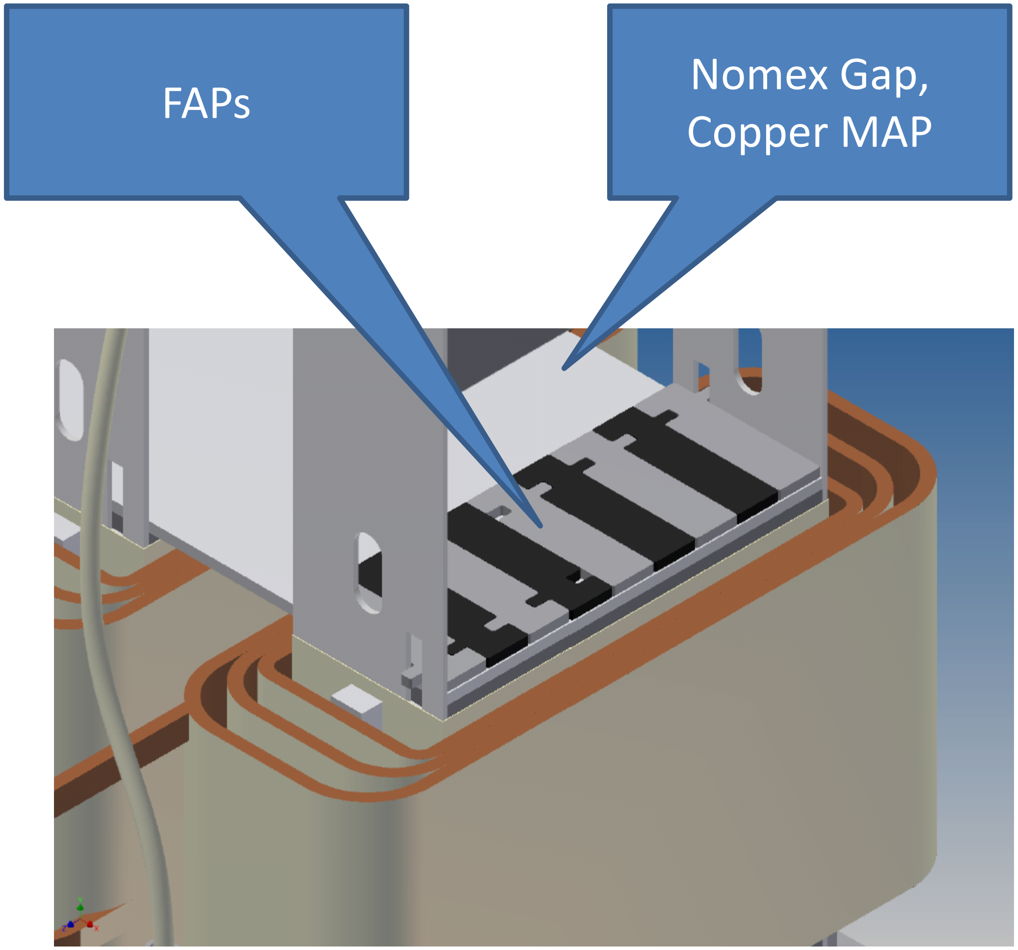
Power quality. Solved.

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.

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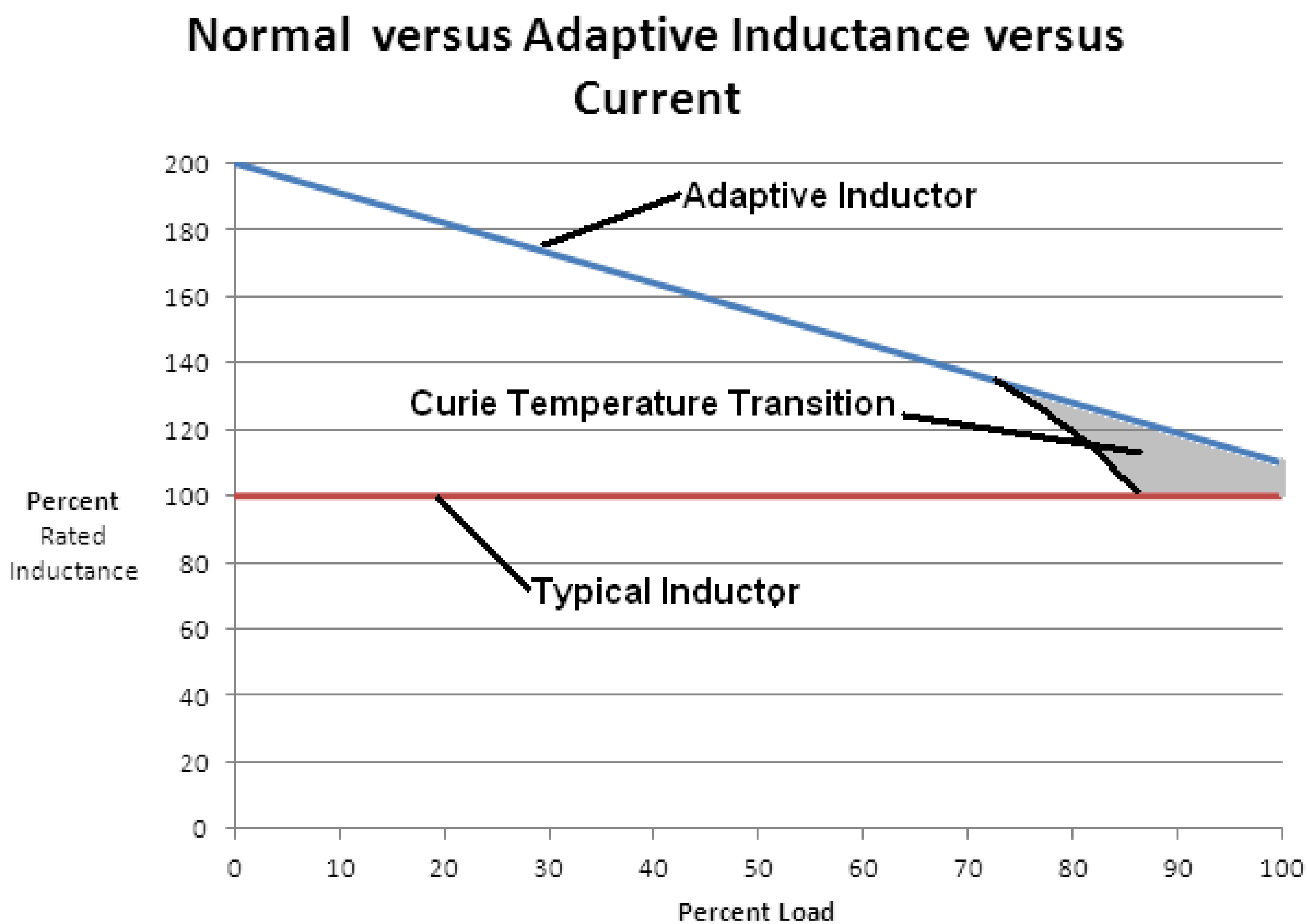
Adaptive Passive Inductance



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Power quality. Solved.

Technology Comparison

Step Gap Swing Choke

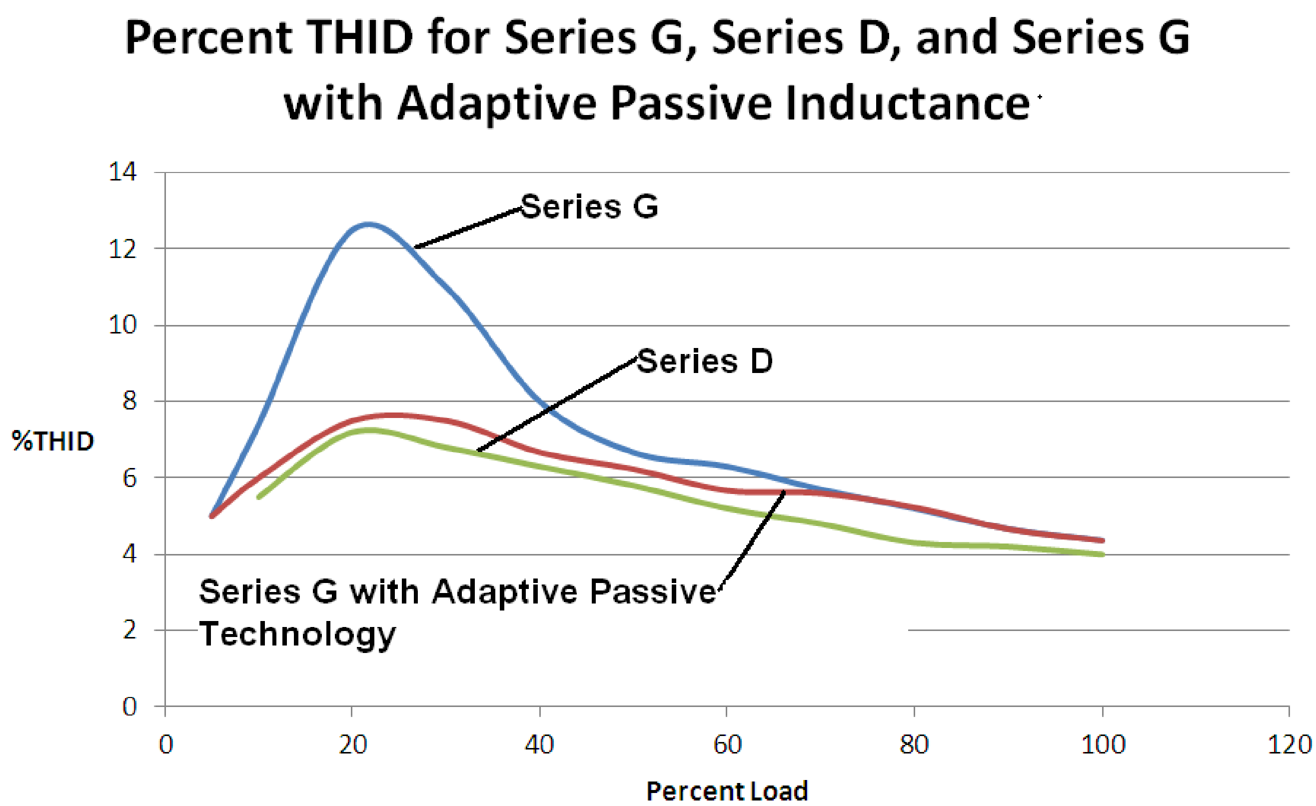
- The inductance change is very non-linear making it unsuitable for AC filters.
- The saturated part of the core can have excessive heating and audible noise.
- No optimally flat inductance characteristic possible.

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.

Power quality. Solved.

Matrix G with AP technology results



Power quality. Solved.

Matrix® AP Advantages

- MTE's patented **A**daptive **P**assive 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

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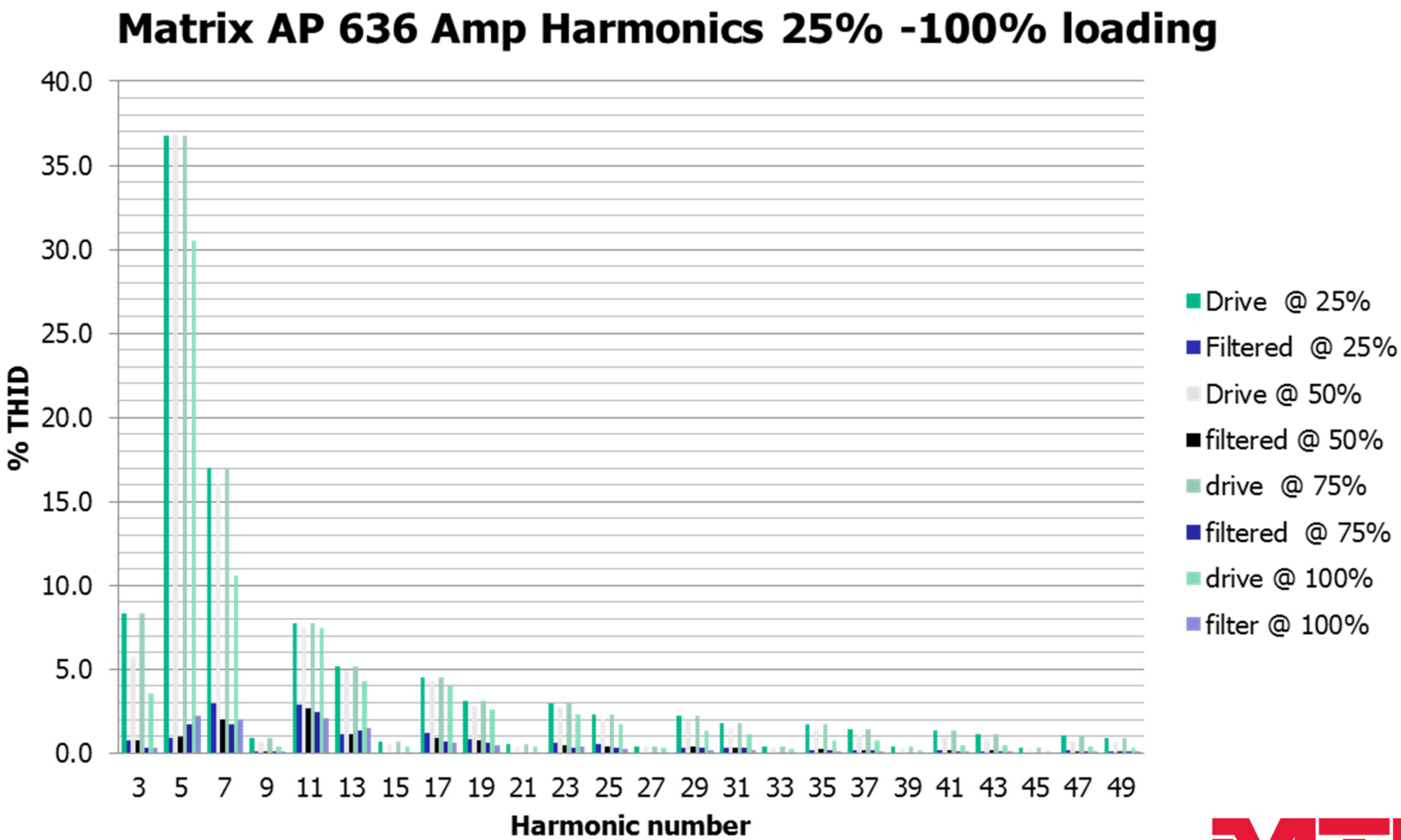
Power quality. Solved.

Matrix AP Loaded



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Matrix® AP Marketing Collateral: See Nate

- Two page sell sheet (PSP)
- Product selector (PSL)
- Technical Reference Manual (TRM)
- Website

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Power quality. Solved.

Application Profiles – Mitigating Harmonics

Application Profile

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 rely on a large counterweight to offset the weight of the pump rod which can be several hundred feet long. This produces a motor and drive load profile that is cyclical with a frequency from 2 to 5 cycles per minute. During one of these cycles, the load can vary 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 are the main load on the power grid and sometimes can be the only load for many square miles. 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 80% and 100% load.

In the oil fields, the cumulative effect of lightly loaded drives and filters results in background voltage distortion of 10% or more.

The power grids that feed these reciprocating pumps cannot support the additive harmonic distortion created resulting in nuisance tripping, overheating of transformers, and overall system downtime.

The solution:

MTE worked closely with a large energy company to test the Matrix AP Harmonic Filter against a competitor's filter on 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 THID at 45% load.

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

The result:

MTE's Matrix AP Harmonic Filter proved to be the best solution for keeping low level harmonic distortion from accumulating on the power grid.

Current distortion was 15% to 30% lower with the Matrix AP Filter. Voltage distortion at the utility transformer was lower as well.

MTE's Matrix AP Harmonic Filters, with its patent pending adaptive passive technology, together with 6-pulse drives out-performed the competition.

The solution ensured that the energy company minimized harmonic distortion to the grid and stay in production, thus maximizing revenue.

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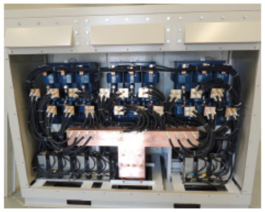
Application Profile

Reducing Harmonics 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 supplies (over 3 Megawatts) has harmonic issues that are created by the system. These power supplies have a Silicon-Controlled Rectifier (SCR) bridge to generate and regulate power for heat treating and hardening. These large rectifiers cause significant distortion on the power line if left unmitigated. The effect can cause serious damage to neighboring power consumers causing disturbance to various electronics such as computers, televisions, telephones, and stereos.



The challenge:

A standard harmonic filter capable of several thousand amps is not readily available and to custom design a filter at this power level would not be practical. The harmonics created by these power supplies can affect residential homes in a nearby subdivision causing the electric utility company to shut down the heat treating factory.

The solution:

MTE worked closely with the OEM to develop a solution by paralleling harmonic filters. Several 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 over a very wide operating load range. Less than 5% total harmonic current distortion THID is achievable at 45% load. Working with MTE, the OEM developed methods for parallel buss-work and cooling to maintain the integrity of the filter, thereby achieving the desired results.

The result:

Working with MTE, the end user was able to achieve the required reduction of the overall harmonic distortion. The secondary distortion that might have affected the local residence was no longer a problem. Paralleling harmonic filters was a cost effective solution for the end user instead of creating a large custom designed filter.

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Power quality. Solved.

Application Profile – Multi-pulse

Application Profile

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.

Progressive Cavity Pumps (PCPs) on artificial lift systems are often driven by Variable Frequency Drives (VFDs). These drives help the motors run more efficiently but also introduce harmonic distortion. Unmitigated harmonics can lead to power quality problems on the system as well as the power grid. A global drive manufacturer working with MTE achieved a winning solution with improved quality, increased productivity, and greater operational efficiencies.

The challenge:

A large global drive manufacturer was looking for a competitive edge. They wanted to win by lowering the total cost of ownership for the oil producer.

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

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

The solution:

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

Test data provided by MTE demonstrated that the Matrix AP Harmonic Filter, with a 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 with its patent-pending adaptive passive technology, provides strong harmonic filtering performance across a wide range of loads and less heat rejection.

The result:

Teaming with the global drive manufacturer, MTE's technical experts delivered an optimized, low-cost winning solution that outperformed the multi-pulse drive. Benefits included:

- Reduced power loss and improved efficiency
- Higher performance under unbalanced line conditions
- Better overall power factor due to reduced distortion
- Improved reliability
- Lower initial capital expediture and overall operating costs

MTE AN SL INDUSTRIES COMPANY Power quality. Solved.

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DRIVING POWER QUALITY
ISO 9001:2008 Certification

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

November 13, 2012
Todd Shudarek, Principal Engineer

Abstract

The proliferation of variable frequency drives (VFDs) has bro
effects created by drives. A standard 6-pulse drive with no harmoni
with neighboring equipment, reduce equipment life, and negatively i
some circumstances the total harmonic current distortion (THID
fundamental current. Drive manufacturers offer a low harmonic, 18-
An alternative solution is the use of a traditional 6-pulse drive equi
however, typical passive harmonic filters experience reduced effectiv
the introduction of adaptive passive technology, the Matrix AP harm
filtering performance across a wide range of loads. This paper com
18-pulse drive with the performance of a standard 100 HP 6-pulse d
AP harmonic filter.

The 6-Pulse drive with Matrix AP harmonic filter outperforme
important areas:

- **Power loss:** Approximately 665 less watts consumed.
- **Overall efficiency:** 0.5% more efficient (99.0% vs. 98.5%).
- **Harmonic performance under balanced line conditions**
  loads 25-75% and equal performance for loads greater than
- **Harmonic performance under line imbalance condition**
  For example under 3% line imbalance, performance was 32
  25% load and 13% better (12% vs 25% THID) at 50% load..
- **Power Factor:** Better to equal performance for loads 50-100

A 6-pulse drive with a Matrix AP harmonic filter has a number of
drive: smaller equipment size and weight, lower price, and shorten
drives and corresponding replacement parts.

*The Matrix AP harmonic filter exhibited a reduced leading p
advantageous in some circumstances, a capacitor contactor optio
capacitors from the circuit and eliminate this condition.

Background

The proliferation of variable frequency drives (VFDs) has brought increased attention to harmonic effects created by drives: a standard 6-pulse drive with no harmonic mitigation technology may interfere with neighboring equipment, reduce equipment life, and negatively impact the utility power quality. Under some circumstances the total

harmonic cur
the level of
manufacturers
drive to com
solution is th
equipped with
typical pass

MTE Corporation, N83 W13330 Leon Road, Menomonee
Phone: 262-253-8200 • Fax: 262-253-8222 • Email: sales@mt

LINE/LOAD REACTORS • MATRIX® HARMONIC FILTERS • RFI/EMI FILTERS • DC LINK CHOKES

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Harmonic Mitigation in Variable Frequency Drives: 6-Pulse Drive with Matrix AP Harmonic Filter vs. AFE Drive

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Abstract

The proliferation of variable frequency drives (VFDs) has brought increased attention to harmonic effects created by drives. A standard 6-pulse drive with no harmonic mitigation technology may interfere with neighboring equipment, reduce equipment life, and negatively impact the utility power quality. Under some circumstances the total harmonic current distortion (THID) may approach the level of the fundamental current. Some drive manufacturers recommend Active Front End (AFE) drives to combat these effects. An alternative solution is the use of a traditional 6-pulse drive equipped with a passive harmonic filter; however, typical passive harmonic filters experience reduced effectiveness at loads less than 100%. With the introduction of adaptive passive technology, the Matrix AP harmonic filter maintains strong harmonic filtering performance across a wide range of loads. This paper compares the performance of a 20 HP AFE drive with the performance of a standard 30 HP 6-pulse drive equipped with a 44 amp Matrix AP harmonic filter.

The 6-pulse drive with Matrix AP harmonic filter outperformed the AFE drive in the following important areas:

- Harmonic performance under balanced line conditions: 2-9% better THID performance 25-75% loads and similar performance (about 4% THID) at 100% load.
- Harmonic performance under line imbalance conditions: Significantly better performance. For example, under 3% line voltage imbalance performance was 28.8% better (26.3% vs. 44.3% THID) at 25% load and 6% better (12.3% vs. 18.3% THID) at 50% load.
- Power Factor: Similar performance for loads 50-100%. Equal performance at 25% load and 3% voltage imbalance.*

A 6-pulse drive with a Matrix AP harmonic filter has a number of additional benefits over the AFE drive: smaller equipment size, lower price, shortened lead time, and increased availability of drives and corresponding replacement parts.

*The Matrix AP harmonic filter exhibited a reduced leading power factor under light loads. While advantageous in some circumstances, a capacitor contactor option may be used to remove the filter capacitors from the circuit and eliminate this condition.

Background

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