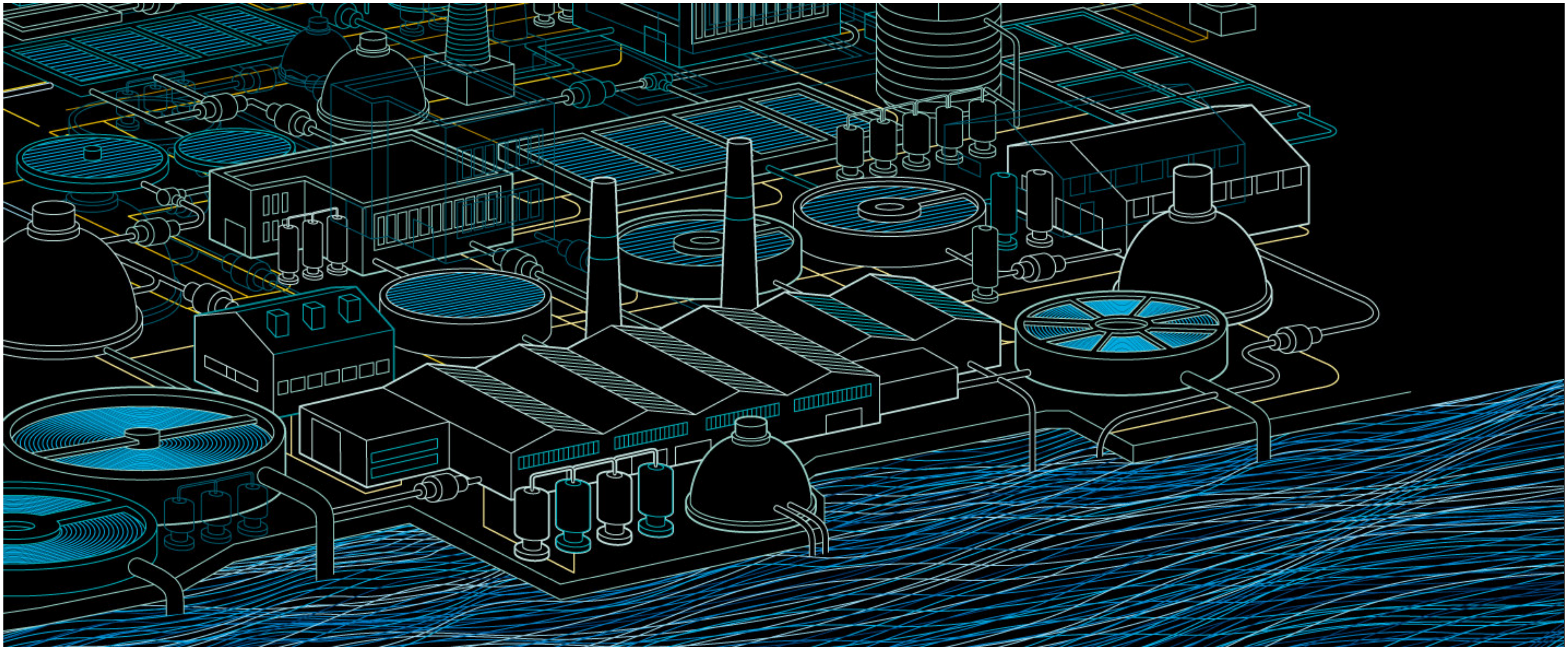

Matthew LaRue, ABB Drives Product Manager Philadelphia District, Baldor of Philadelphia

A Common Cure for Harmonics: ABB Ultra Low Harmonic Drives

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Power and productivity
for a better world™

Session Goals

- Understand what harmonics are
- Understand why harmonics may be a concern
- Provide simple guidelines for when to be concerned
- Understand what options are available for addressing harmonic issues

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Harmonics —

What?

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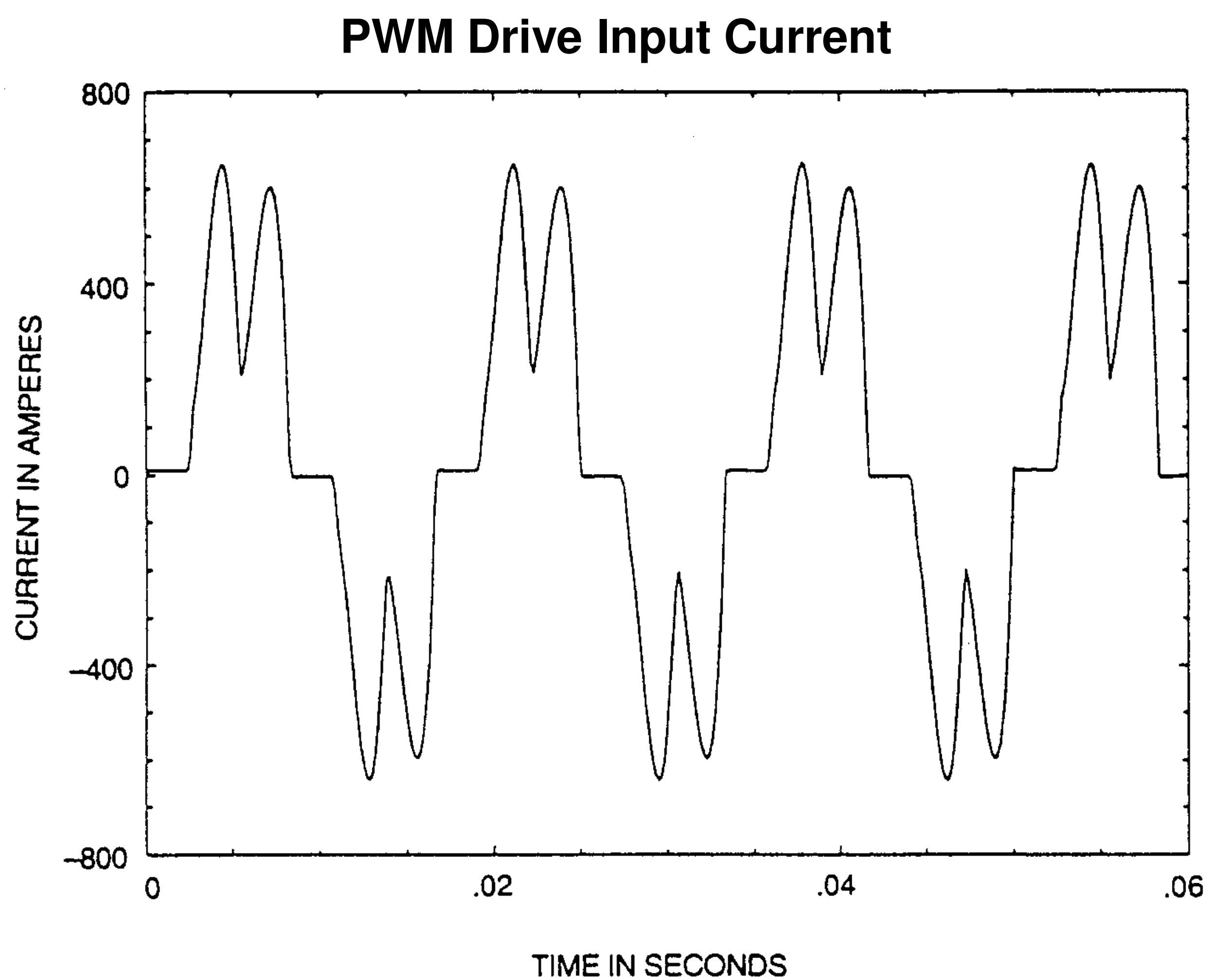
Harmonics — What?

- Non-linear loads draw non-sinusoidal current from a sinusoidal line (current doesn't look like voltage):
  - Non-incandescent lighting
  - Computers
  - Uninterruptible power supplies
  - Telecommunications equipment
  - Copy machines
  - Battery chargers
  - Any load with a solid state AC to DC power converter
  - Electronic variable speed drives

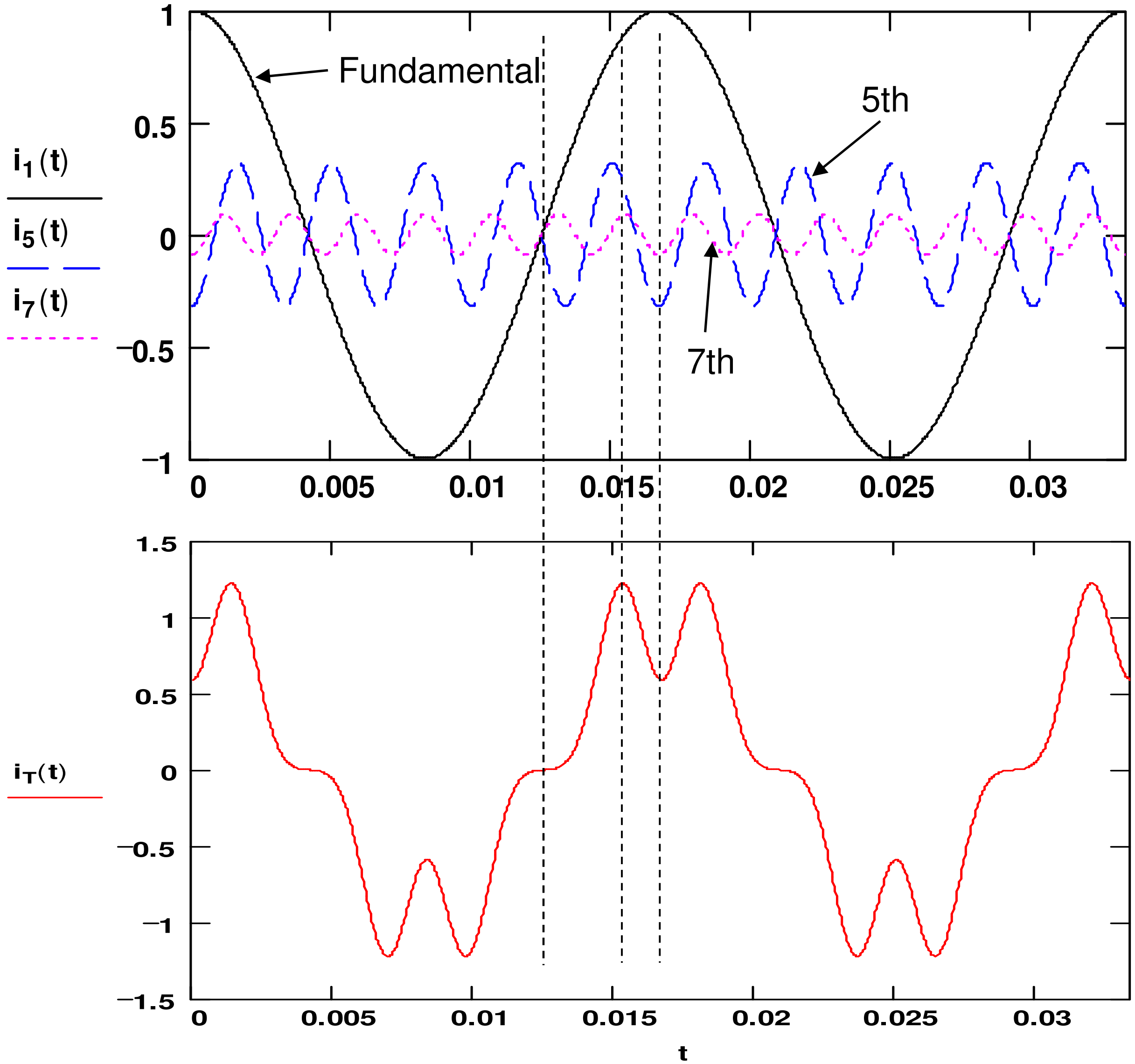
Harmonics — Key Concepts

- Non-linear loads draw current in a periodic non-sinusoidal or distorted manner
- Line transients are not harmonics
- Harmonics or harmonic content is a mathematical concept implemented to allow quantification and simplified analysis of non-linear waveforms
- Harmonics are typically present in both network currents and network voltages
- Non-linear current draw creates non-linear voltage as it flows through the electrical network
  - Current harmonics → Voltage harmonics

The Real World, 6- Pulse Drive



The Theory: Fundamental, 5th and 7th Harmonics



Components

Summation

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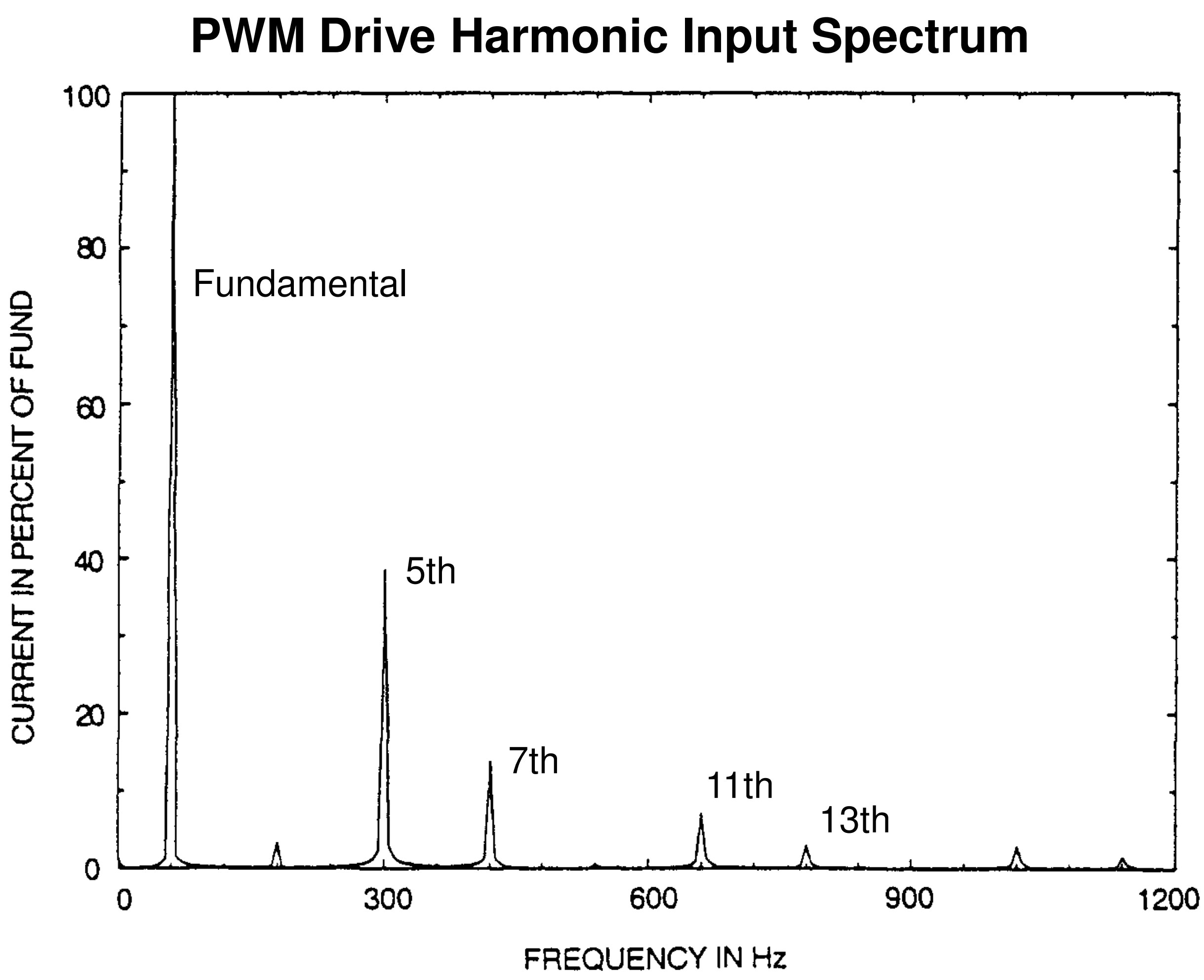
Harmonic Content, 6- Pulse Drive



Harmonics —

Why worry?

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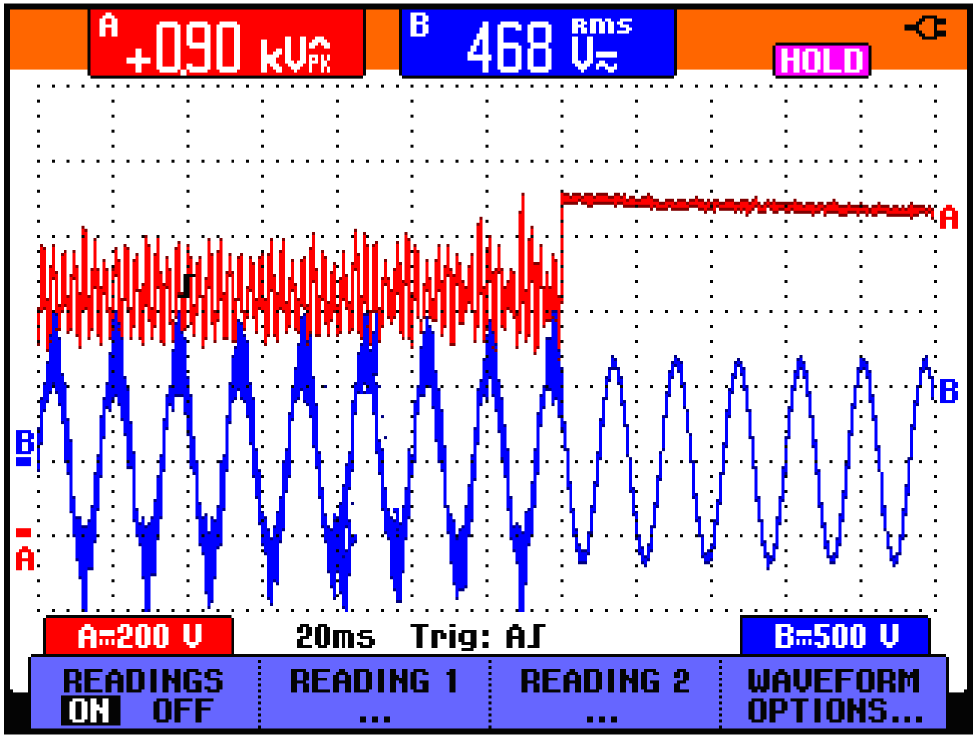
Harmonics — Why worry?

- Harmonic Current Distortion —
  - Added heating in transformers and cables, reduces available capacity
  - May stimulate a PF correction resonance condition
    - Excessive voltage
    - Overheating of capacitors
    - Tripping of protection equipment
    - Shutdown / damage to electronic equipment
  - May cause telephone or electronic interference

Beware Harmonic Resonance



DC bus VS I/P voltage-with reactor.

Undamped power factor correction capacitors on the same bus as nonlinear loads may create a resonance condition with consequent severe bus voltage distortion and excessive peak voltage

© ABB Group

Harmonics — Why worry? (cont.)

- Harmonic Voltage Distortion —
  - Increased heating in motors and other electromagnetic equipment
  - Noisy operation of electromagnetic equipment
  - Malfunction of sensitive electronics
  - Nuisance tripping of electronic circuit breakers
- Equipment downtime
  - Premature component failures
  - Failed transformers, motors and capacitors
- Compliance with codes or specifications

Harmonics, Important Terminology

(definitions per IEEE 519-1992)

- **Harmonic -** A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.
- **Harmonic, characteristic -** Those harmonics produced by semiconductor converter equipment in the course of normal operation.

  $h = kq \pm 1$

  k = any integer

  q = pulse number of the converter
- **Point of common coupling (PCC)**

  Def. 1 - "point of common coupling (PCC) with the consumer-utility interface." (current harmonic emphasis)

  Def. 2 - "Within an industrial plant the point of common coupling is the point between the nonlinear load and other loads." (voltage harmonic emphasis)

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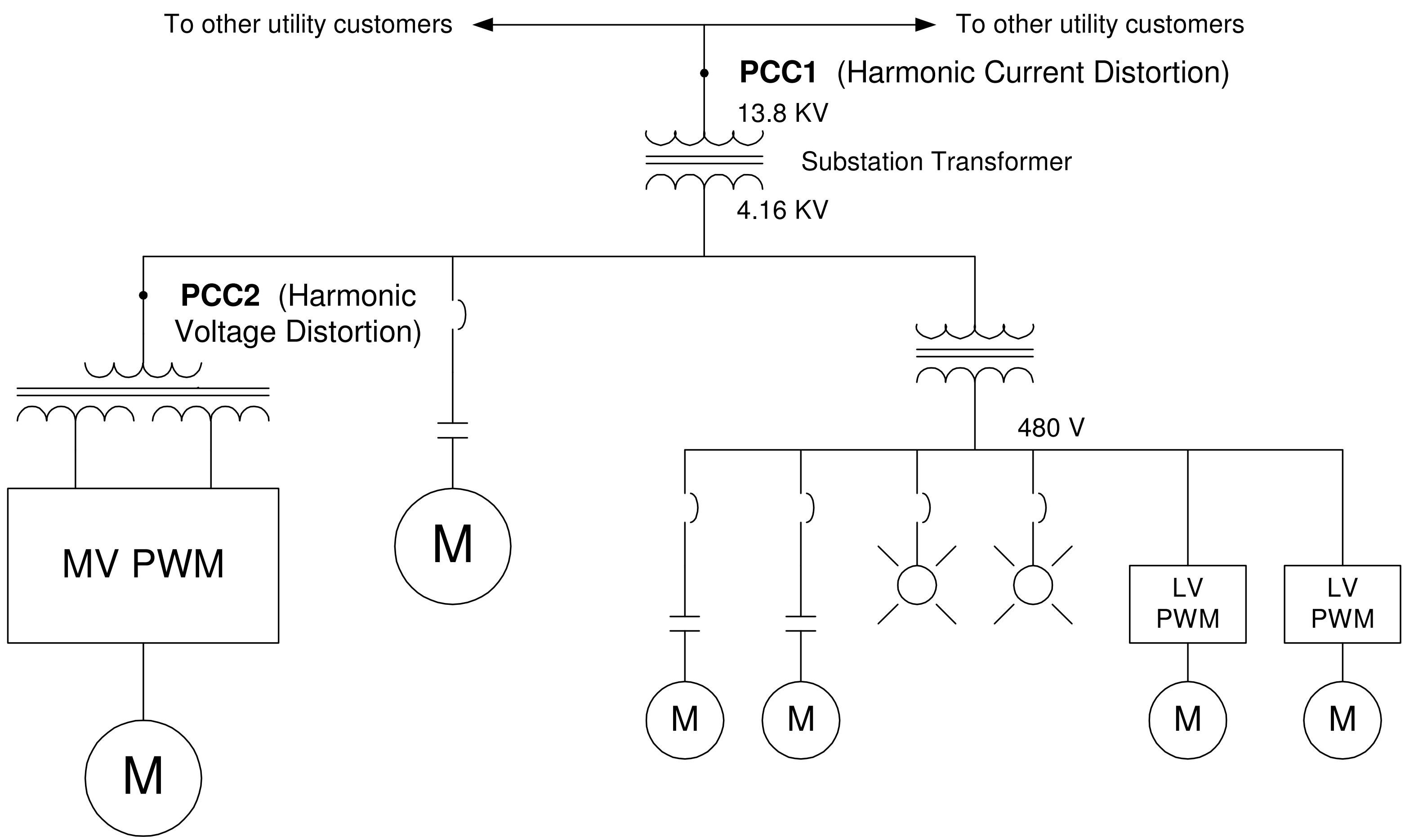
PCC Example



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Harmonics, Important Terminology (cont.)

- **I_{SC}/I_L -** The ratio of the short-circuit current available at the point of common coupling, to the maximum fundamental load current.
- **Total harmonic distortion (THD) or distortion factor -** The ratio of the root-mean-square of the harmonic content to the root-mean-square value of the fundamental quantity, expressed as a percent of the fundamental.

$$THD = DF = \sqrt{\frac{\text{sum of the squares of amplitudes of all harmonics}}{\text{square of amplitude of fundamental}}} * 100\%$$

- **Total demand distortion (TDD) -** The root-sum-square harmonic current distortion, in percent of the maximum demand load current (15 or 30 min demand).

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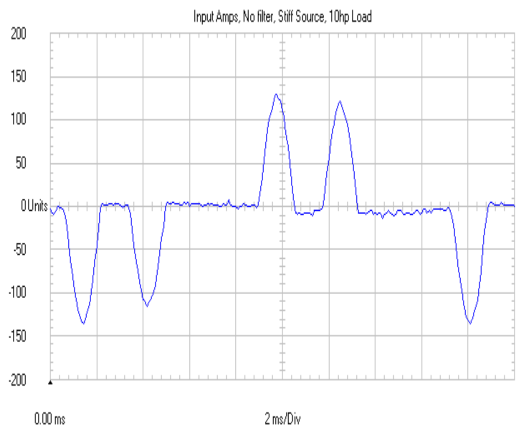
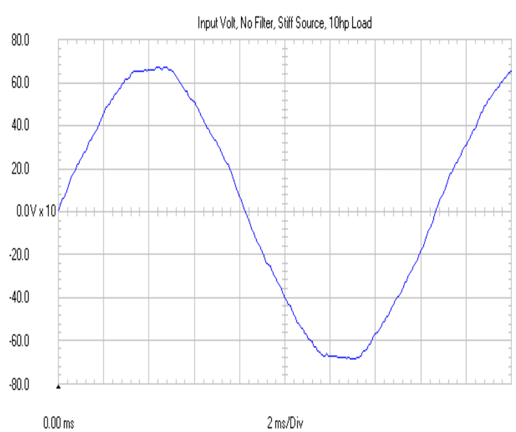
Effect of Short Circuit Ratio on Harmonics

$$\frac{I_{SC}}{I_L} \sim 400$$

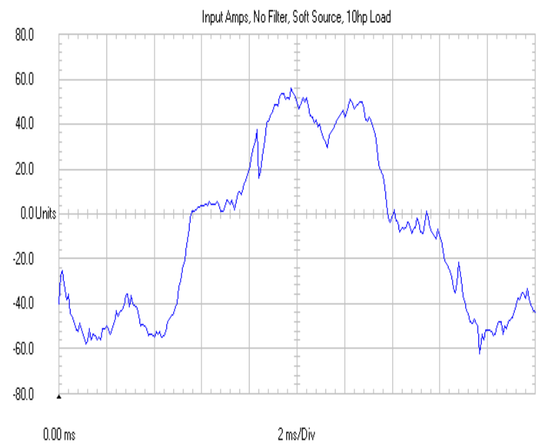


LINE CURRENT, NO FILTER
Fig. 1 THID = 108%

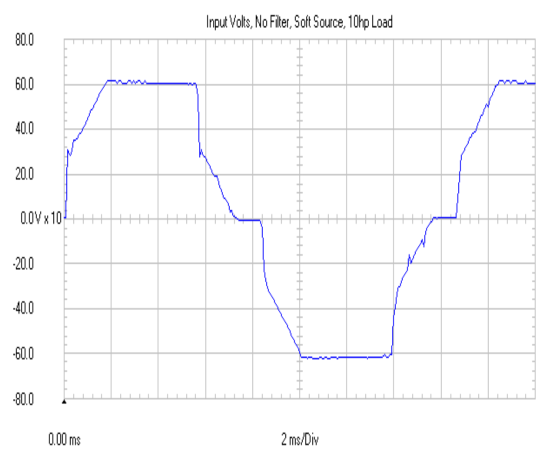


LINE VOLTAGE, NO FILTER
Fig. 3 THVD = 2.2%

$$\frac{I_{SC}}{I_L} \sim 8$$



LINE CURRENT, NO FILTER
Fig. 5 THID = 25.8%



LINE VOLTAGE, NO FILTER
Fig. 7 THVD = 13.8%

Harmonics - A System Issue!

- Harmonics produced by an individual load are only important to the extent that they represent a significant portion of the total connected load (Harmonics are expressed as a percentage)
- **Linear loads help reduce system harmonic levels (percentages)**
- **TDD (Total Demand Distortion) equals the THD (Total Harmonic Distortion) of the nonlinear** load multiplied by the ratio of nonlinear load to the total (demand) load:

$$TDD = THD_{NL} \cdot \frac{NL}{TL}$$

Where

TDD	=	TDD of the system
THD_{NL}	=	THD of the nonlinear loads
NL	=	kVA of nonlinear load
TL	=	kVA of total load (nonlinear + linear)

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Harmonics — By the Numbers

IEEE 519 - 1992

Table 10.2
Low-Voltage System Classification and Distortion Limits

	Special Applications	General System	Dedicated System
Notch Depth	10%	20%	50%
THD (Voltage)	3%	5%	10%
Notch Area, μVs	16,400	22,800	36,500

Note: Notch area for other than 480 V systems should be multiplied by V / 480.

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Harmonics — By the Numbers (cont.)

R_{SC}

IEEE 519 - 1992

Table 10.3
Current Distortion Limits for General Distribution Systems

I_{SC} / I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD
<20	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

Note: All harmonic current levels are in percent with fundamental current I_L as the base.

Harmonics — By the Numbers (cont.)

IEEE 519 - 1992

Table 10.3 - Calc 1
Current Distortion Limits for General Distribution Systems
Modified to Reflect 12 Pulse Rectifier Requirements
For Characteristic Harmonic Orders (11,13,23,25,35,37,47,49, etc.)

I_{SC}/I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≤h
<20	na	2.83	na	0.85	0.42
20<50	na	4.95	na	1.41	0.71
50<100	na	6.36	na	2.12	0.99
100<1000	na	7.78	na	2.83	1.41

Table 10.3 - Calc 3
Current Distortion Limits for General Distribution Systems
Modified to Reflect 12 / 24 Pulse Rectifier Requirements
For Even and Noncharacteristic Harmonic Orders

I_{SC}/I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≤h
<20	1.00	0.50	0.38	0.15	0.08
20<50	1.75	0.88	0.63	0.25	0.13
50<100	2.50	1.13	1.00	0.38	0.18
100<1000	3.00	1.38	1.25	0.50	0.25

Harmonics —

Will it be a problem?

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Harmonic Voltage, Will it be a problem?

- THD (Voltage) will be acceptable (<5%) if the % drive load times the % impedance feeding the drive load is <3%

%DriveLoad x %Impedance < 3%

- E.g. a 45% drive load fed from 6% impedance feeder bus: 45% x 6% = 2.7%   2.7% < 3% → Acceptable
- E.g. a 70% drive load fed from 5% impedance feeder bus: 70% x 5% = 3.5%   3.5% > 3% → Not Acceptable

(Approximate rule of thumb for 6-pulse drives with 3% reactor, all other loads assumed to be linear)

Harmonic Current, Will it be a problem?

- THD (Current) on a network with a short circuit ratio <20 (20<50, 50<100, 100<1000) will be acceptable if the % drive load times 45% is <5% (<8%, <12%, <15%)

%DriveLoad x 45% < 5% (R_{SC} <20)

%DriveLoad x 45% < 8% (R_{SC} 20<50)

%DriveLoad x 45% < 12% (R_{SC} 50<100)

%DriveLoad x 45% < 15% (R_{SC} 100<1000)

- E.g. a network with a short circuit ratio of 35 has 15% drive load: 15% x 45% = 6.75% 6.75% < 8% → Acceptable
- E.g. a network with a short circuit ratio of 65 has 30% drive load: 30% x 45% = 13.5% 13.5% > 12% → Not Acceptable

(Rule of thumb for 6-pulse drives with 3% reactor,, all other loads assumed to be linear)

Harmonics —

What can I do?

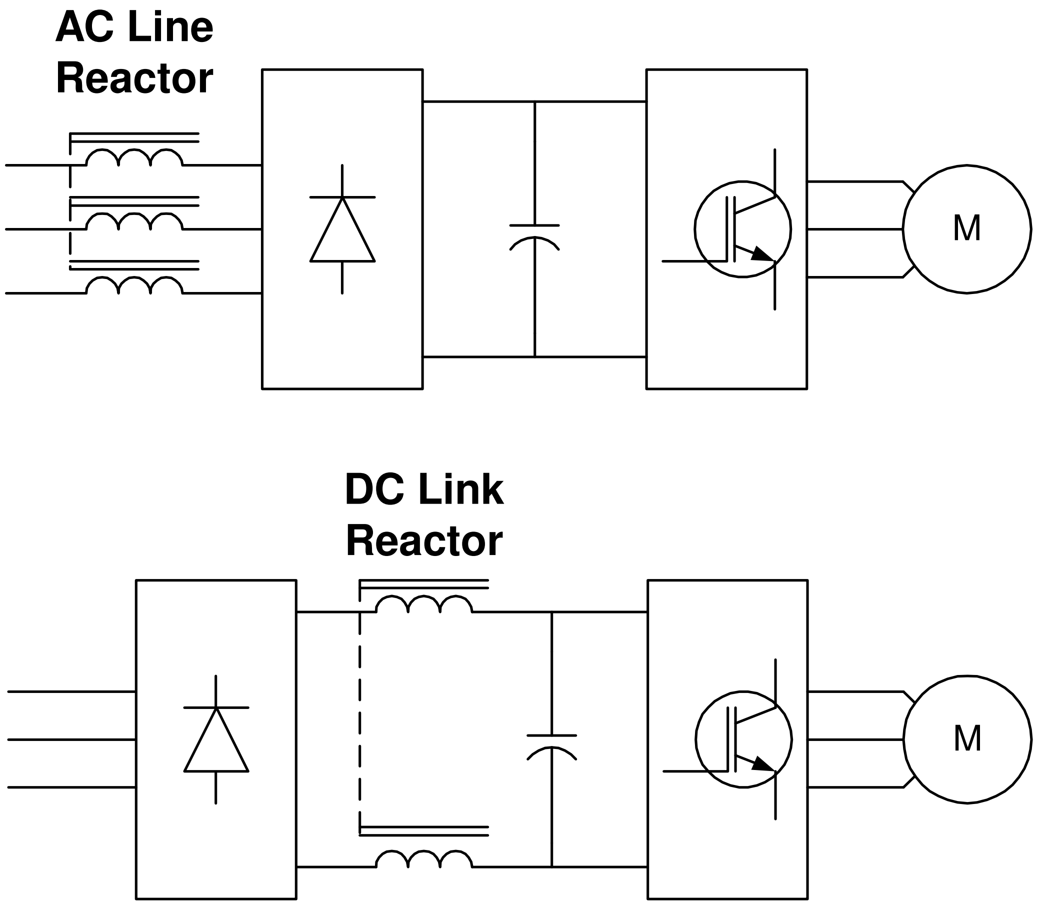
Harmonics — What can I do?

- Reactors (Chokes)
- Passive Filters
  - Harmonic Trap
  - Hybrid
- High Pulse Count Rectification
- Active Filters
  - Stand Alone
  - Drive Active Front End

Reactors (Chokes)

- Simplest and least expensive harmonic reduction technique
- May be included in base drive package
- Often meet harmonic needs provided drive load is a small portion of total connected load
- May be implemented with AC line reactors or with DC link reactors
  - AC line reactors provide better input protection
  - DC link reactors provide load insensitive drive output voltage
  - Both types provide similar harmonic benefits
- “Swinging” choke design provides enhanced light load harmonic performance

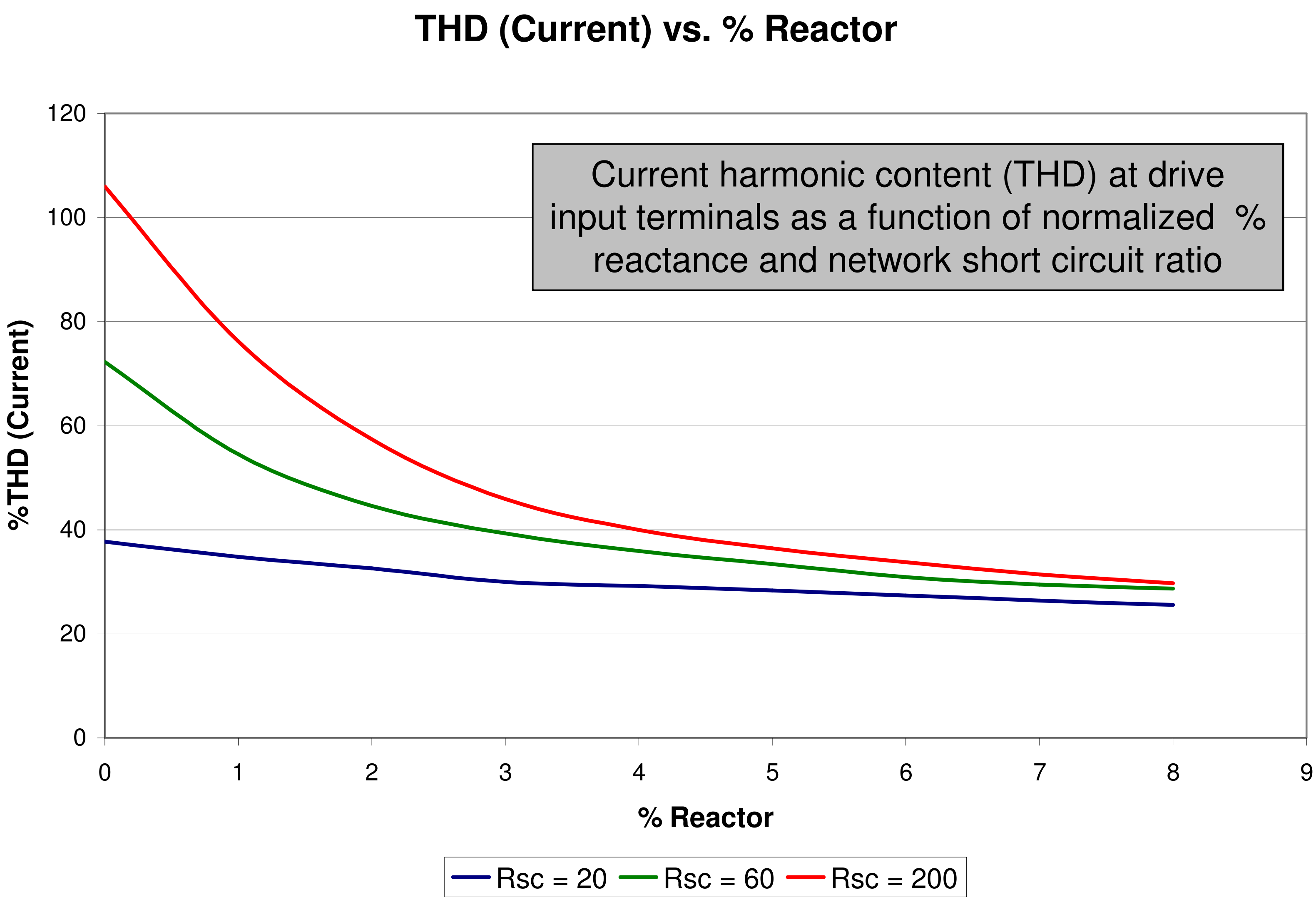
Reactors, AC Line or DC Link



- Different design techniques
- Equal harmonic reduction for same normalized % reactance
- Typical full load THD (current) at drive input terminals
  28% → 46%

Existence - not position - is what is important

Reactor Effectiveness



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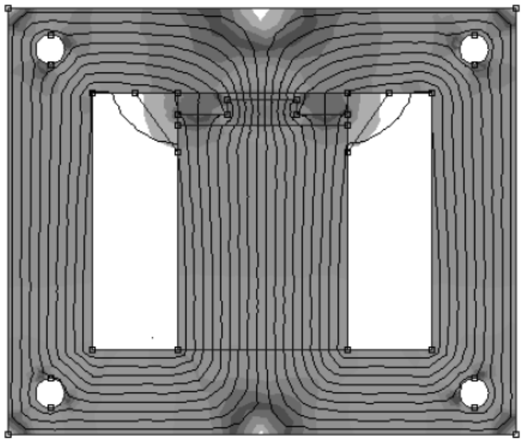
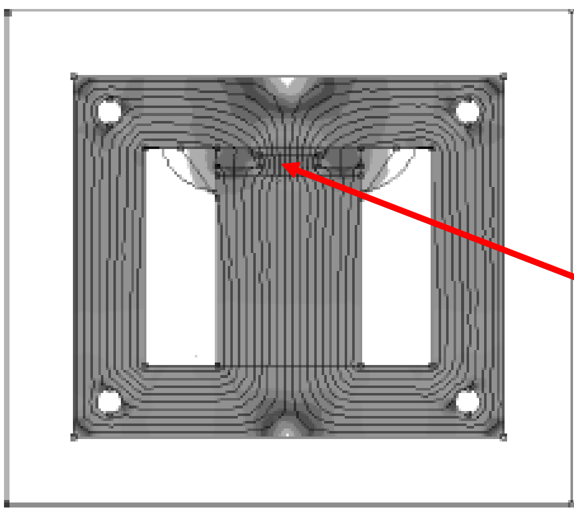
Swinging Chokes

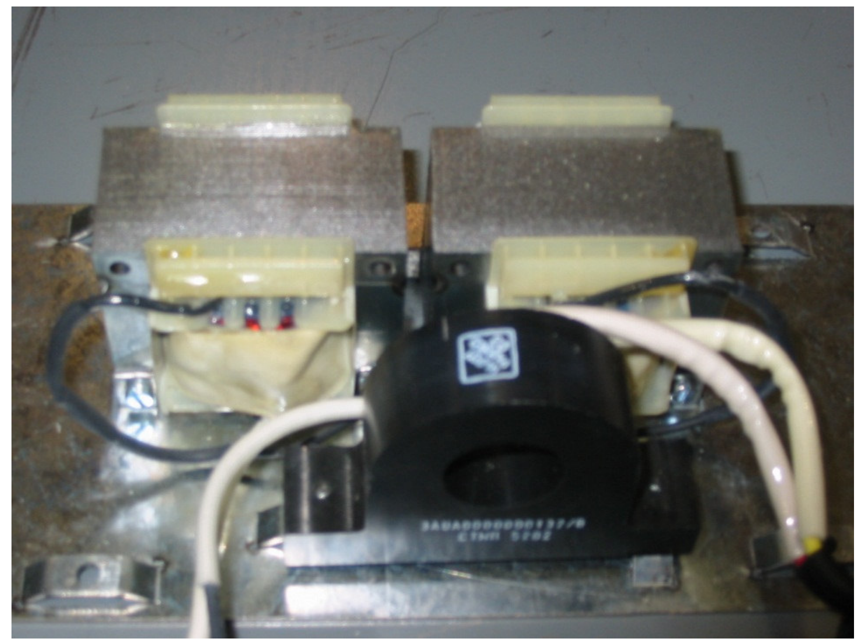


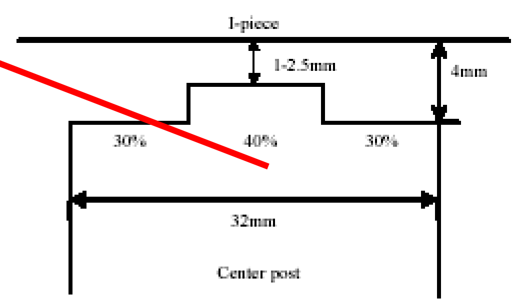
- Provide increased inductance at reduced current
- Reduce harmonics up to 30% more than traditional designs
- “Swing” portion of choke characteristic significantly improves harmonic performance at reduced loads

Swinging DC Link Choke

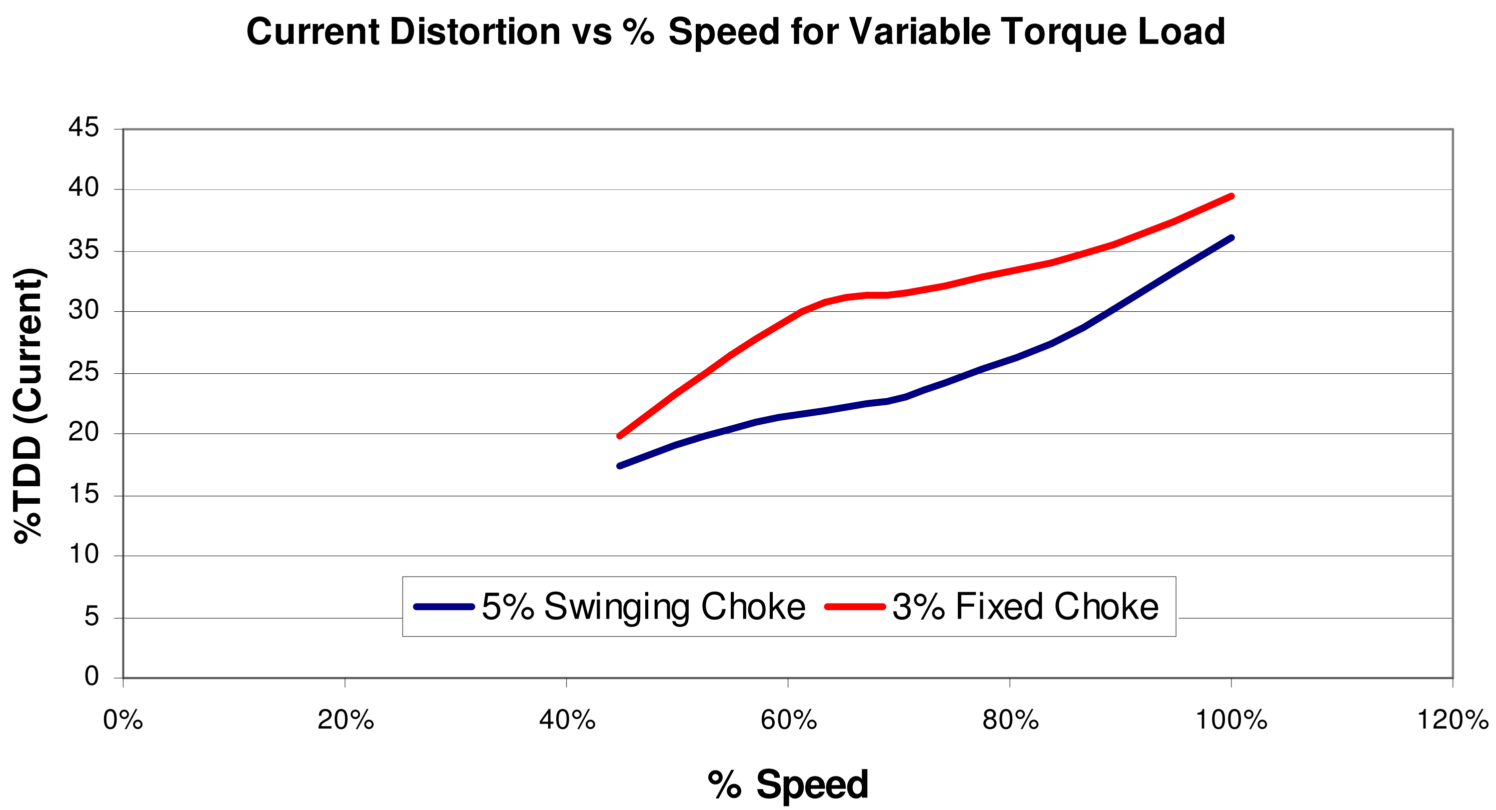
- Designed to reduce harmonics at full and partial loads
- Perfect for Variable Torque Centrifugal Loads
- Equivalent to **5%** line reactor
- More inductance per volume/weight of material







Swinging Choke Vs. Fixed Choke



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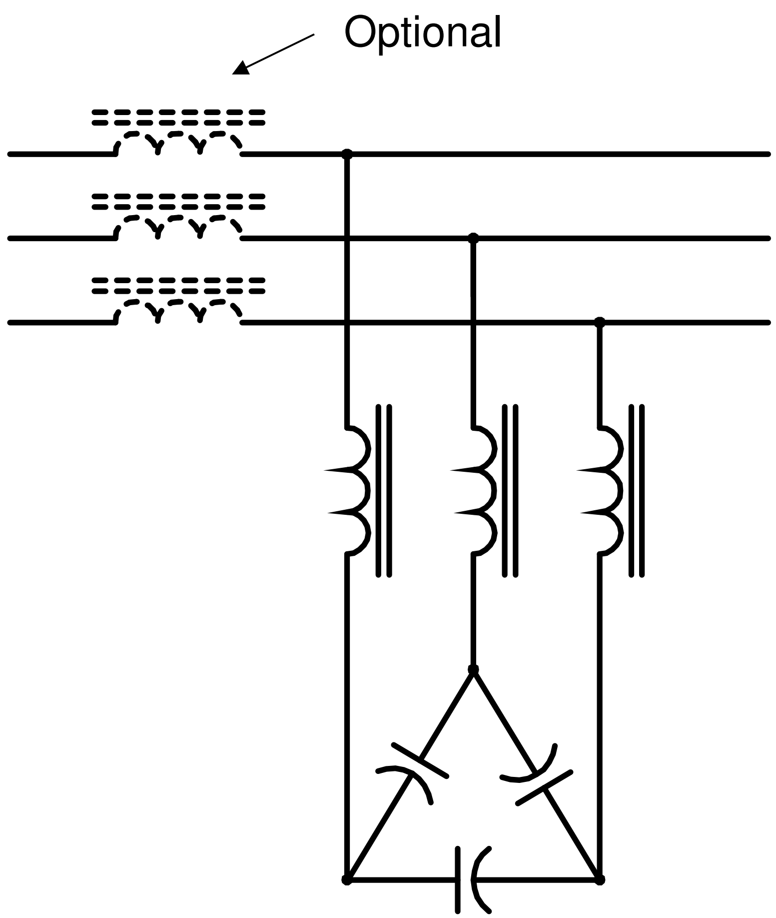
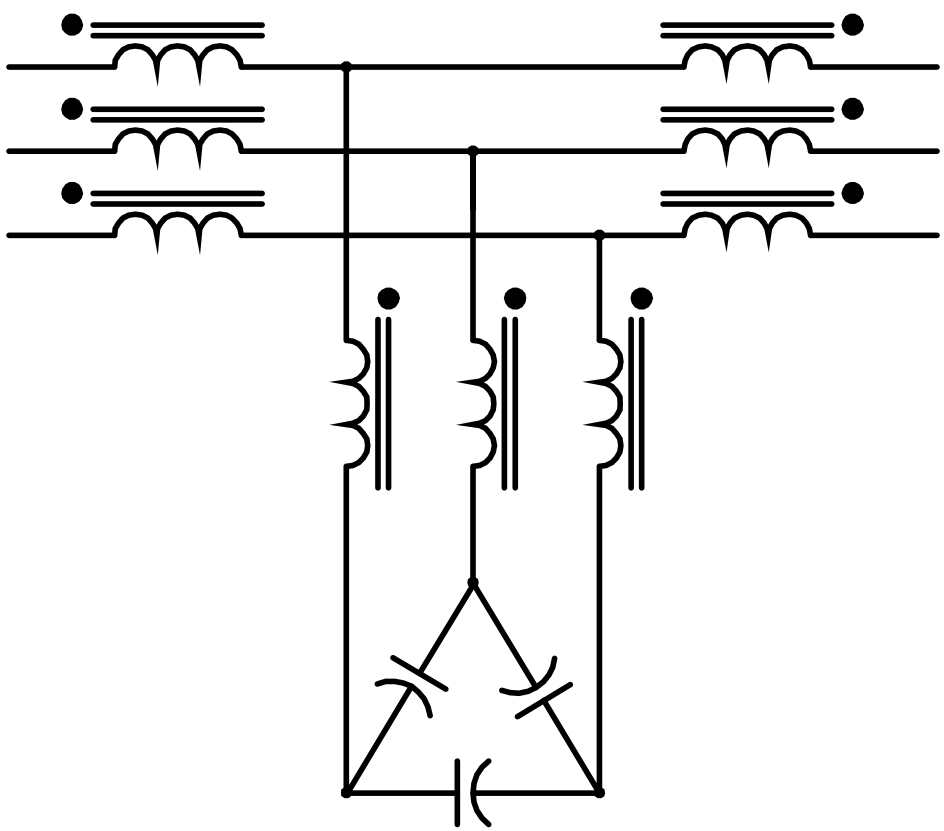
Harmonic Trap Filter



- Installs in series with drive input
- May feed multiple drives
- Improves power factor (may go leading)
- Typical full load THD (current) at filter input terminals (line side) 10% → 14%
- Performance reduced by line imbalance

Hybrid Filter



- Installs in series with drive input
- May feed multiple drives
- Improves power factor (may go leading)
- Typical full load THD (current) at filter input terminals (line side) 5% → 8%
- Relatively unaffected by line imbalance

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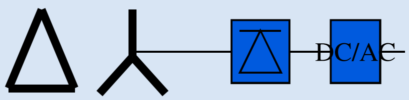
High Pulse Count Rectification

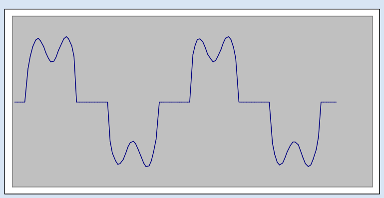
- Typical configurations are either 12 pulse or 18 pulse
- Phase shifting transformer is required
- Additional drive input bridges are needed
- Typical full load THD (current) at transformer primary 8% → 12% (12 pulse), 4% → 6% (18 pulse)
- Performance significantly reduced by line imbalance (voltage or phase)
- Excellent choice if stepdown transformer is already required

High Pulse Count Rectification (cont.)

- **6 pulse rectifier**

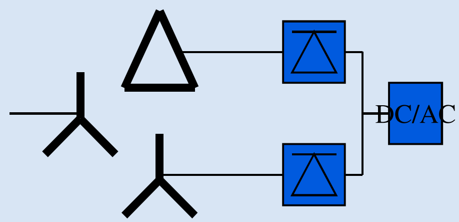


Transformer (if included) and cabling simple

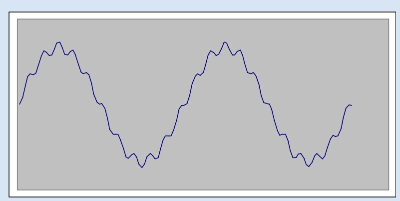


Current quite distorted
I_{thd} 32% to 48% with 3% reactor (depending on network impedance)

- **12 pulse rectifier**

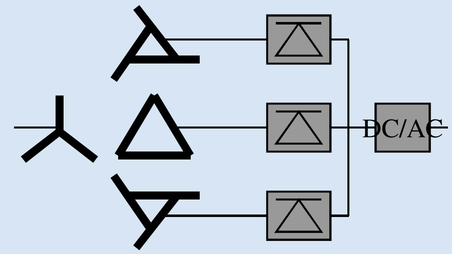


Transformer and cabling more complicated

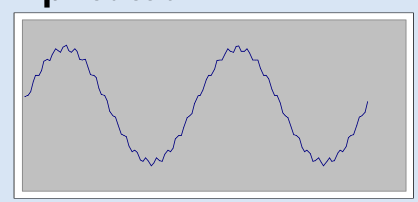


Current slightly distorted
I_{thd} 8% to 12% (depending on network impedance)

- **18 pulse rectifier**



Transformer and cabling complicated

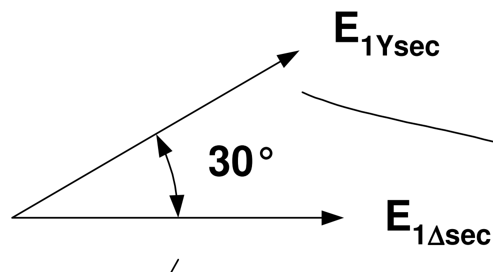


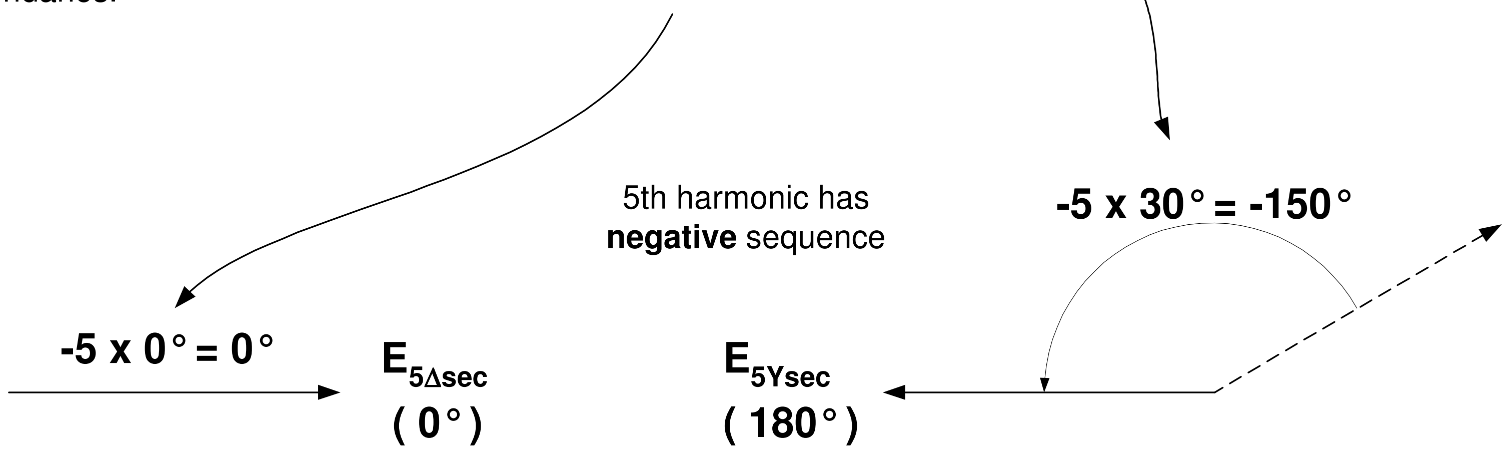
Current wave form good
I_{thd} 4% to 6% (depending on network impedance)

Harmonic Cancellation, 5th

12 Pulse Configuration

Transformer with delta primary and delta / wye secondary produces a 30° phase shift between the two secondaries.



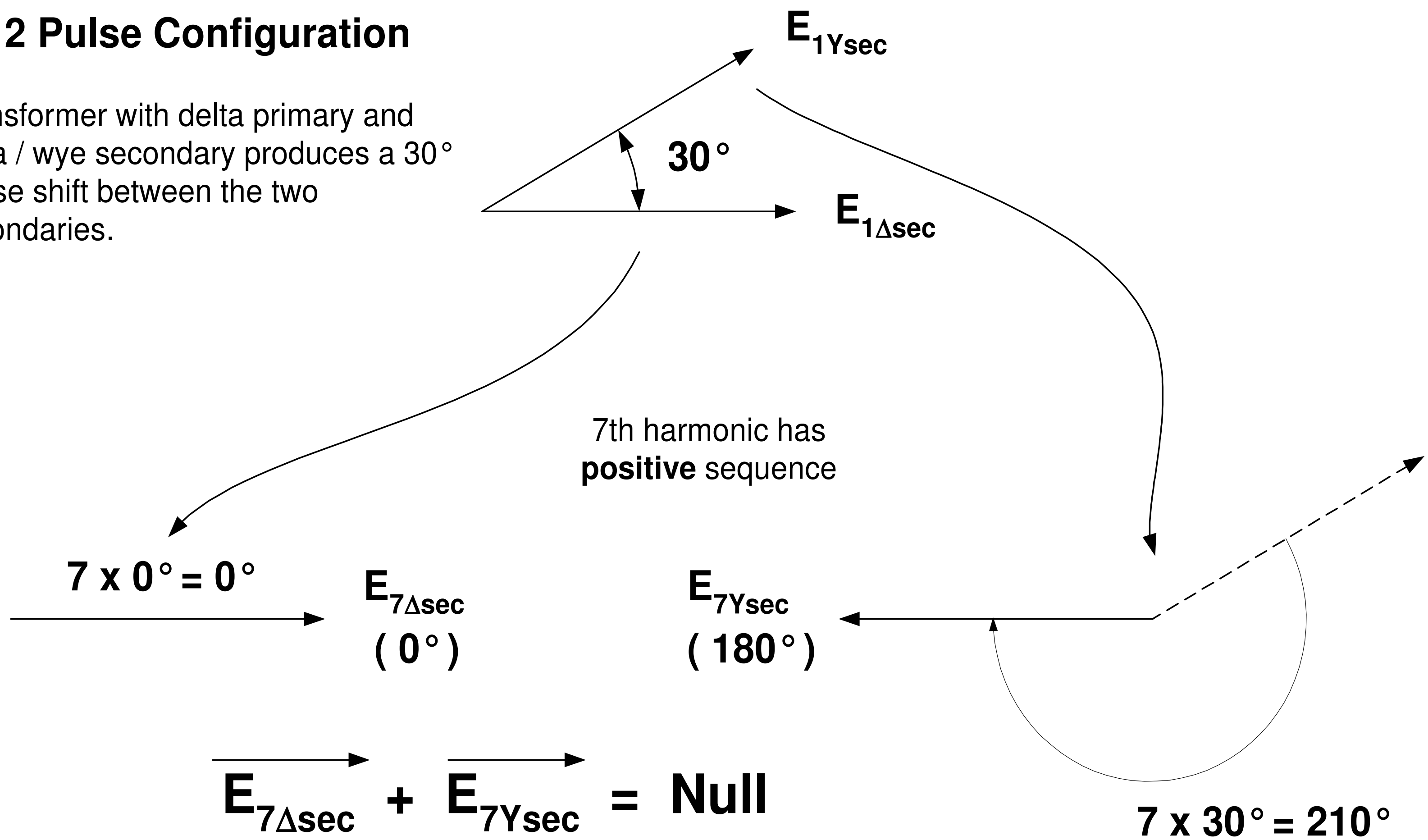


$$\vec{E}_{5\Delta sec} + \vec{E}_{5Ysec} = \text{Null}$$

Harmonic Cancellation, 7th

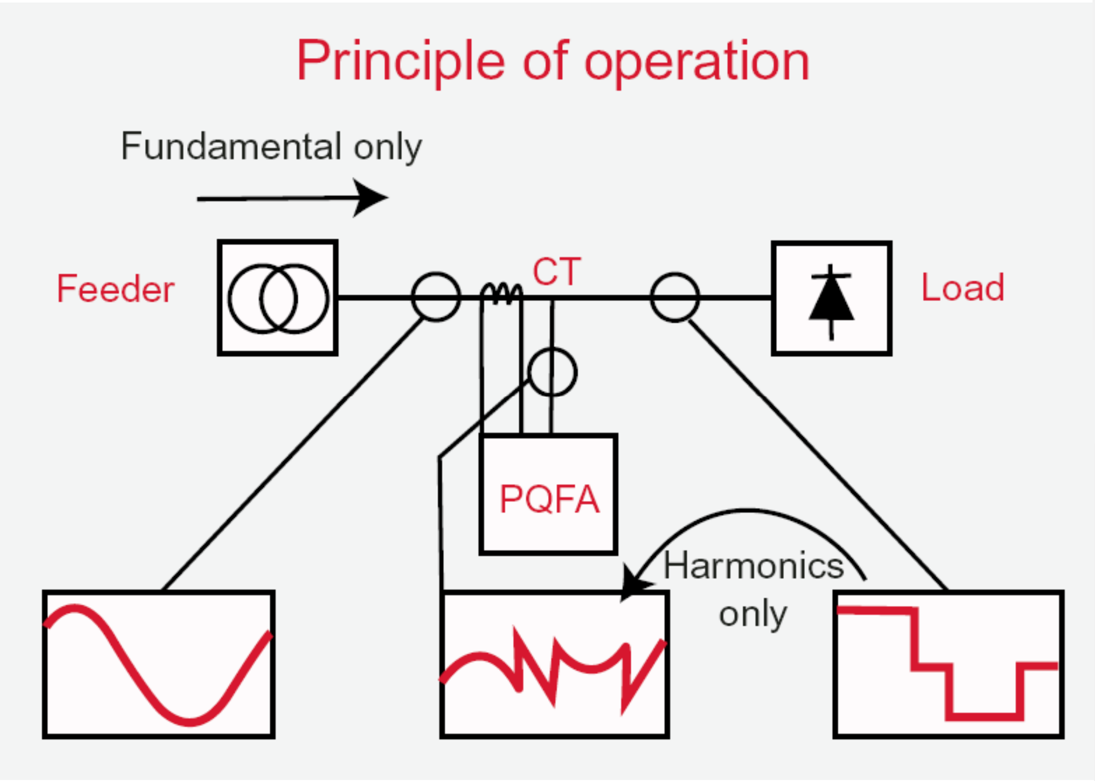
12 Pulse Configuration

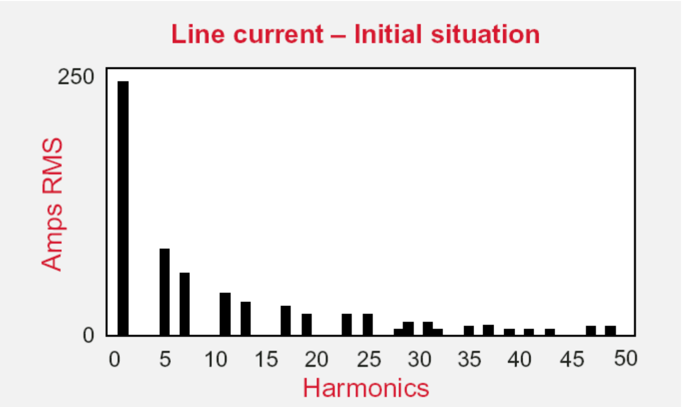
Transformer with delta primary and delta / wye secondary produces a 30° phase shift between the two secondaries.

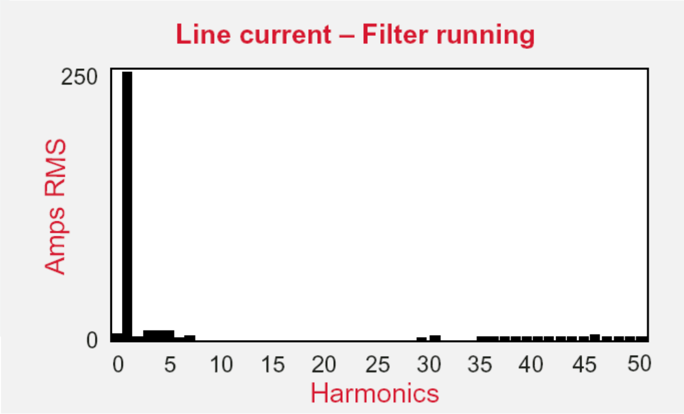


$$\overrightarrow{E_{7\Delta sec}} + \overrightarrow{E_{7Ysec}} = \text{Null}$$

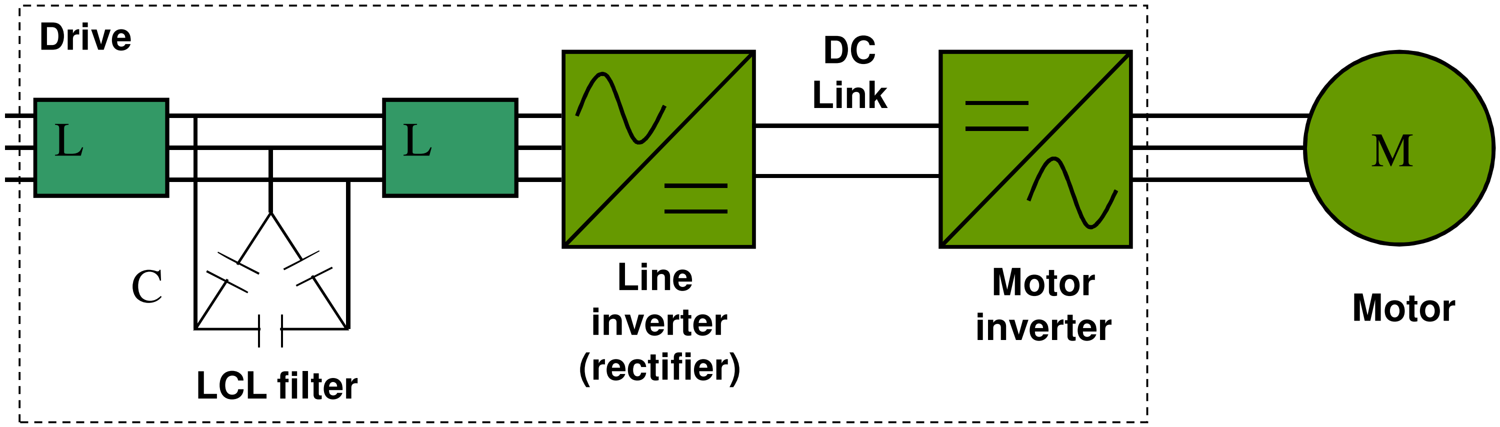
Active Front End Filter







Active Filter Front End with LCL Filter



- Active Filter Line Inverter removes low frequencies < 1kHz
- LCL Filter (passive filter) removes high frequencies >1 kHz. (Current and voltage)
- Full output voltage is available with 80% input voltage ($400V_{In} = 480V_{Out}$)
- Full regenerative capability (ACS800-U11/-17)
- No transformer required
- Not affected by line imbalance

Beauty Instead of Beast

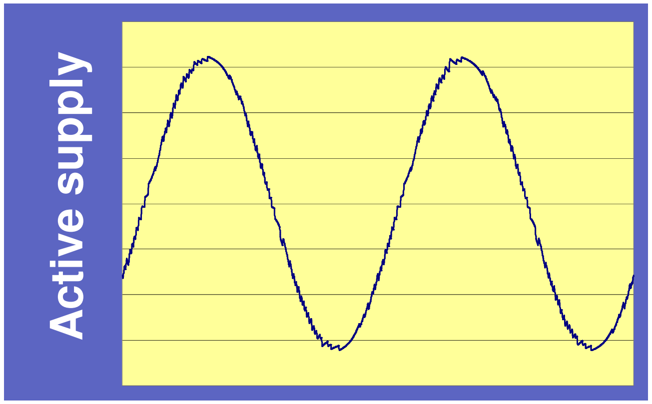
- IGBT line supply controls the current

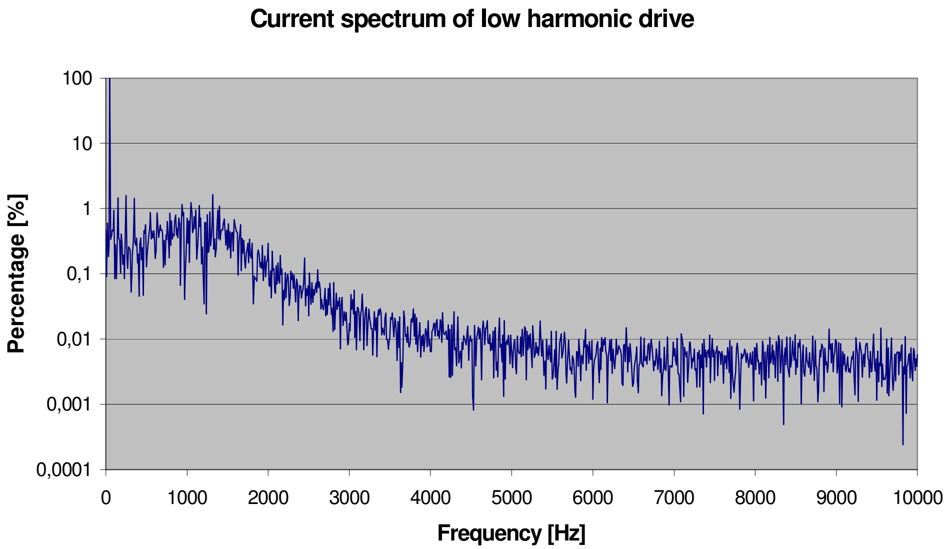
  Sinusoidal line current

  Low distortion below switching frequency

- LCL Line filter removes high frequency distortion

  Cleans the waveform above switching frequency





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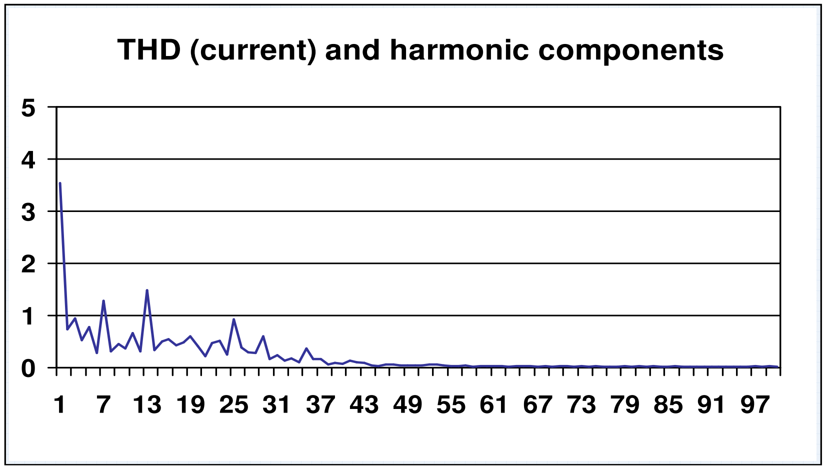
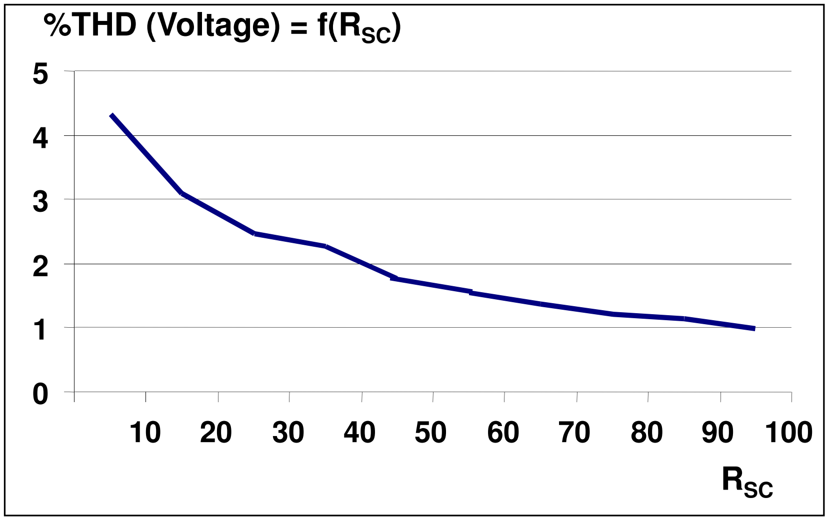
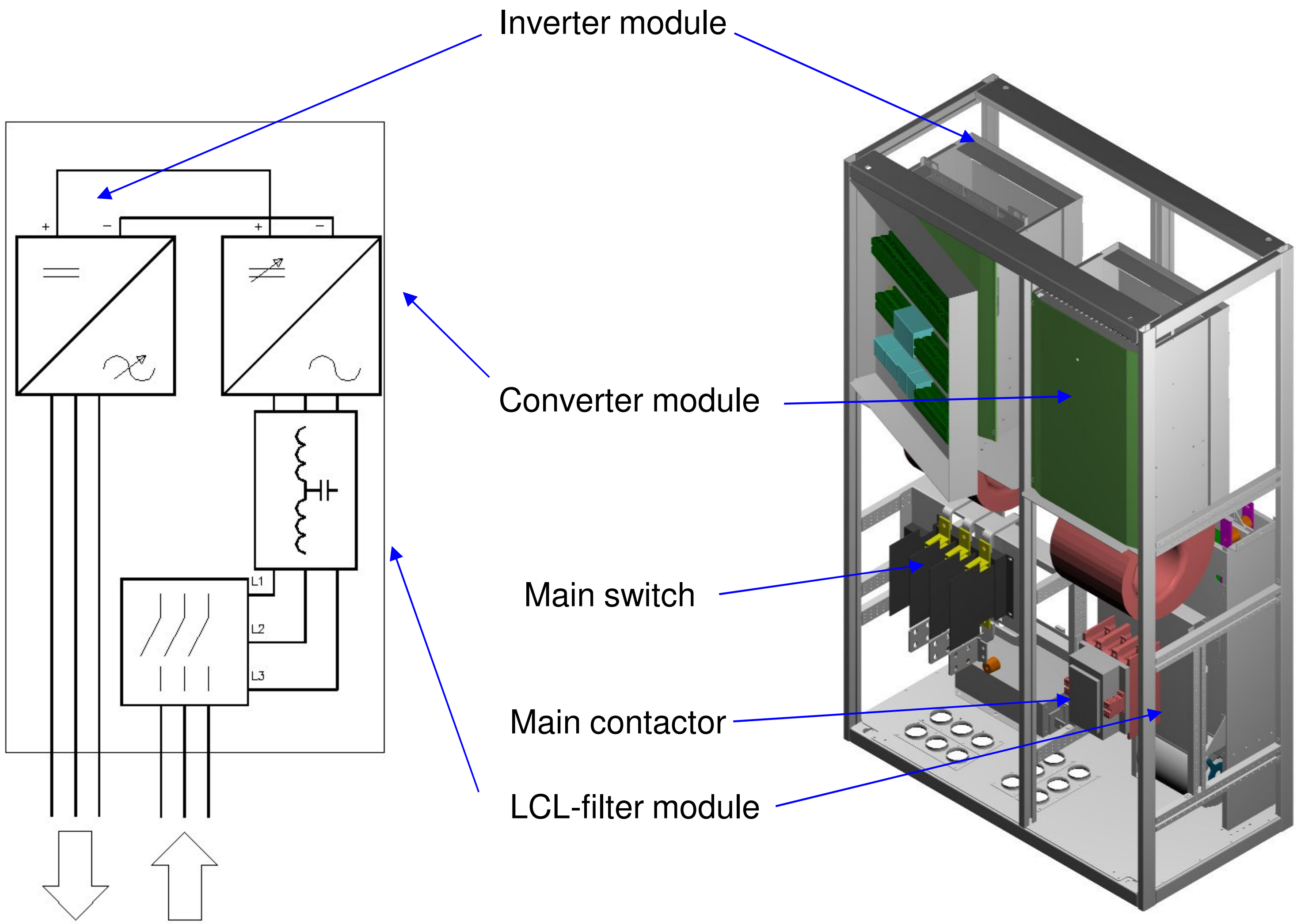
Impressive Numbers

- Total current distortion less than 3.5% to 4.5%
- Total voltage distortion less than 5%
- Power factor adjustable from 0.85 (leading or lagging) to 1.0





Active Front End Drive, Construction



Product offering

- Wall-mounted low harmonic drive ACS800-U31

  10 – 125 HP

- Cabinet-built low harmonic drive ACS800-37

  75 - 2800 HP

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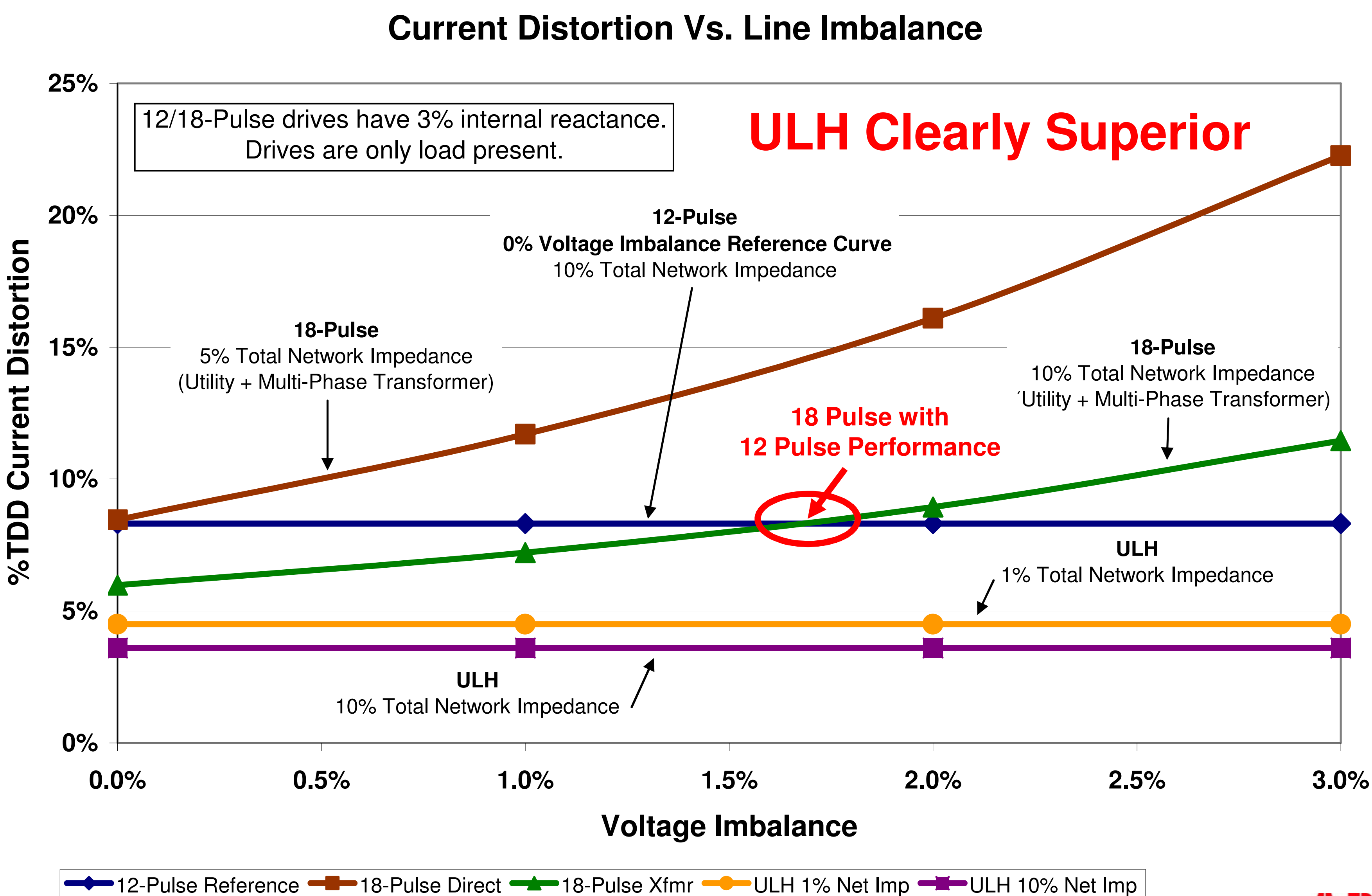
18-Pulse Impedance and Imbalance Dependencies



Harmonic Reduction Summary

Effectiveness of Harmonic Mitigation Techniques

(Assuming 100% Nonlinear Loading, $I_{SC} / I_L = 60$)

Technique	THD (Current)	Harmonic Reduction
No mitigation (reference level)	72%	—
3% line reactors (or equivalent DC link reactor)	39%	45.8%
5% line reactors (or equivalent DC link reactor)	33%	54.2%
5% line reactors + 5th harmonic trap filter	12%	83.3%
12 pulse input rectifier with 5% impedance transformer	10%	86.1%
Hybrid filter	7%	90.3%
18 pulse input rectifier with 5% impedance transformer	5%	93.1%
12 pulse input rectifier with 5% impedance transformer + 11th harmonic trap filter	4%	94.4%
Active harmonic filter	3.5%	95.1%

Remember!

Even an 80% THD nonlinear load with a will result in only 8% TDD if the nonlinear load is 10% and the linear load is 90%. (80%•(10%/(10%+90%))=8%)

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