Overview of the Guide for Applying Harmonic Limits on Power Systems - IEEE P519A

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Electrotek Concepts, Inc.

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Scope of IEEE 519-1992

- Provide methodology for preventing harmonic voltage and current distortion problems on the power system through utility and customer cooperation.

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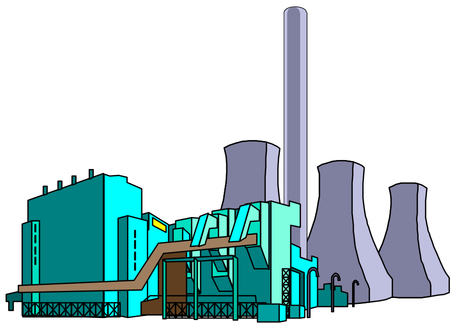
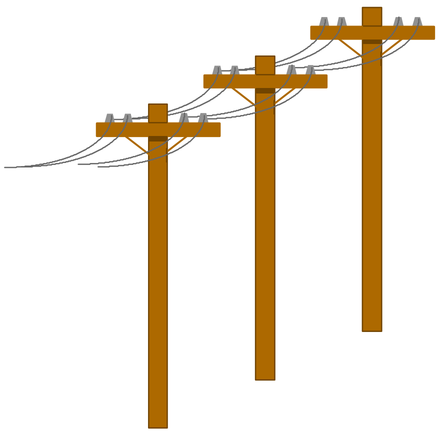
Basic Philosophy of IEEE 519





- The customer is responsible for limiting harmonic currents injected onto the power system.
- The utility is responsible for maintaining quality of voltage waveform.

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Harmonic Voltage Limits

Harmonic Voltage Limits - Utility Responsibility

Bus Voltage	Maximum Individual Harmonic Component (%)	Maximum THD (%)
69 kV and below	3.0%	5.0%
115 kV to 161 kV	1.5%	2.5%
Above 161 kV	1.0%	1.5%

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Meeting Voltage Distortion Limits

- Limit the harmonic currents from nonlinear devices on the system (*customer harmonic current limits*).
- Make sure that system resonances do not result in excessive magnification of the customer harmonic currents (*utility control of system response)*.

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Harmonic Current Limits

Harmonic Current Limits - Customer Responsibility

SCR $=I_{sc}/I_L$	<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
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Values shown are in percent of "*average maximum demand load current*"

SCR = short circuit ratio (utility short circuit current at point of common coupling divided by customer average maximum demand load current)

TDD = Total Demand Distortion (uses maximum demand load current as the base, rather than the fundamental current)

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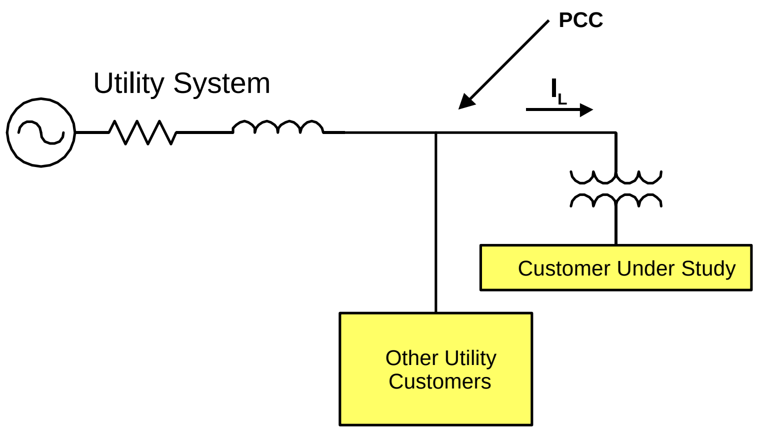
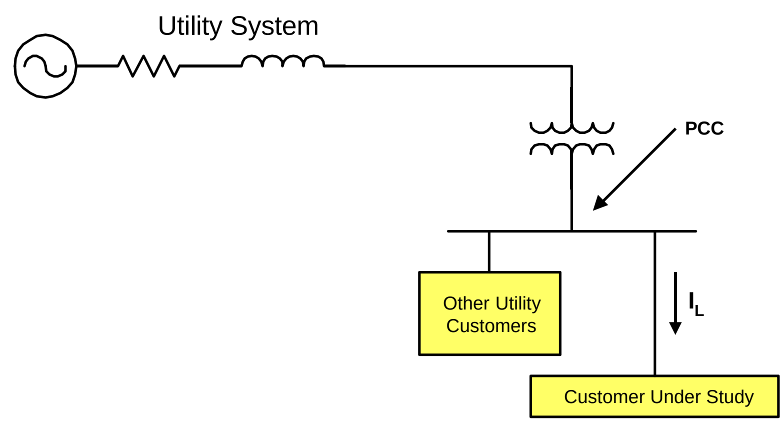
Important Concepts

- Point of Common Coupling
- Average Maximum Demand Load Current
- SCR - Short Circuit Ratio





Important Sections of P519A

- General Procedure
- Applying Limits for Large Nonlinear Loads
- Applying Limits for Industrial Facilities
- Applying Limits for Commercial Facilities
- Applying Limits for Residential Loads
- Utility Considerations

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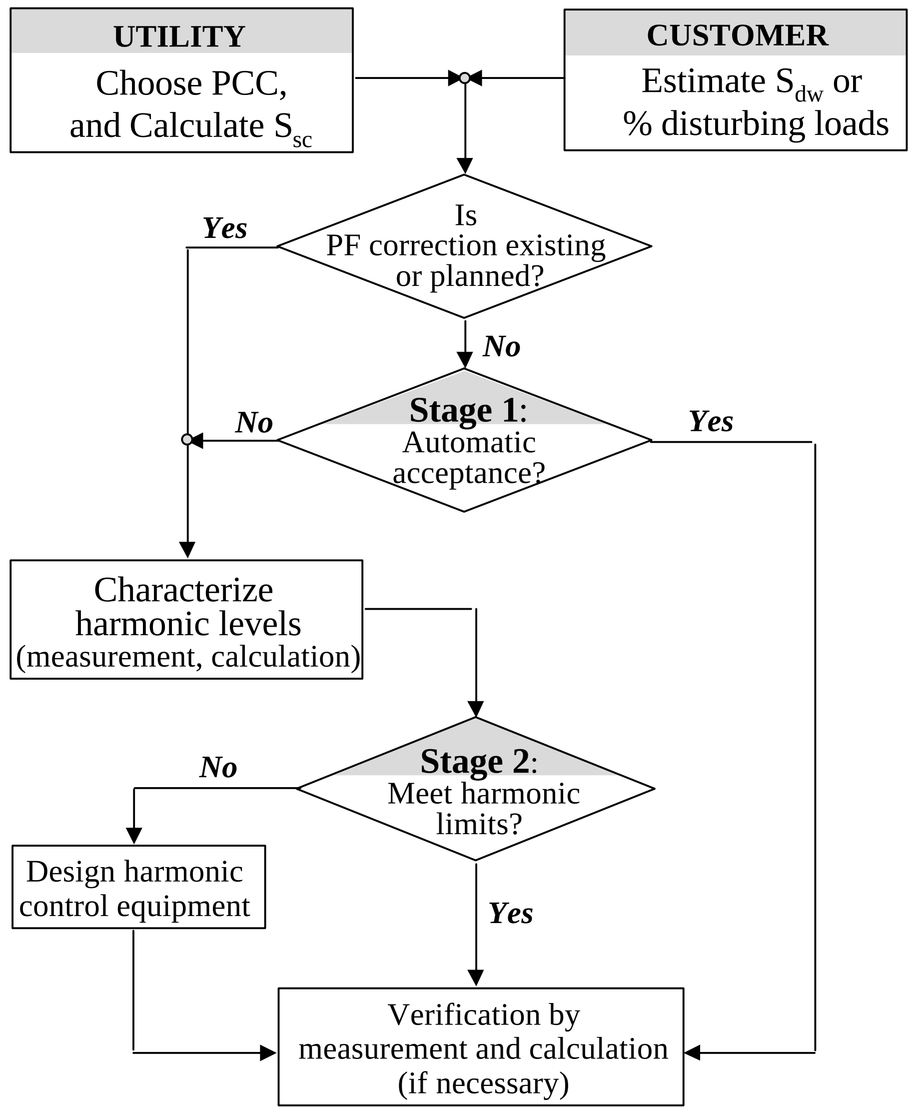
General Procedure

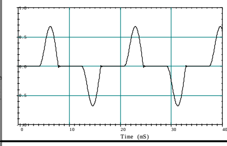
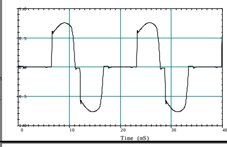
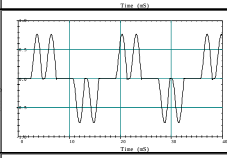
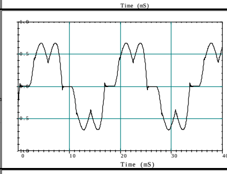
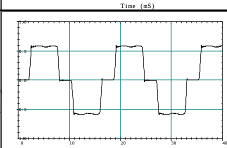
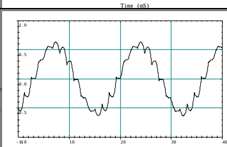
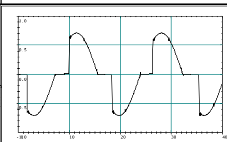


Automatic Acceptance

Automatic Acceptance if:

$$S_{Dw} / S_{SC} < 0.1\ \%$$

Note: detailed evaluation should always be performed if power factor correction capacitors exist or are planned

Type of Load	Typical Waveform	Current Distortion	Weighting Factor (W_i)
Single Phase Power Supply		80% (high 3rd)	2.5
Semiconverter		high 2nd,3rd, 4th at partial loads	2.5
6 Pulse Converter, capacitive smoothing, no series inductance		80%	2.0
6 Pulse Converter, capacitive smoothing with series inductance > 3%, or dc drive		40%	1.0
6 Pulse Converter with large inductor for current smoothing		28%	0.8
12 Pulse Converter		15%	0.5
ac Voltage Regulator		varies with firing angle	0.7

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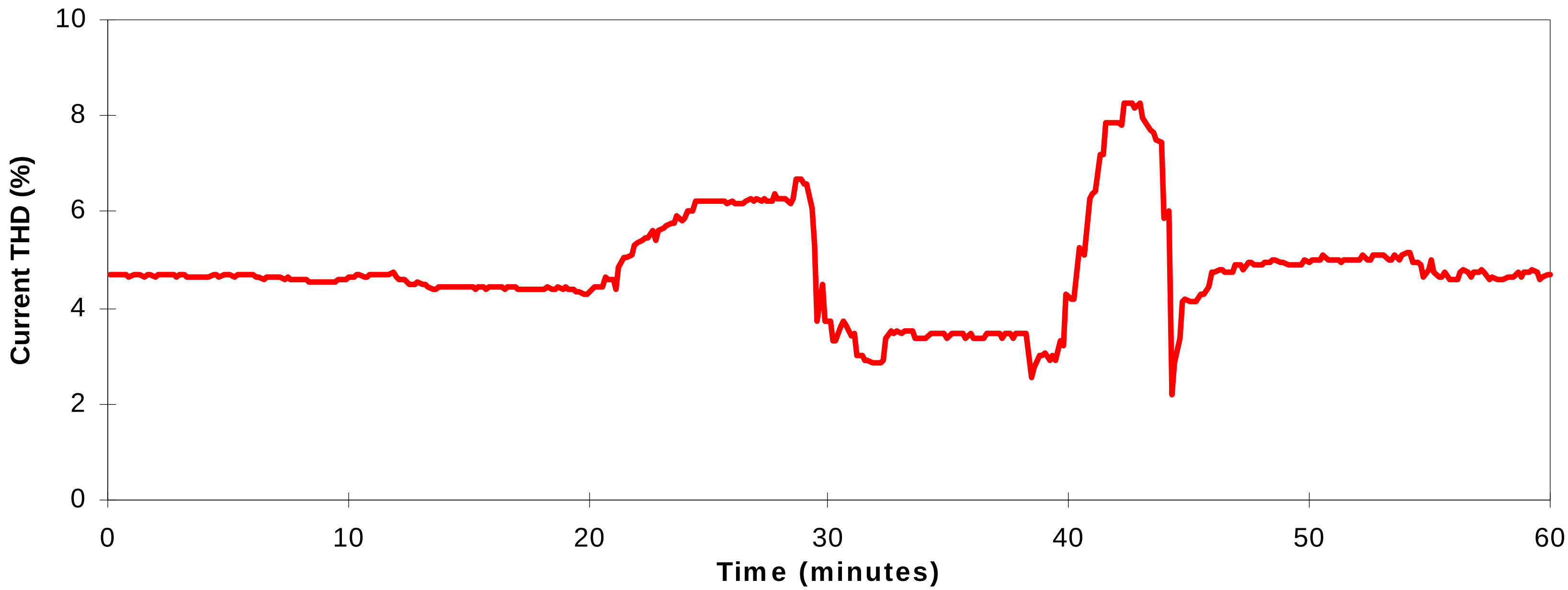
Important Concept - Time Varying Nature of Harmonics



Current THD measured at Port of Vancouver, B.C.
(harmonic bursts are caused by cranes lifting containers)

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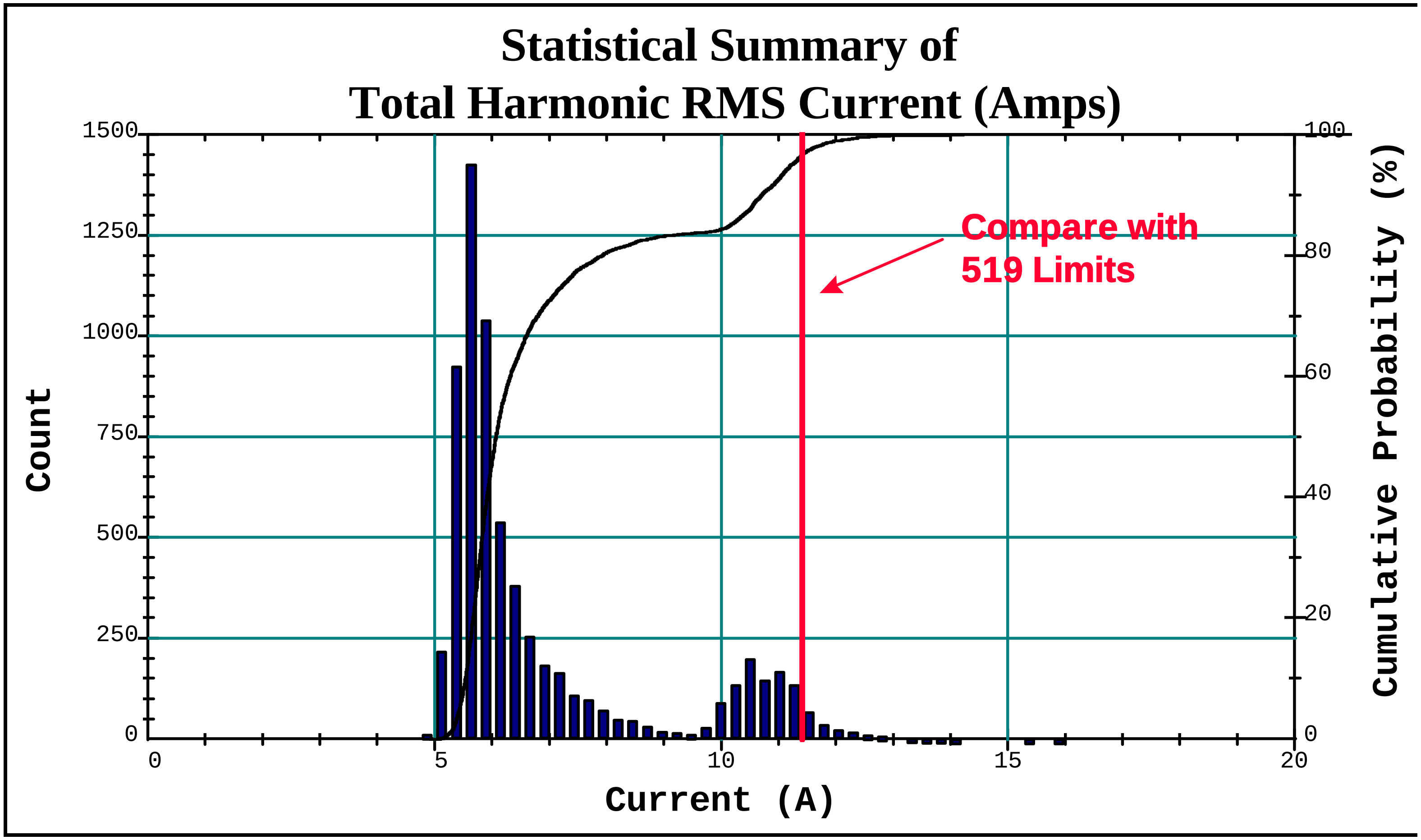
Use statistics to describe the harmonic levels



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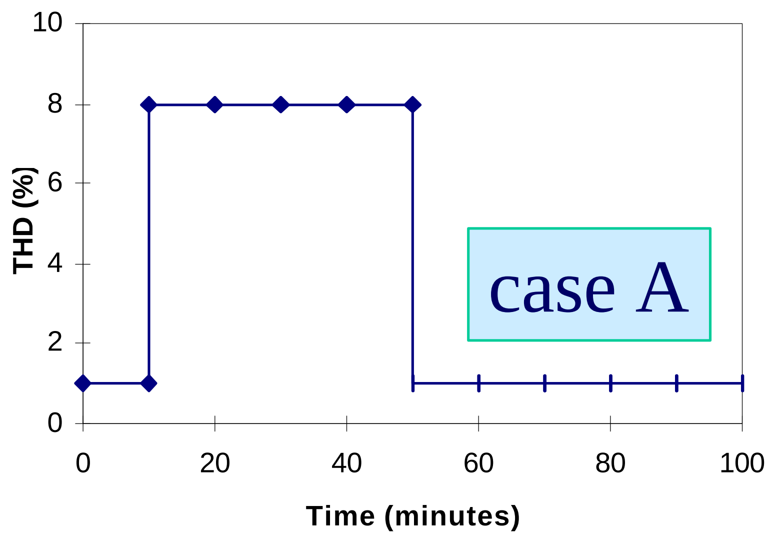
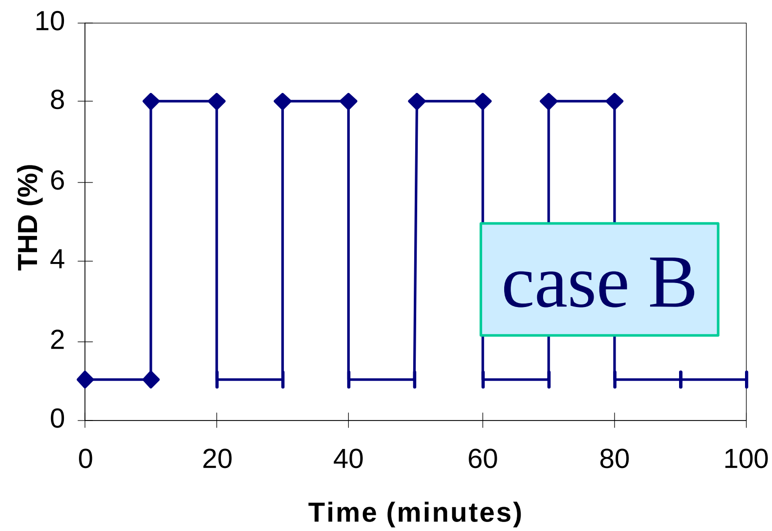
Short bursts vs. continuous harmonic distortion





Both cases have THDs exceeding 5% for 40% of the measurement period. But case A is more severe since the harmonic bursts are concentrated in a single period.

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BC Hydro limits

Acceptable harmonic distortion level	Maximum duration of a single harmonic burst ($T_{maximum}$)	Total duration of all harmonic bursts (T_{total})
3.0 x (design limits)	1 sec < $T_{maximum}$ < 5 sec	15 sec < T_{total} < 60 sec
2.0 x (design limits)	5 sec < $T_{maximum}$ < 10 min	60 sec < T_{total} < 40 min
1.5 x (design limits)	10 min < $T_{maximum}$ < 30 min	40 min < T_{total} < 120 min
1.0 x (design limits)	30 min < $T_{maximum}$	120 min < T_{total}

The limits apply to a 24 hour measurement period

Measurement Considerations

- Where to measure
  - effect of transformer when measuring on the low side and PCC is on the high side
- Voltage measurements
- Current measurements
  - what is the base current?
- Monitoring Durations
- Sampling Requirements

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System Conditions to Consider (for analysis of potential problems)

- power factor correction capacitors in the customer facility
- harmonic filter out of service
- power factor correction capacitors on the utility supply system
- alternative sources from the utility (e.g. alternate feeders)
- different load combinations than can be evaluated in the field tests
- nearby customers with significant harmonic production

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Summary

1. A two staged procedure to evaluate a facility

- Stage 1: Automatic acceptance for facilities with little disturbing loads
- Stage 2: Should demonstrate compliance to harmonic limits

2. Apply steady-state limits to time varying data

- Methods to characterize time varying harmonic measurements
- Methods to apply the limits to measured data
- Consideration of plant operating cycles at the design stage

3. Conditions to evaluate limit compliance

- Measurement: instrumentation, monitoring duration, ...
- Calculation: modeling assumptions, plant operating conditions, ...

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IEEE P519A
Concerns for Industrial Facilities

October, 1998

Industrial Concerns

- Nonlinear Loads
  - ASDs, dc drives, rectifiers for dc processes, induction furnaces, arc furnaces
- Power Factor Correction
  - capacitors result in resonance concerns
- Motor Loads
  - do not provide much damping for harmonics

Industrial Evaluations: The Six-Step Process

- Step 1: Select the PCC
  - normally the high-side of the supply transformer(s)
- Step 2: Characterize the nonlinear loads
  - "typical" spectra may be used
  - measurements are needed for load groups
- Step 3: Determine power factor correction needs
  - parallel resonance may magnify harmonics
  - series resonance may "sink" harmonics from the utility

The Six-Step Process, cont.

- Step 4: Evaluate harmonic performance at PCC
  - frequency response of power circuits
  - harmonic characteristics of loads
- Step 5: Design harmonic mitigation equipment
  - passive filters coordinated with power factor correction capacitors
  - active filters may be better for smaller needs
- Step 6: Verify performance with measurements
  - monitor long enough to capture temporal variations

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Example case to illustrate industrial evaluation issues

- multiple sources, harmonic cancellation effects
- power factor correction/resonance concerns
- choosing the PCC
- design of harmonic filters to control harmonic levels
- evaluating the time varying nature of the harmonic levels

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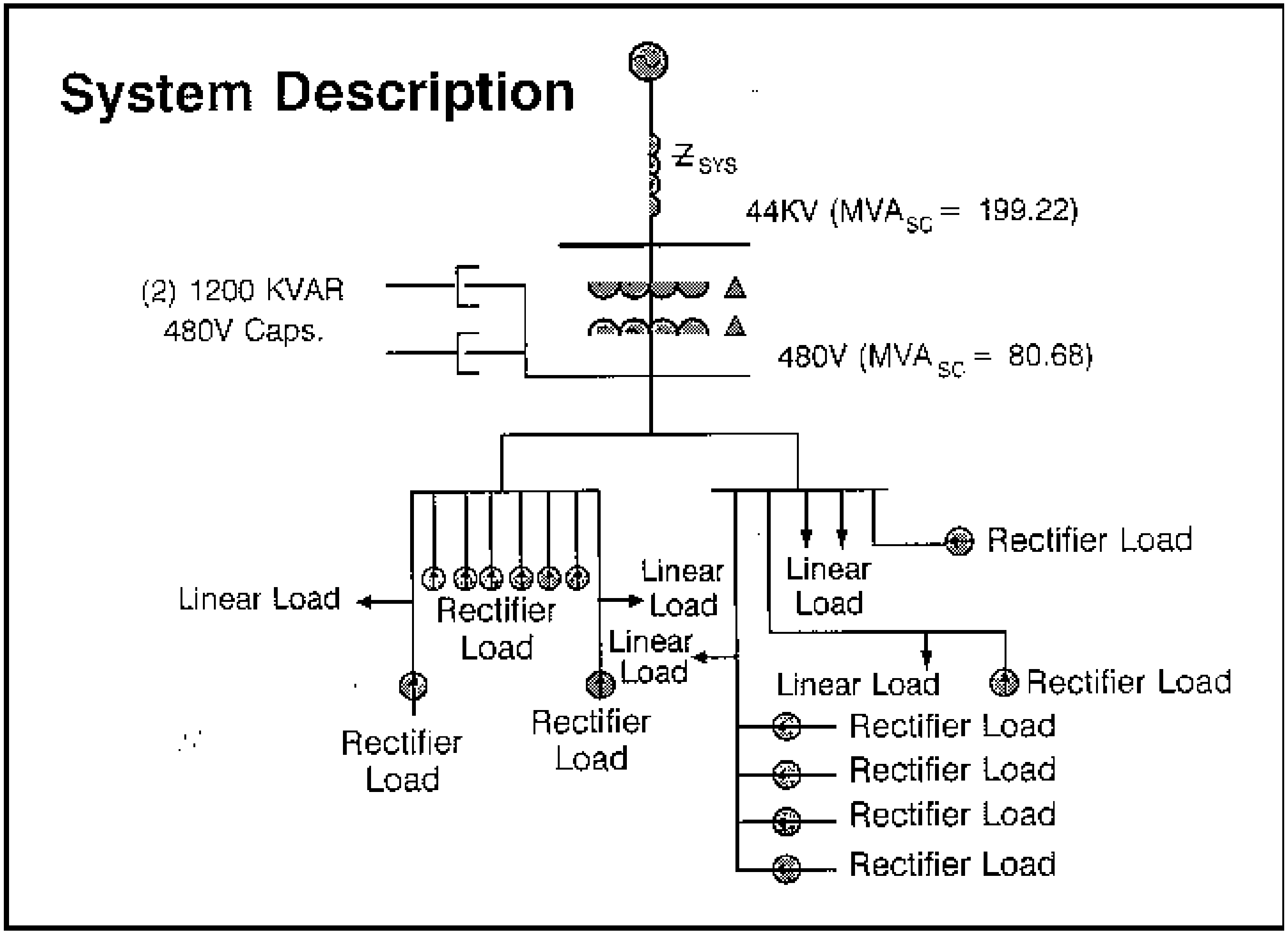
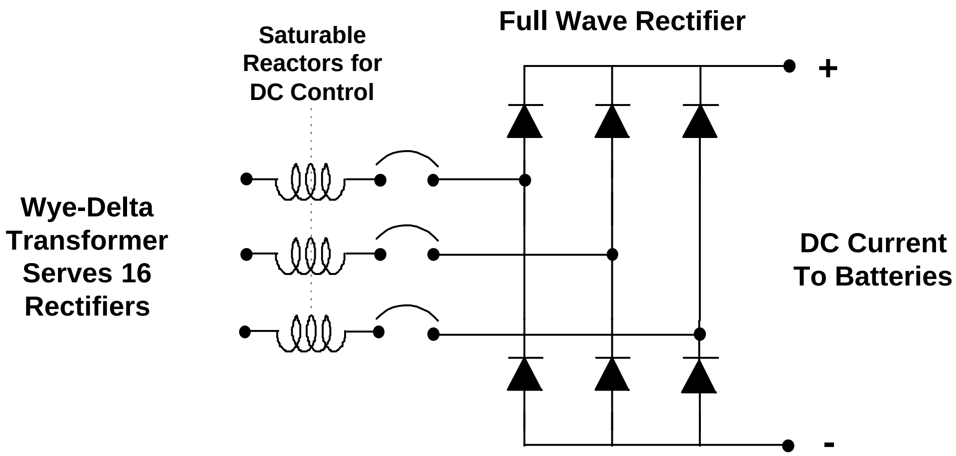
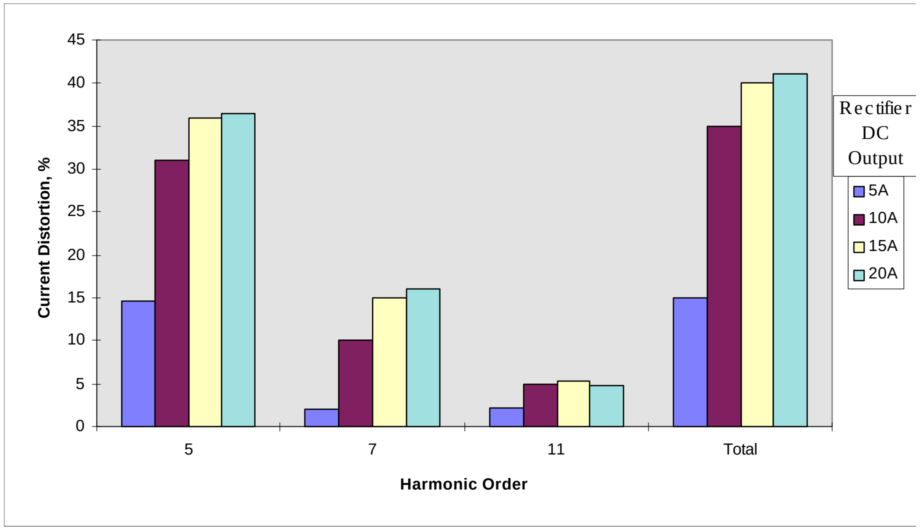
Example System

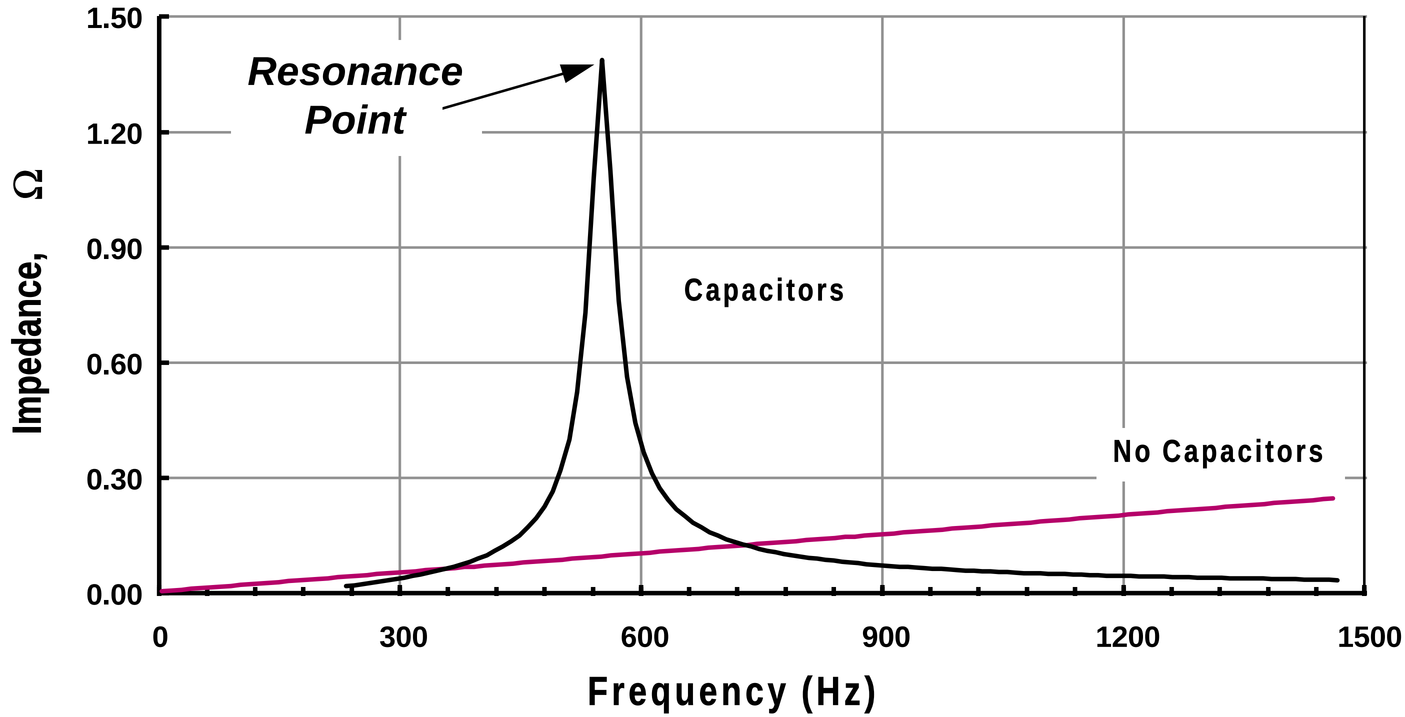


Harmonic Source Characteristics





Resonance Concern



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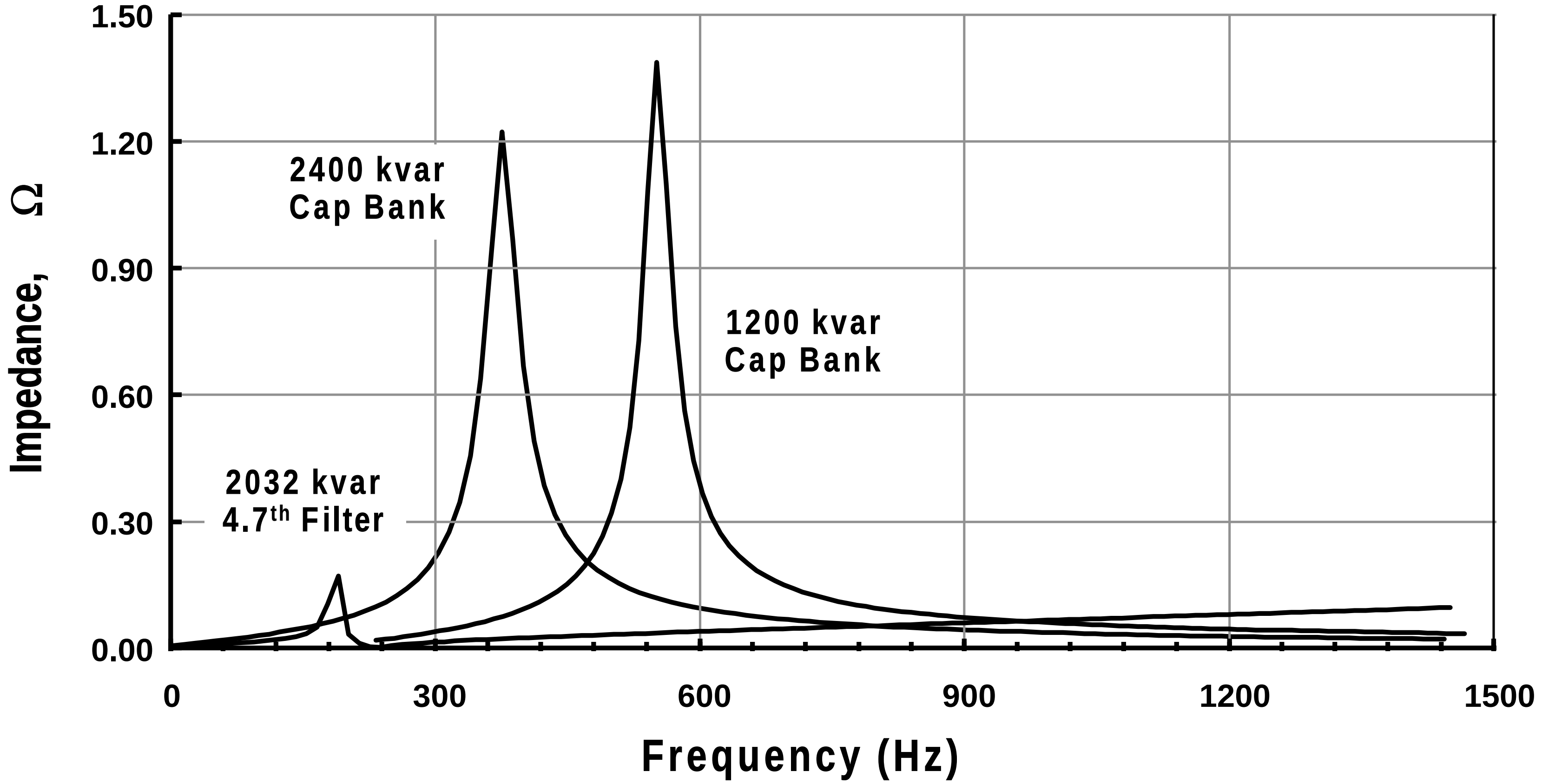
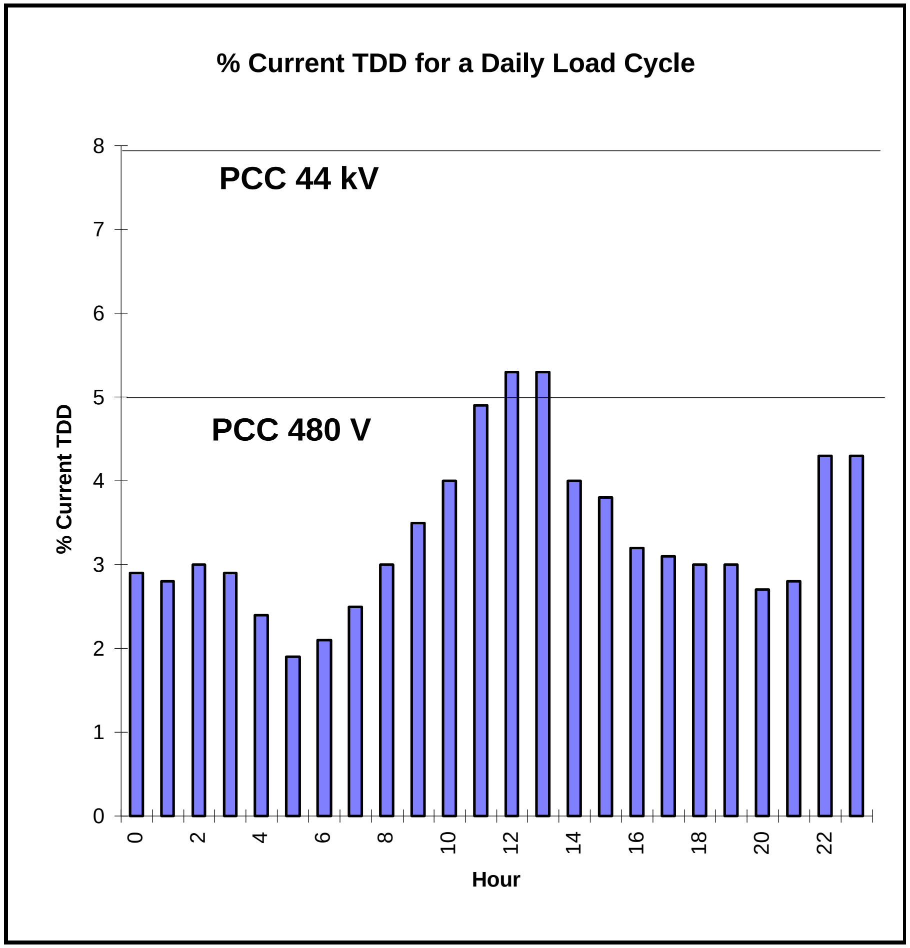
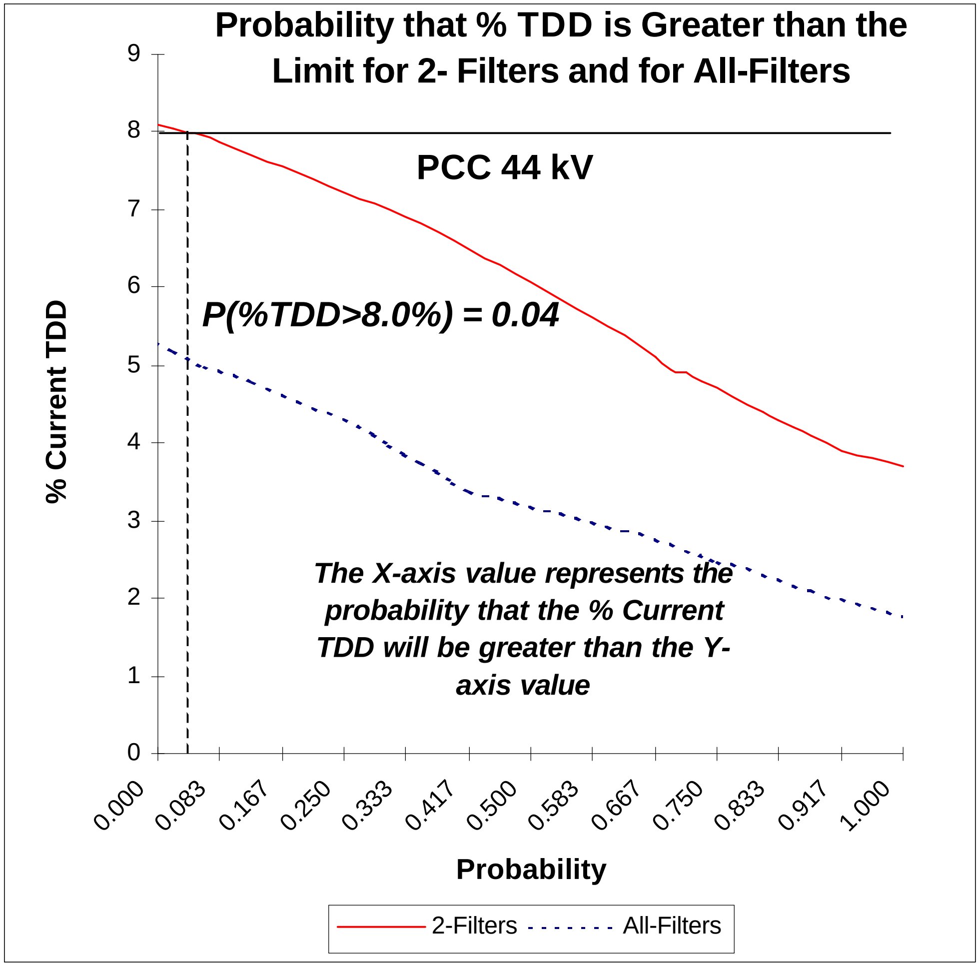
Avoiding Resonance Problems



Measurement results - time varying characteristics



Measurement results - statistical characteristics



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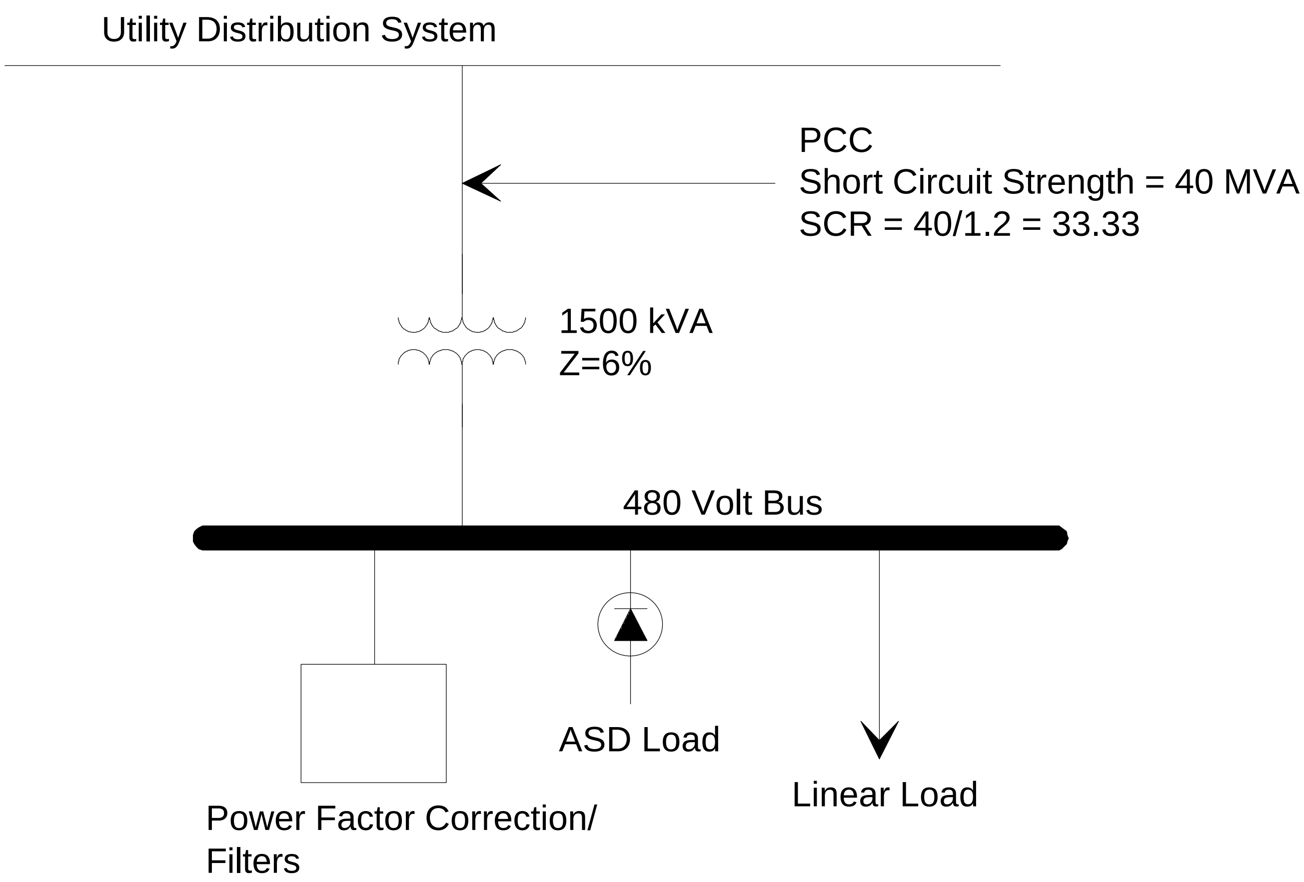
Evaluating ASD Loads - Example System for Analysis



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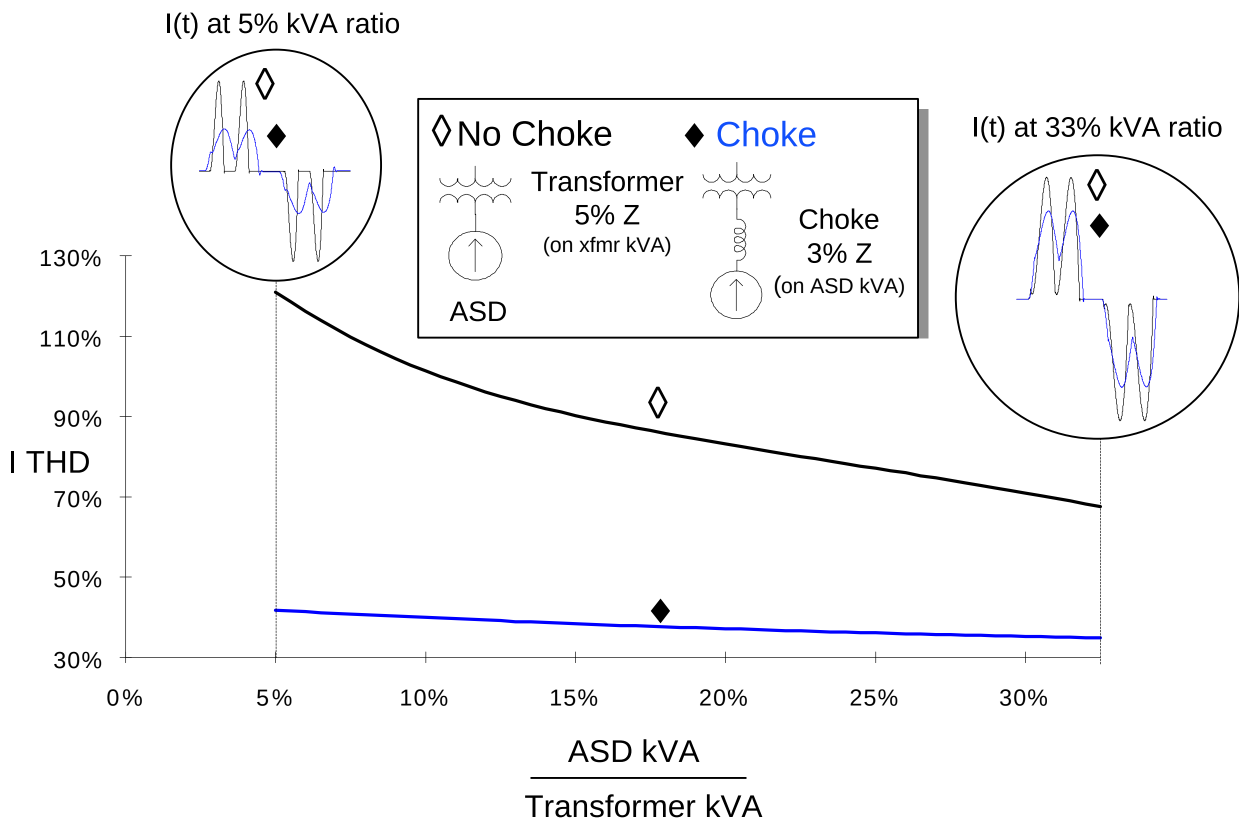
ASD Harmonic Levels



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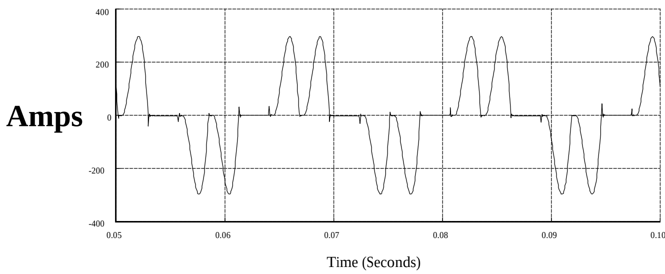
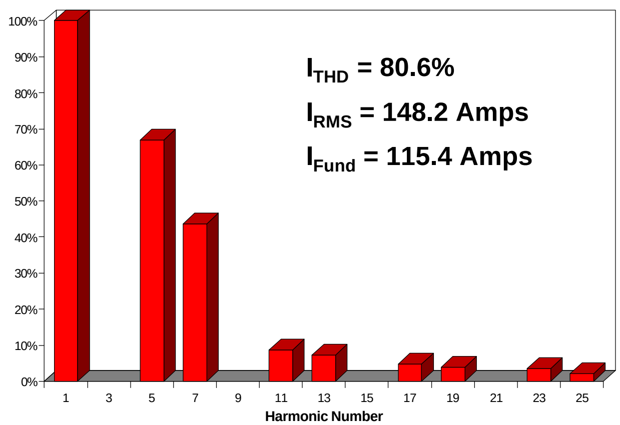
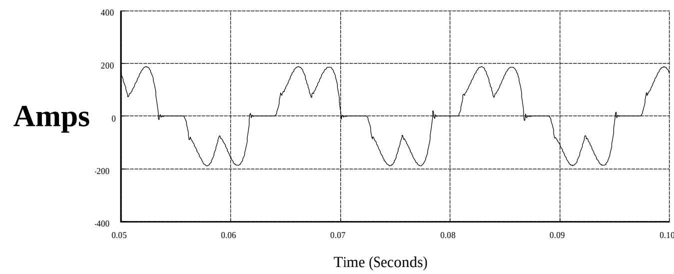
ASD Harmonic Currents

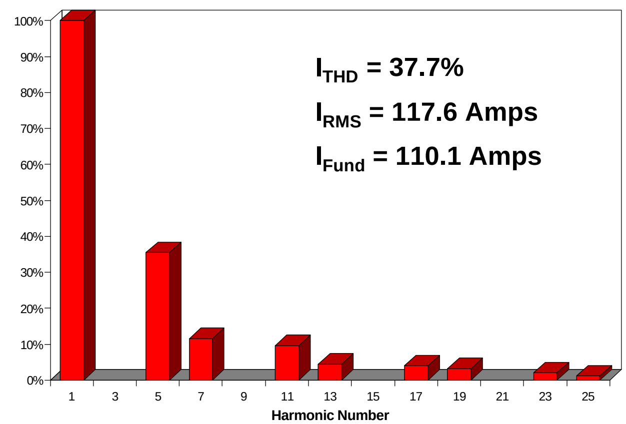
TYPE 1 Waveform
100 HP PWM ASD - No Choke





TYPE 2 Waveform
100 HP PWM ASD - 3% Choke





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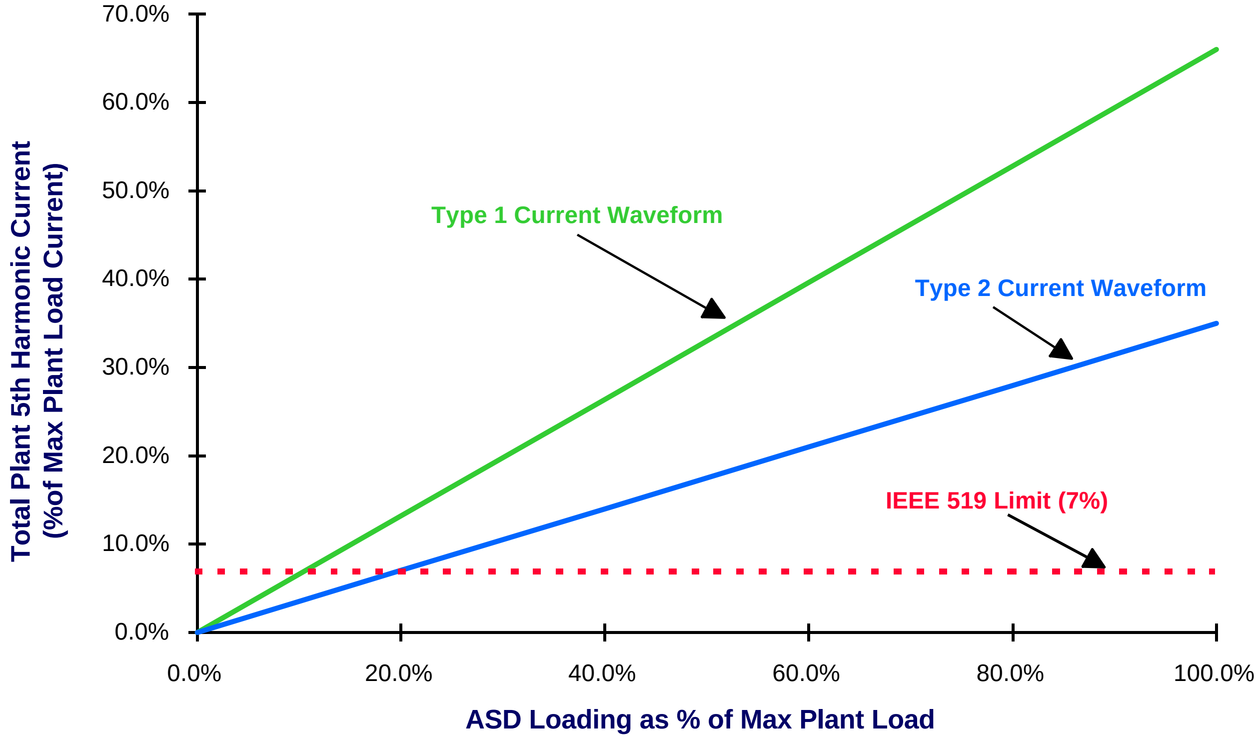
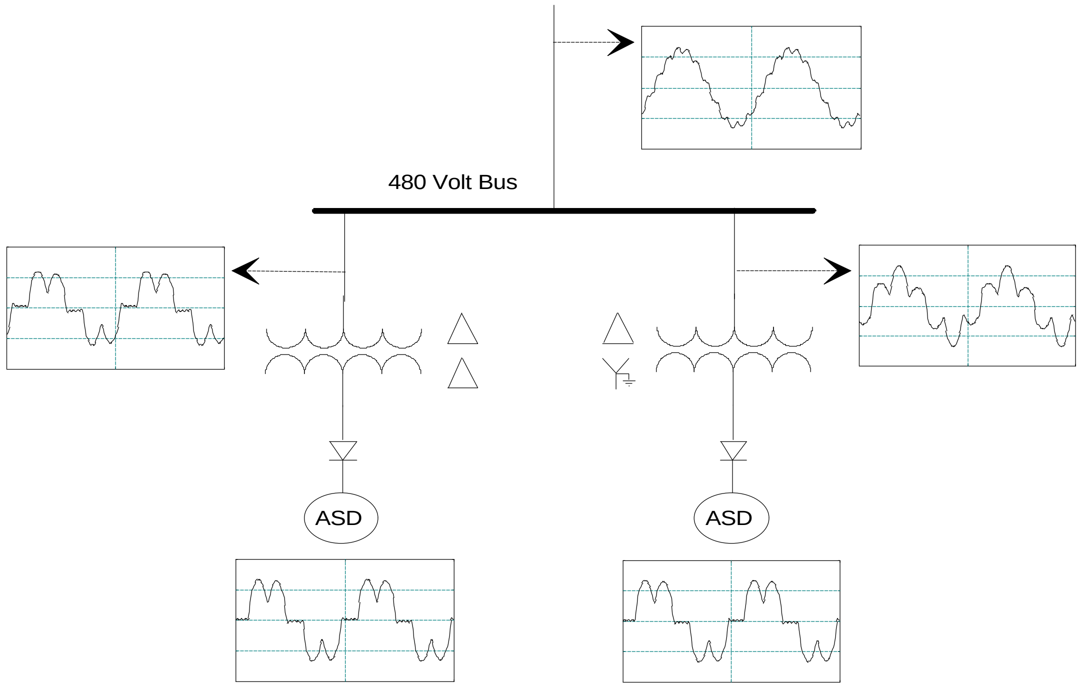
Rules of Thumb

- How much of the plant load can be ASDs without exceeding IEEE 519 guidelines?



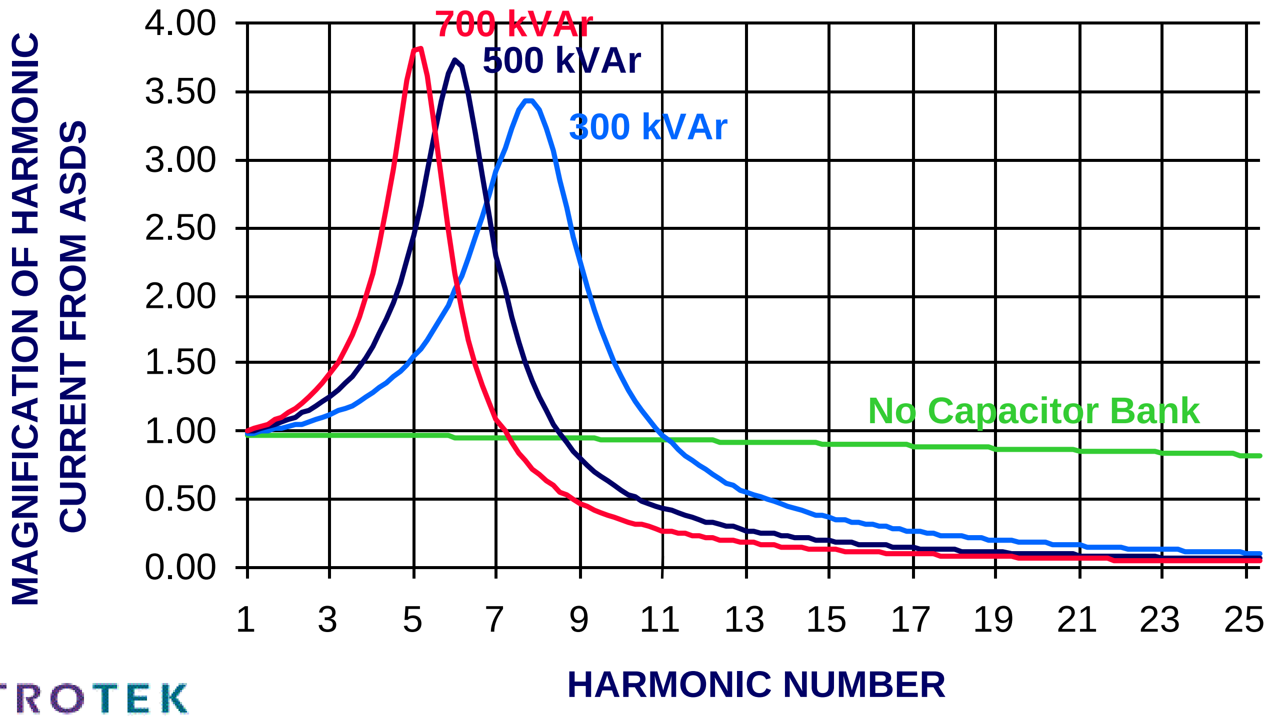
Designing for Cancellation

- Transformer connections can be used to get cancellation of harmonics from different drives.



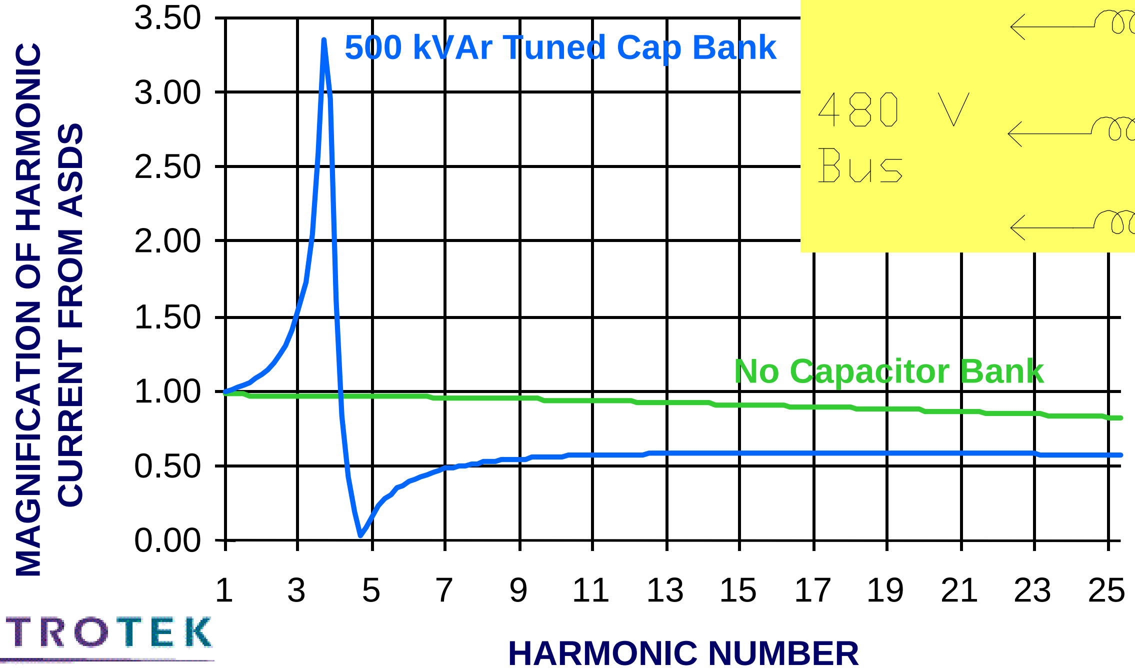
Effect of Power Factor Correction

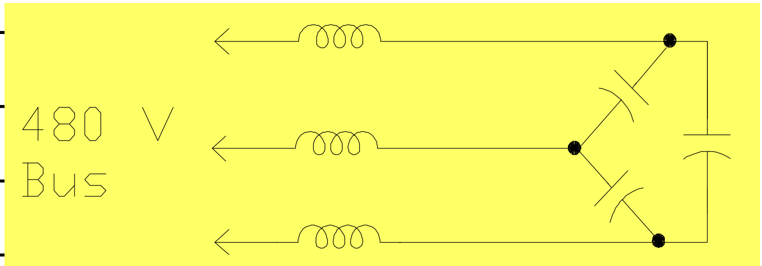
- Rules of thumb only apply if there are no power factor correction capacitors.



Power Factor Correction as Filters

- Power factor correction can be applied as harmonic filters to solve both the power factor problem and the harmonic problem.





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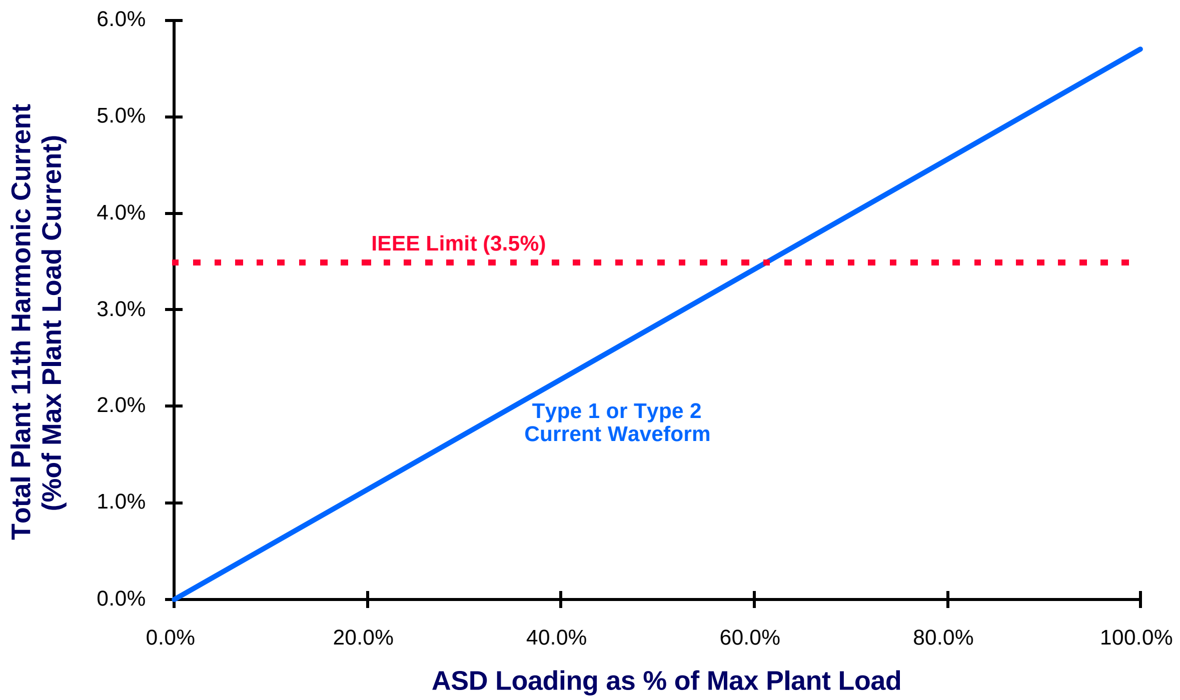
How many filter branches are needed?

- With a fifth harmonic filter, the evaluation will typically be dominated by the 11th harmonic component.



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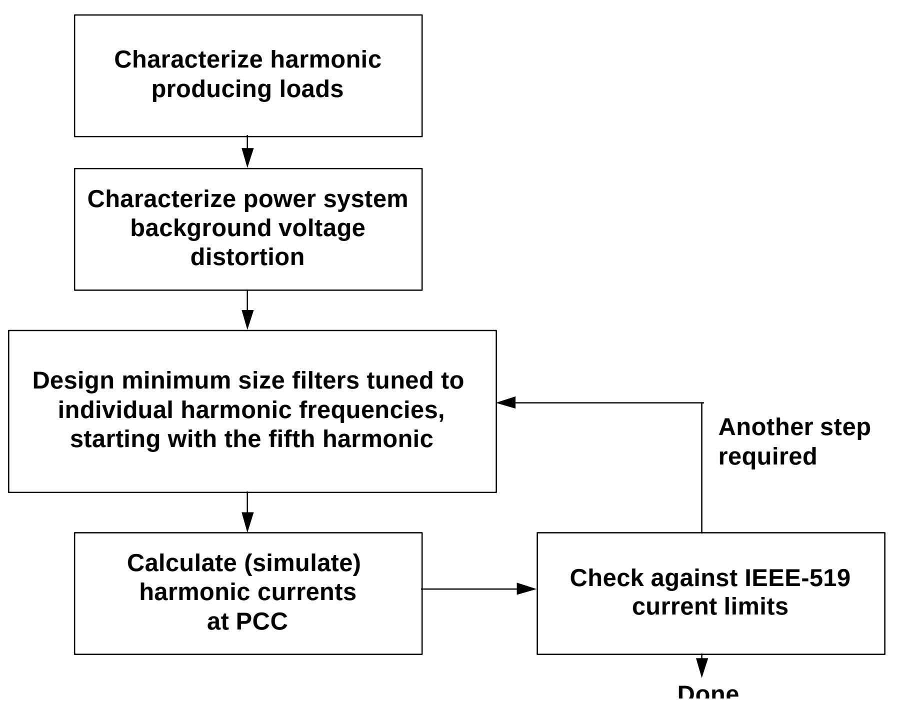
Filter design procedure

- Make sure the filter is designed for harmonic loading from other loads and the supplying power system, as well as the nonlinear loads being evaluated.



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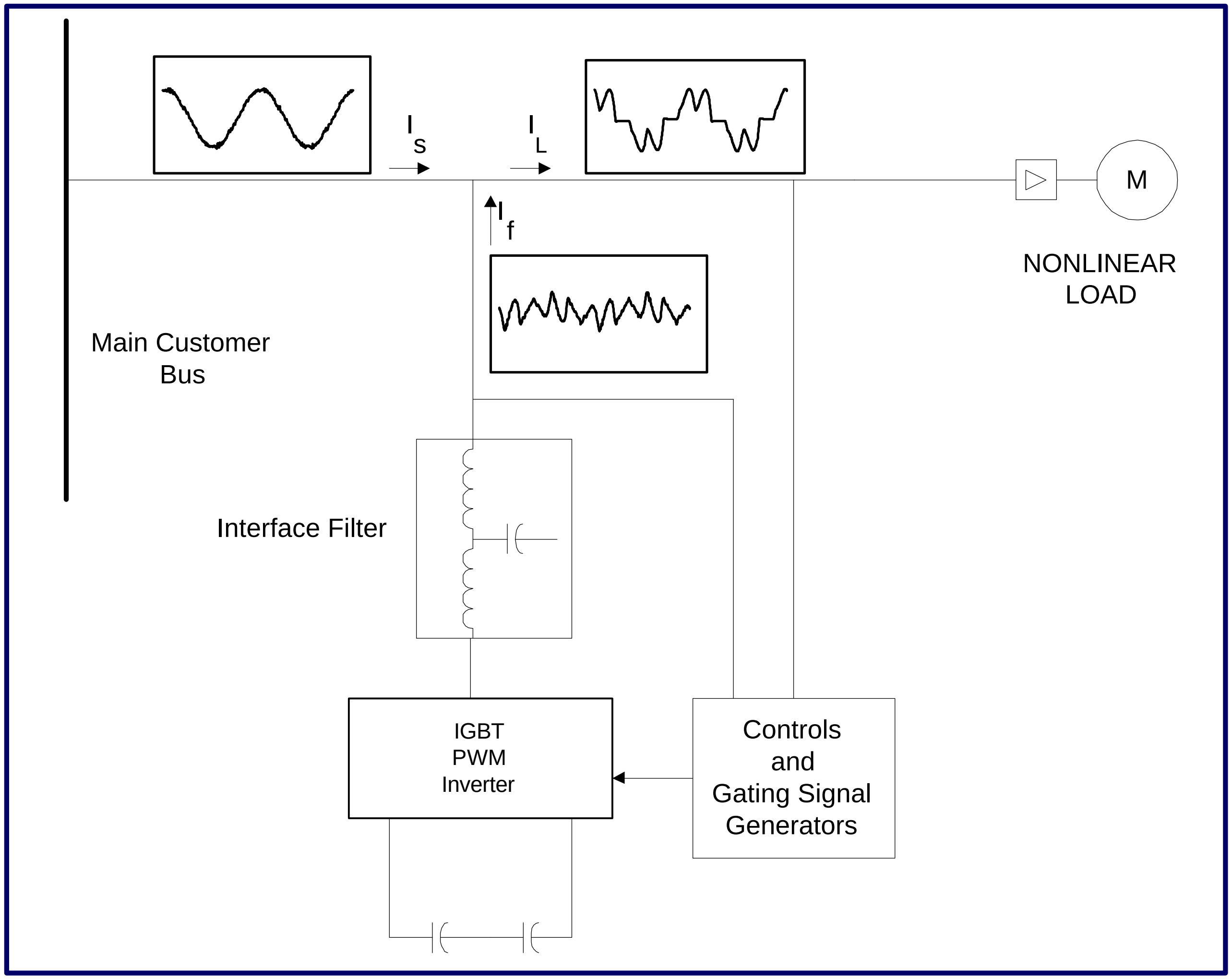
Another Alternative is the APLC



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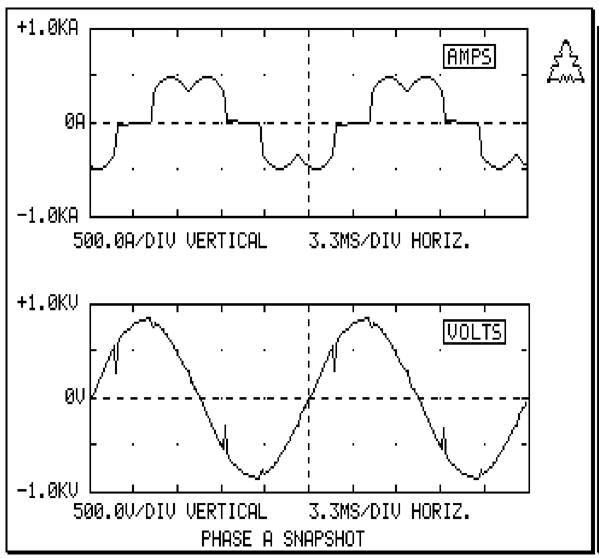
Characteristics of other important harmonic sources

- Dc drives
- Induction furnaces (heating processes)
- Arc furnaces

DC Drives

- Usually displacement power factor characteristics are important (power factor correction often needed)



PHASE A CURRENT SPECTRUN 2:51:53 PM
Fundamental amps: 346.2 A rms
Fundamental freq: 60.0 Hz

HARM	PCT	SINE PHASE	HARM	PCT	SINE PHASE
FUND	100.0%	-43°	2nd	0.3%	68°
3rd	0.4%	-126°	4th	0.2%	30°
5th	25.3%	-30°	6th	0.1%	61°
7th	5.5%	-122°	8th	0.2%	10°
9th	0.6%	37°	10th	0.2%	-45°
11th	8.2%	-102°	12th	0.1%	-37°
13th	3.9%	170°	14th	0.2%	-65°
15th	0.3%	-40°	16th	0.2%	-119°
17th	5.0%	-179°	18th	0.1%	-126°
19th	2.9%	93°	20th	0.2%	-136°
21st	0.3%	-44°	22nd	0.2%	167°
23rd	3.4%	109°	24th	0.1%	162°
25th	2.1%	14°	26th	0.2%	150°
27th	0.2%	-144°	28th	0.2%	100°
29th	2.7%	39°	30th	0.1%	86°
31st	1.9%	-59°	32nd	0.2%	74°
33rd	0.2%	99°	34th	0.2%	29°
35th	2.1%	-35°	36th	0.1%	6°
37th	1.7%	-135°	38th	0.2%	3°
39th	0.3%	41°	40th	0.2%	-42°
41st	1.8%	-110°	42nd	0.2%	-72°
43rd	1.5%	150°	44th	0.2%	-70°
45th	0.5%	-30°	46th	0.3%	-113°
47th	1.7%	177°	48th	0.2%	-146°
49th	1.4%	70°	50th	0.2%	-142°
ODD	28.9%		EVEN	1.0%	
THD:	28.9%				

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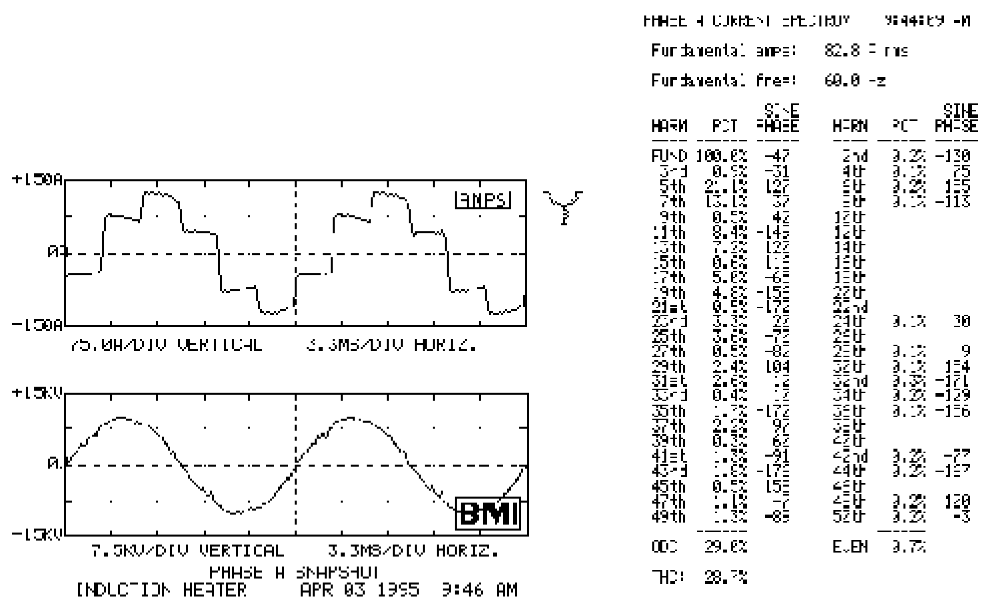
Induction furnace loads

- Rectifier/inverter configurations often exhibit important interharmonic components (coupling of output frequency to the input)



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Arc furnace characteristics

- Unbalanced arc characteristics results in non-characteristic harmonic components (e.g. 3rd).
- Dynamic nature of the arc results in interharmonic components and 2nd harmonic.

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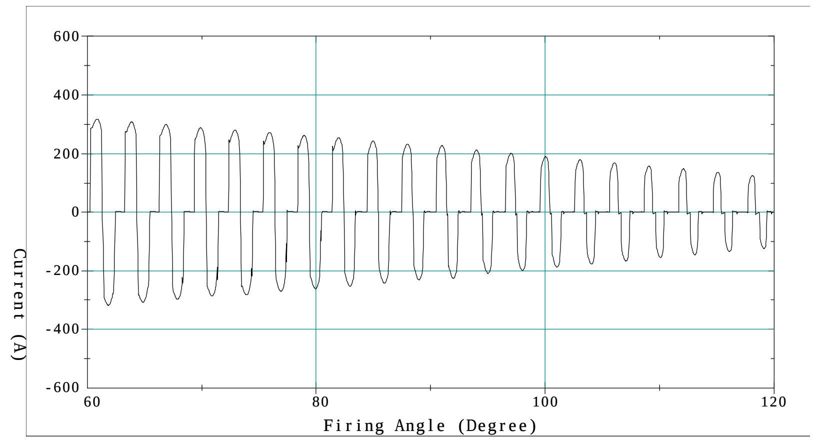
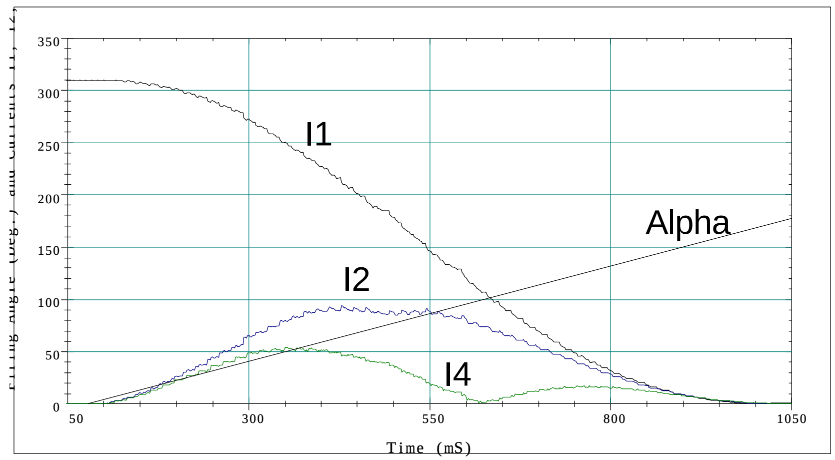
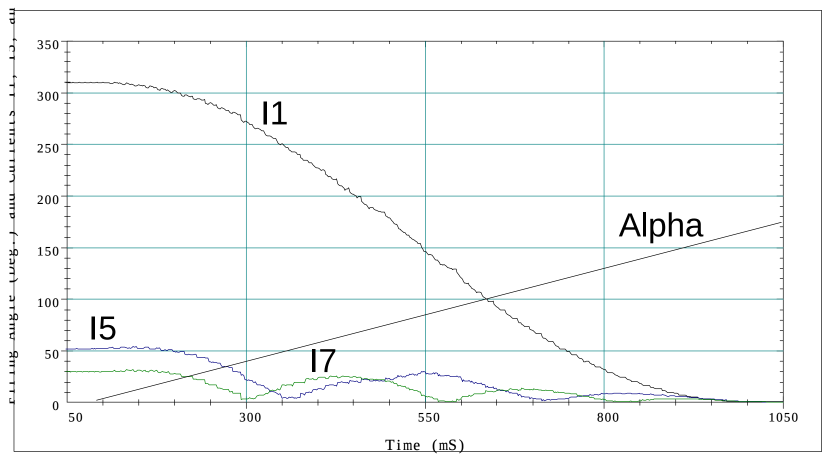
Semiconverters

- Concerns for even harmonics - makes filtering very difficult



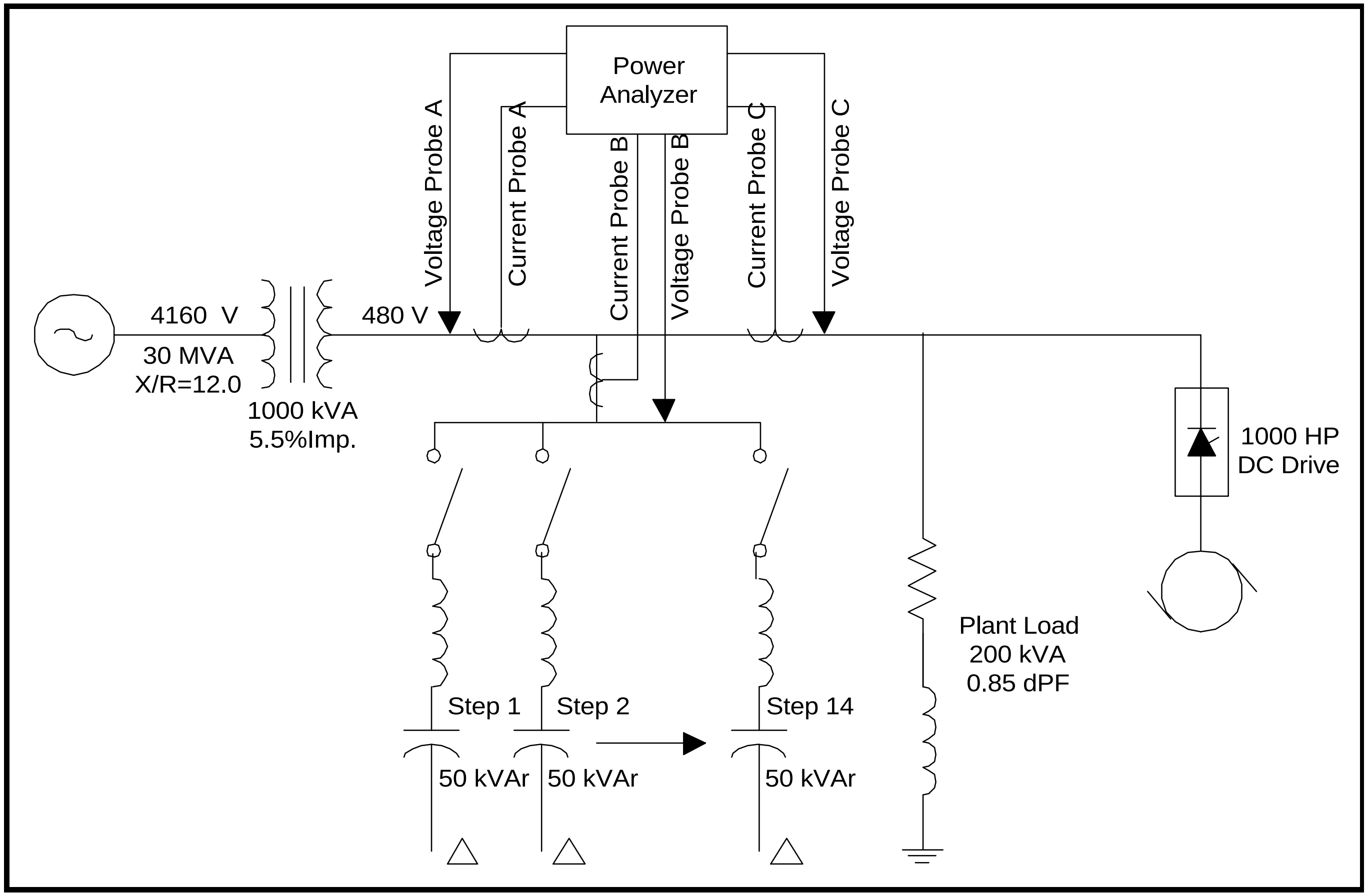




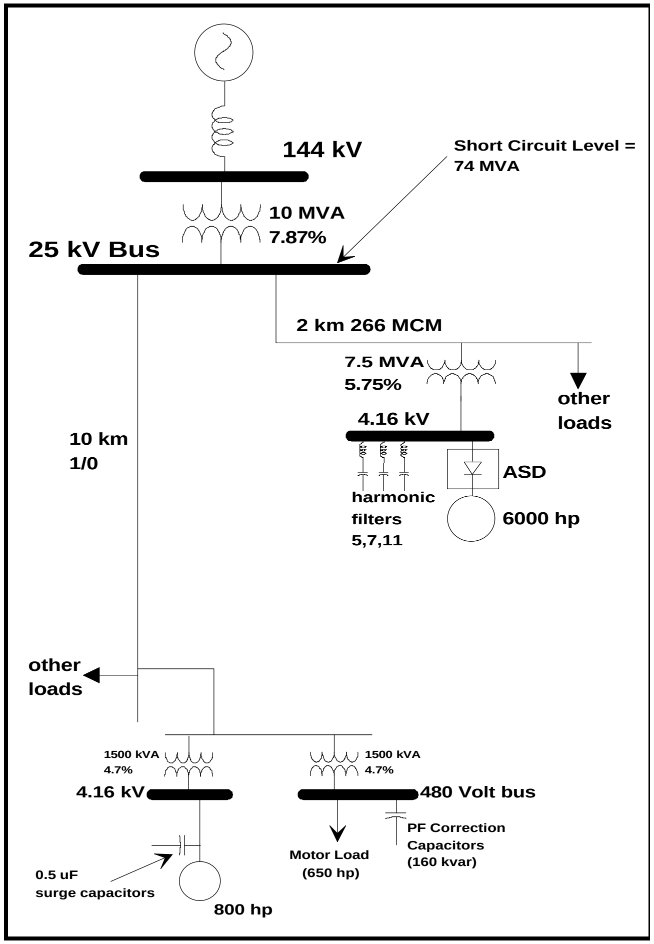
Cycloconverters

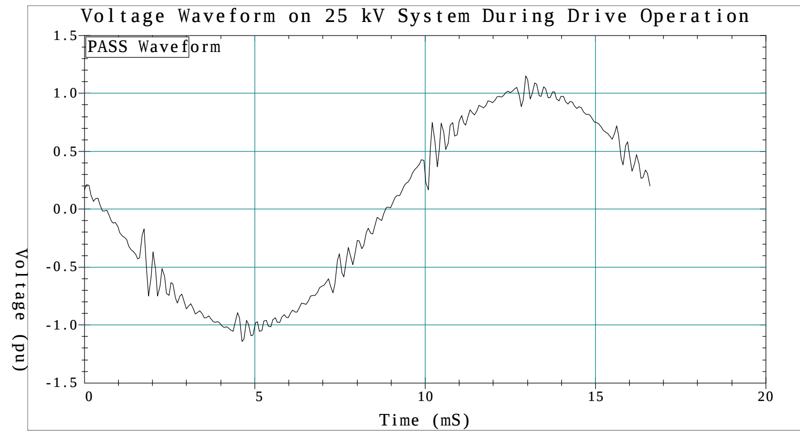
- Concern for interharmonics - interaction of output frequency with the input frequency
- Traction power applications
- Mining, steel industry applications

Measurements to verify performance



Notching Concerns - example case





Summary - Industrial Concerns

- Variety of Nonlinear Loads
- Power factor correction results in resonance concerns
- Time varying nature of the harmonic sources
- Other special concerns (non-characteristic harmonics, interharmonics, notching)
- Filter design issues

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Exercises for Industrial facility evaluations

- Simple circuit to evaluate 519 compliance and filter design issues
- Develop rules of thumb
- Nonlinear load models
- Evaluate alternative solutions
- Filter design - effectiveness evaluation

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IEEE P519A
Concerns for Commercial Facilities

October, 1998

Commercial Facility Concerns

- Proliferation of electronic loads
- Distortion levels within facility vs. service entrance
  - transformer derating
  - neutral currents
  - harmonic cancellation from multiple sources
- Impact of ASDs for HVAC systems
- Standby generators - harmonic concerns

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Commercial Facility Harmonic Sources

- Electronic Loads (switch mode power supplies)
- Fluorescent Lighting
- Adjustable Speed Drives (HVAC Applications)

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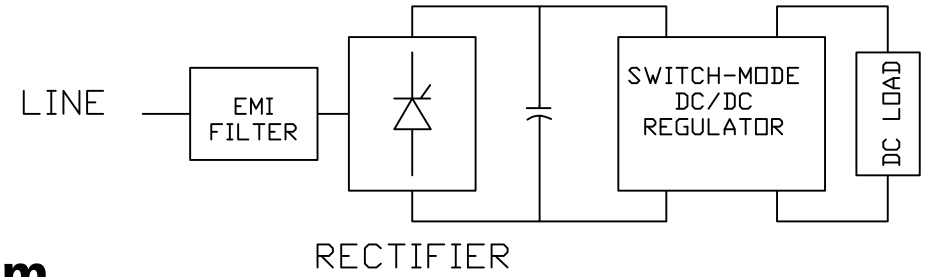
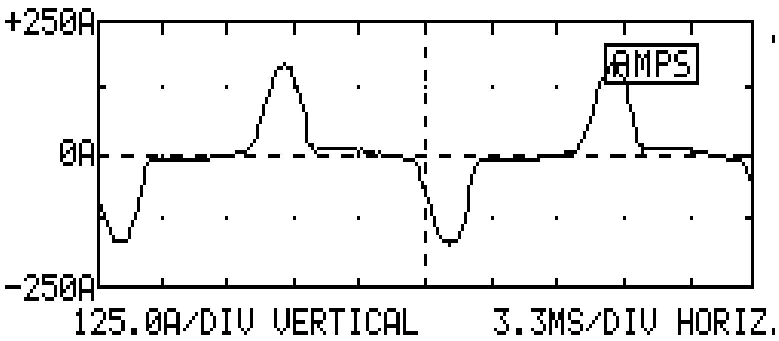
Switch Mode Power Supplies



Waveform and spectrum for a circuit supplying electronic loads.



Fundamental amps: 58.5 A rms
Fundamental freq: 60.0 Hz

HARM	PCT	PHASE	HARM	PCT	PHASE
FUND	100.0%	-37°	2nd	0.2%	65°
3rd	65.7%	-97°	4th	0.4%	-72°
5th	37.7%	-166°	6th	0.4%	-154°
7th	12.7%	113°	8th	0.3%	112°
9th	4.4%	-46°	10th		
11th	5.3%	-158°	12th	0.1%	142°
13th	2.5%	92°	14th	0.1%	65°
15th	1.9%	-51°	16th		
17th	1.8%	-151°	18th		
19th	1.1%	84°	20th		
21st	0.6%	-41°	22nd		
23rd	0.8%	-148°	24th		
25th	0.4%	64°	26th		
27th	0.2%	-25°	28th		
29th	0.2%	-122°	30th		
31st	0.2%	102°	32nd		
33rd	0.2%	56°	34th		

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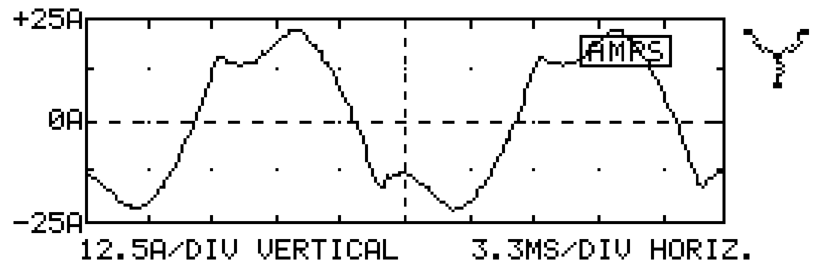
Fluorescent Lighting

Typical waveform and spectrum for lighting circuit with magnetic ballasts



Fundamental amps: 15.2 A rms
Fundamental freq: 60.0 Hz

HARM	PCT	PHASE	HARM	PCT	PHASE
FUND	100.0%	-124°	2nd	0.2%	136°
3rd	19.9%	-144°	4th		
5th	7.4%	62°	6th		
7th	3.2%	-39°	8th		
9th	2.4%	-171°	10th		
11th	1.8%	111°	12th		
13th	0.8%	17°	14th		
15th	0.4%	-93°	16th		
17th	0.1%	-164°	18th		
19th	0.2%	-99°	20th		
21st	0.1%	160°	22nd		
23rd	0.1%	86°	24th		
25th			26th		
27th	0.1%	161°	28th		
29th			30th		
31st			32nd	0.1%	156°
33rd			34th		

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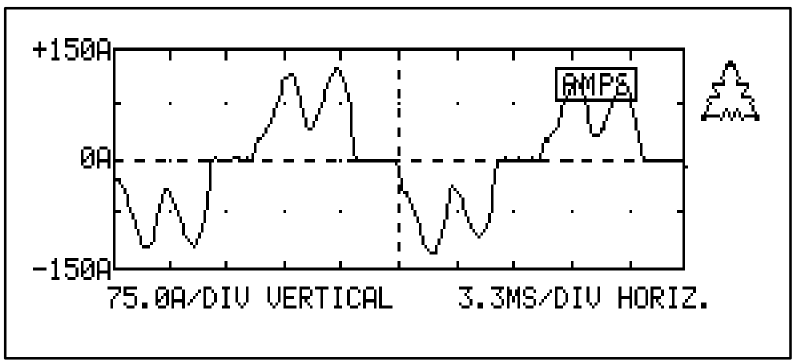
ASDs (HVAC Systems)

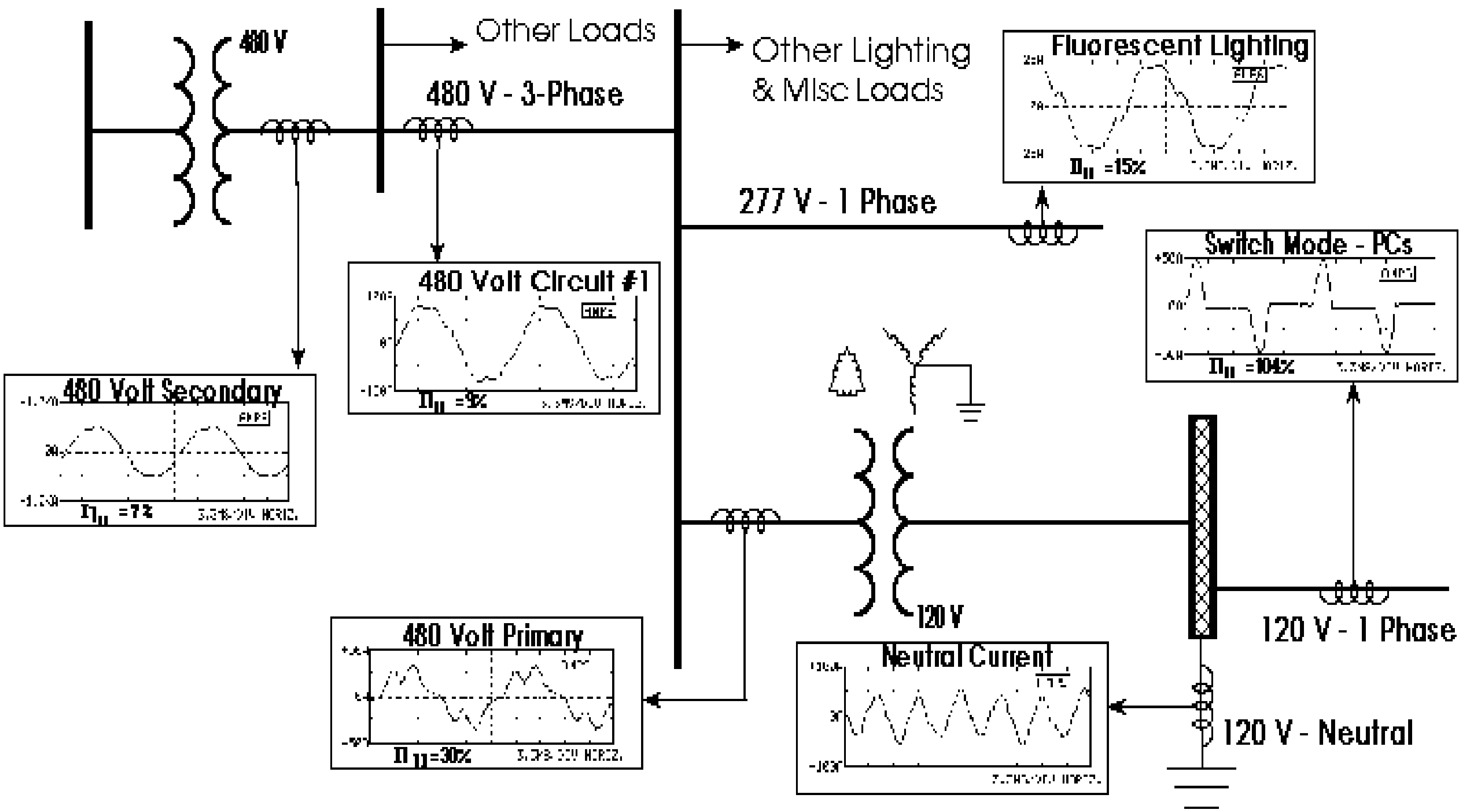
PWM Type ASD
with 3% input choke



PHASE B CURRENT SPECTRUM 2:23:40 PM
Fundamental amps: 61.2 A rms
Fundamental freq: 60.0 Hz

HARM	PCT	SINE PHASE	HARM	PCT	SINE PHASE
FUND	100.0%	-128°	2nd	1.0%	145°
3rd	3.9%	-149°	4th	0.4%	-57°
5th	39.7%	-122°	6th	0.8%	175°
7th	18.9%	122°	8th	0.2%	10°
9th	0.8%	47°	10th	0.2%	159°
11th	6.8%	67°	12th	0.4%	-27°
13th	3.8%	-118°	14th	0.3%	111°
15th	0.4%	-140°	16th	0.4%	6°
17th	3.2%	-144°	18th	0.4%	109°
19th	2.3%	10°	20th	0.3%	2°
21st	0.3%	29°	22nd	0.2%	141°
23rd	1.8%	11°	24th	0.2%	-79°
25th	1.7%	145°	26th	0.2%	124°
27th	0.2%	-165°	28th	0.1%	-81°
29th	1.1%	160°	30th	0.1%	68°
31st	1.3%	-74°	32nd	0.1%	-112°
33rd	0.2%	-32°	34th	0.1%	81°
35th	0.7%	-49°	36th	0.1%	-114°
37th	1.0%	67°	38th		
39th	0.2%	153°	40th		
41st	0.5%	96°	42nd	0.1%	-1°
43rd	0.8%	-147°	44th	0.1%	134°
45th	0.2%	-59°	46th		
47th	0.4%	-112°	48th		
49th	0.7%	-5°	50th		
ODD	45.1%		EVEN	1.6%	
THD:	45.1%				

How do the harmonic currents combine?

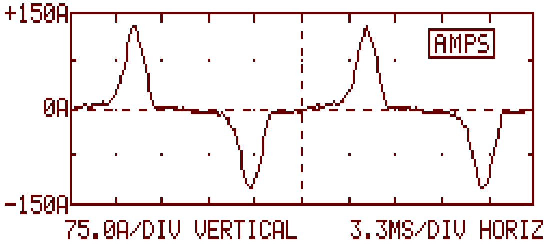


Commercial Facility Concerns

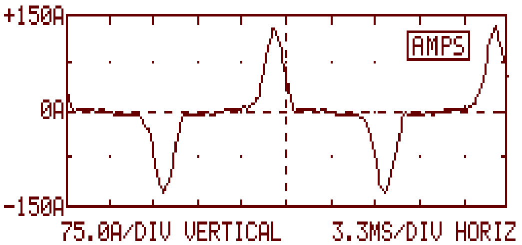
- Neutral currents
- Transformer derating requirements
- Standby generator rating requirements

Example of High Neutral Current

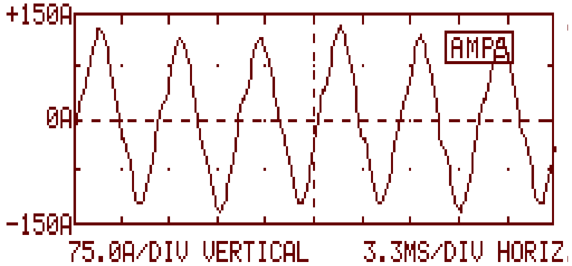
Phase A (50 Amps)



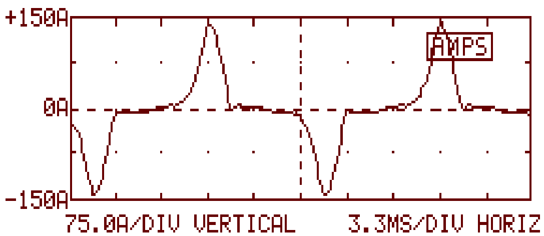
Phase B (50 Amps)



Neutral (82 Amps)



Phase C (57 Amps)



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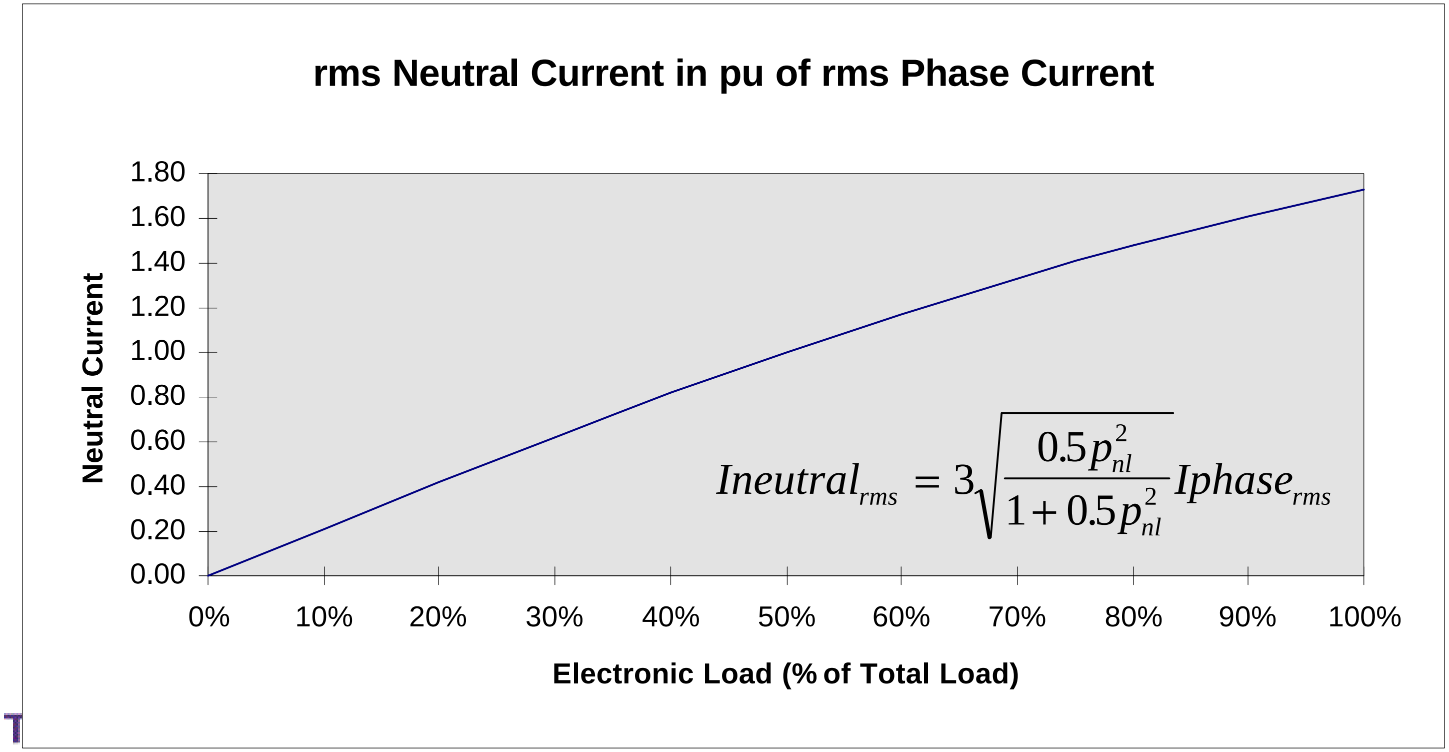
Estimating neutral currents

- Neutral currents can be estimated based on the percentage of the load on the three phase circuit that consists of single phase electronic equipment



$$Ineutral_{rms} = 3\sqrt{\frac{0.5p_{nl}^2}{1+0.5p_{nl}^2}}Iphase_{rms}$$

Solutions to Overloaded Neutrals

- Increase the neutral conductor size
- Neutral for each phase
- Double neutral
- Third harmonic filter at each load
- Zig Zag transformer close to loads
- Active filter(s)

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Transformer Derating Considerations

- Transformer derating requirements for harmonics specified in ANSI/IEEE C57.110-1991.
- Function of Transformer Eddy Current Losses
- Derating needs to be applied whenever the full load current distortion exceeds 5%
- K-Factor transformers designed to supply nonlinear loads without derating

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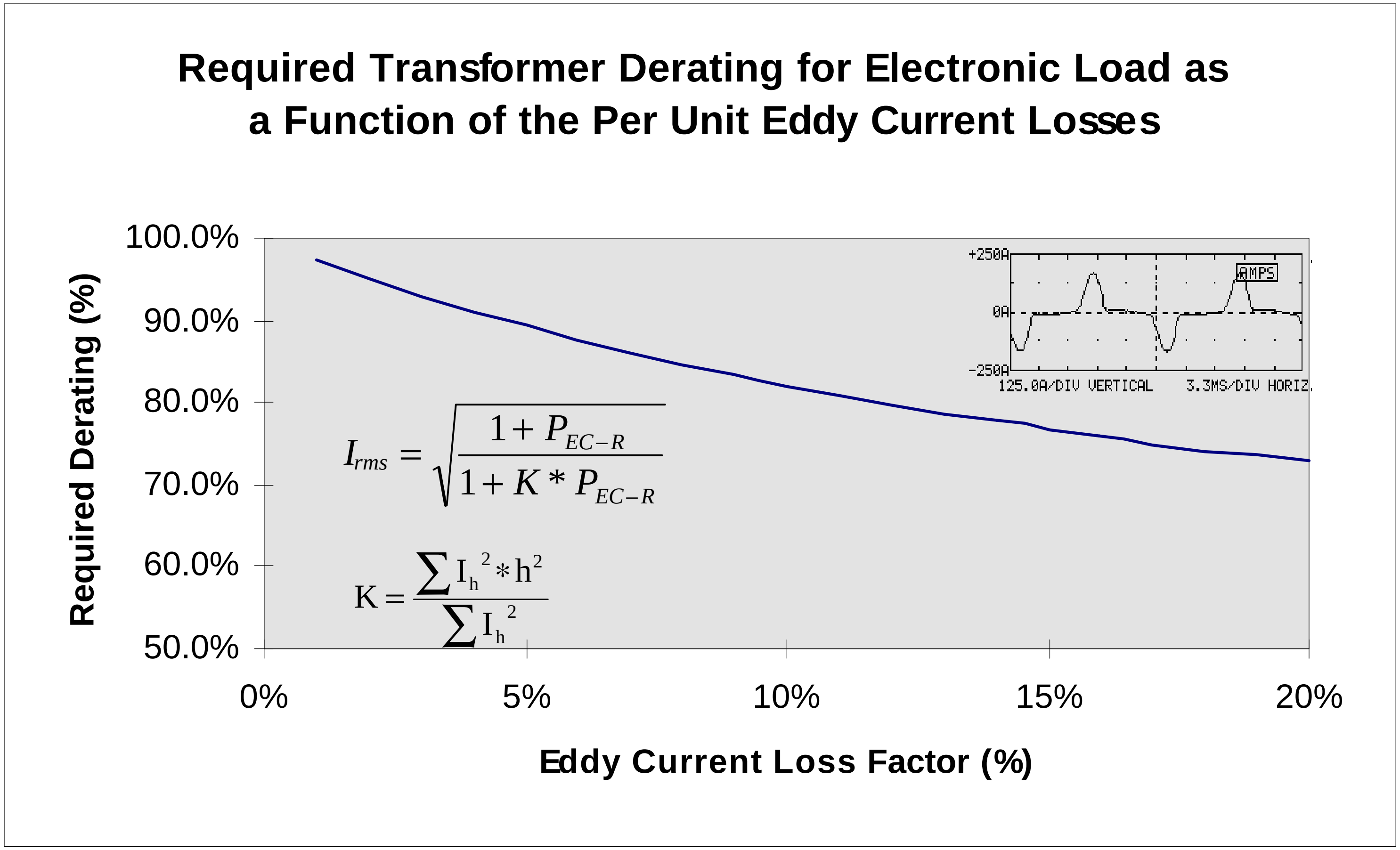
Transformer Derating - ANSI C57.110



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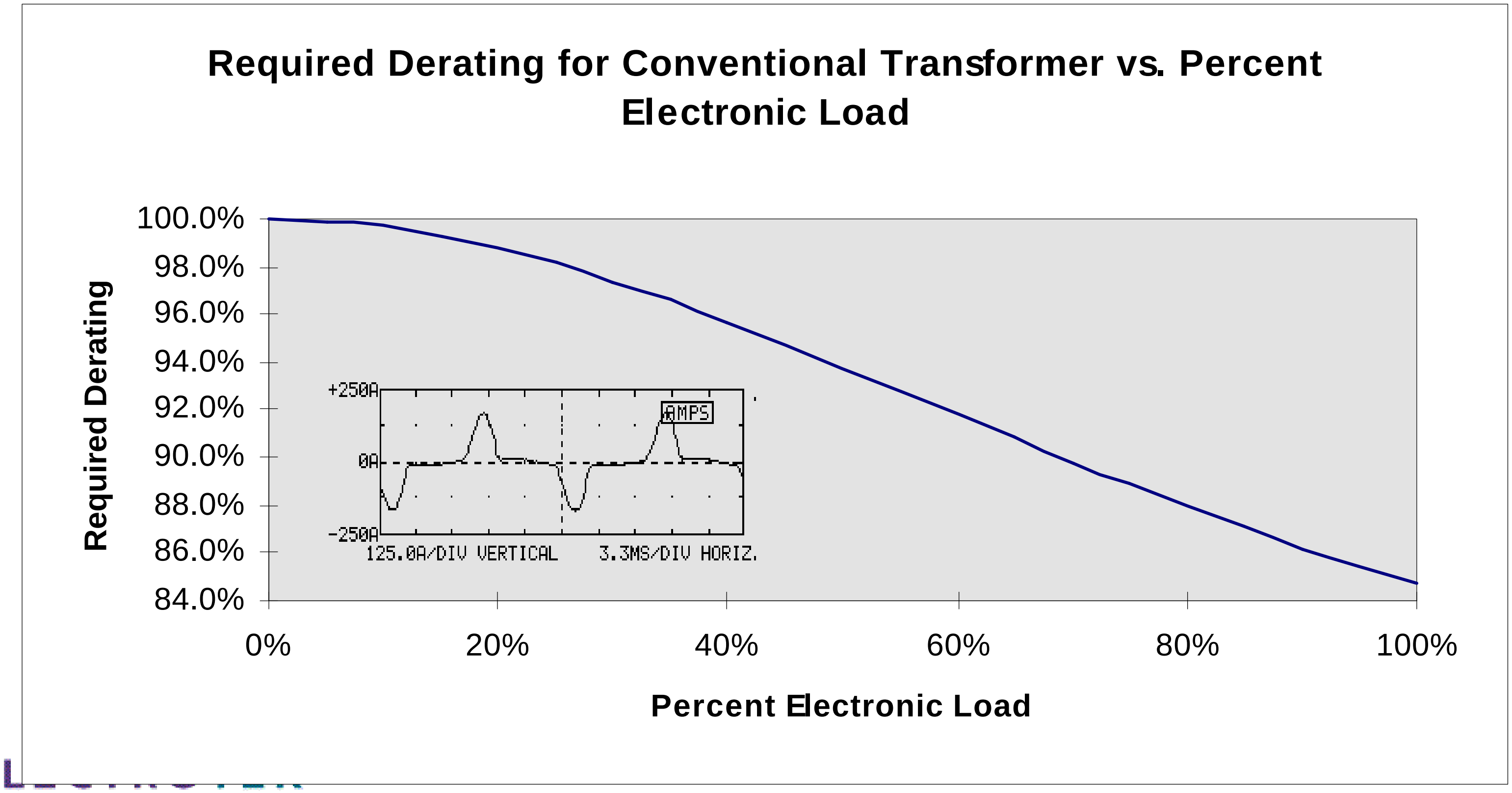
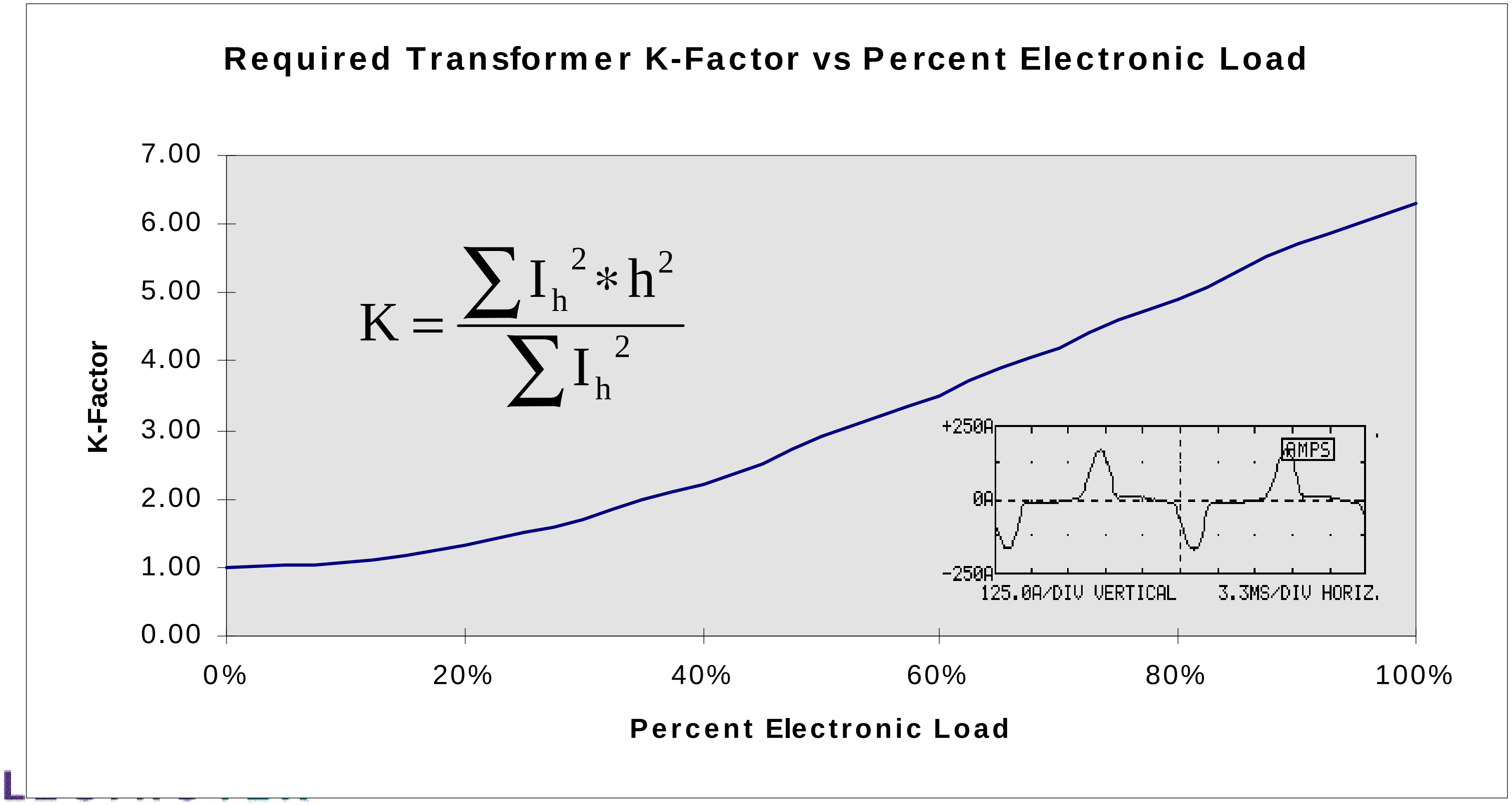
Derating vs. Nonlinear Load

The required derating also depends on the percent of the load made up of electronic equipment (or other nonlinear loads).



K-Factor Transformers

K-Factor Transformers are designed to supply nonlinear loads without derating. The K-Factor defines the level of current distortion that is acceptable.



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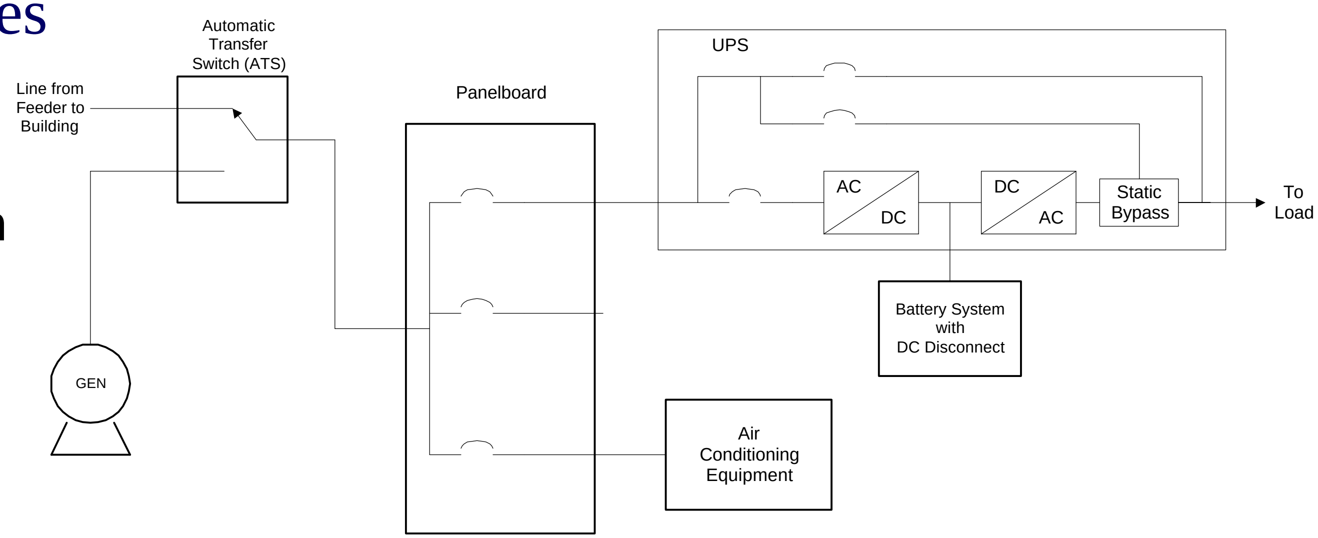
Standby Generator Requirements

- Harmonics can be more of a problem during backup generator operation due to generator impedance.
- Calculate voltage distortion with generator operating and limit to 5%
- Make sure harmonic currents do not exceed generator capabilities

Typical configuration of UPS system for critical loads with backup generator



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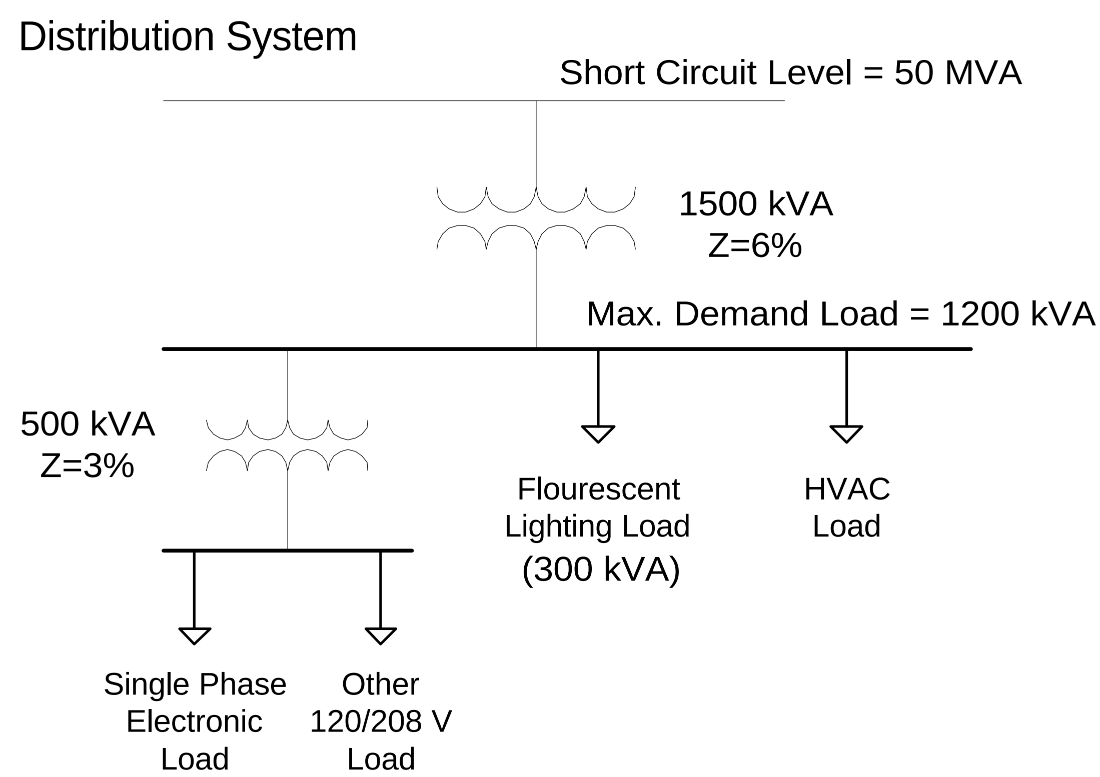
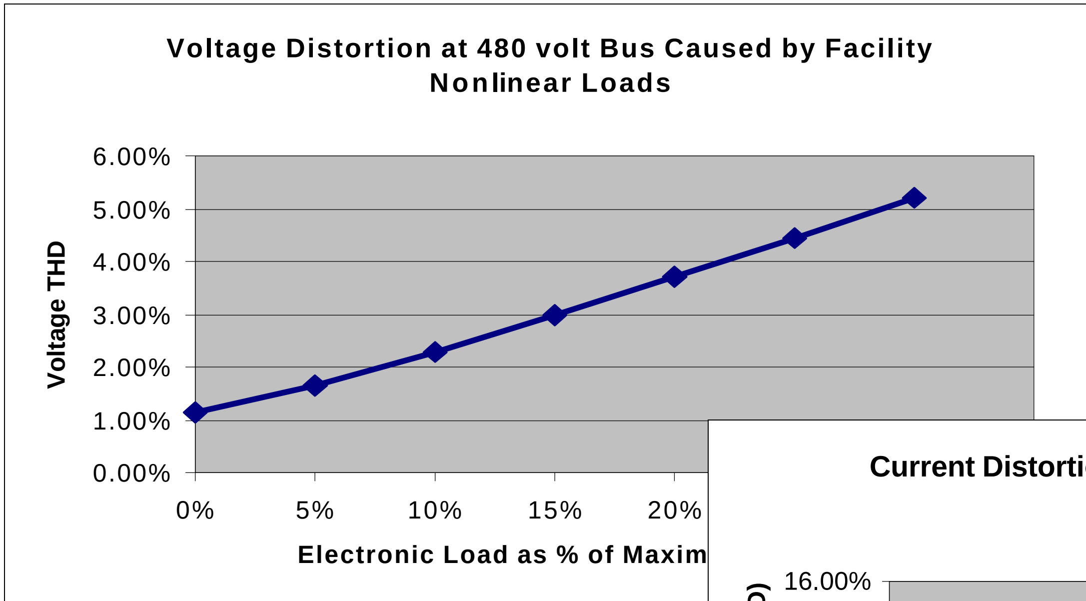
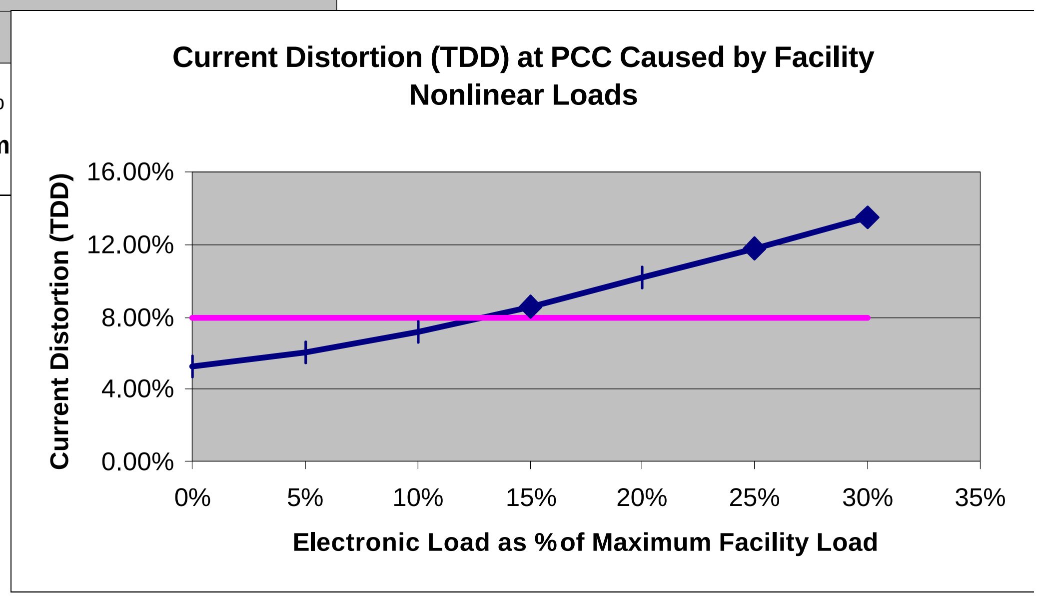
Overall Facility Harmonic Levels

Example System to evaluate distortion levels at the PCC



Voltage and Current Distortion without ASDs





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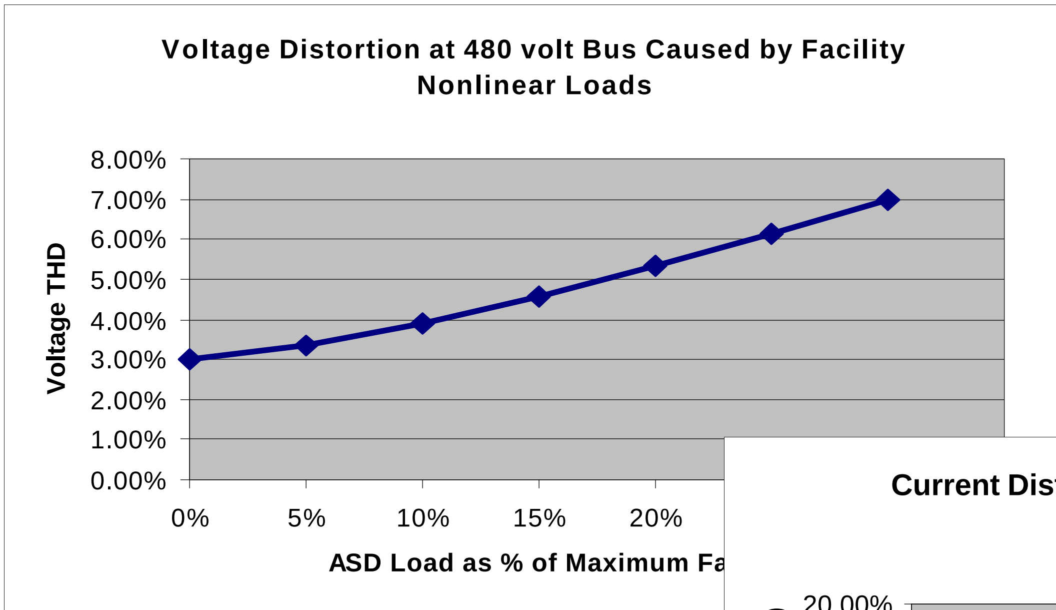
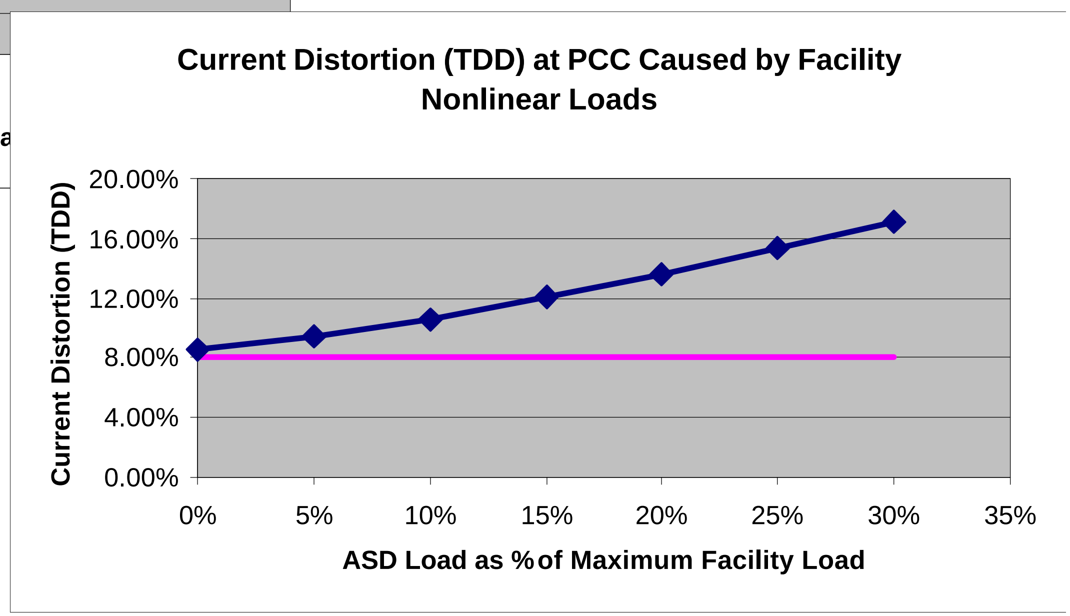
Voltage and Current Distortion Levels with ASDs





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Summary - Concerns for 120/208 circuits

- Neutral conductors in 3-phase, 4-wire circuits serving electronic loads should be rated for 170% of the maximum line current.
- Neutral conductors in fluorescent lighting circuits should be rated for maximum line current.
- Transformers for step down to 120/208 that supply electronic loads should be derated for harmonics or should be k-factor transformers
- Voltage distortion on 120/208 v secondary circuits will be dominated by electronic loads. Distortion should be below 5% if total electronic load is below 25% of transformer rating.

Summary - Concerns for overall facility

- Voltage distortion in 480 v circuits will depend on the cumulative effect of office loads, fluorescent lighting, and HVAC equipment.
- Most commercial facilities should not exceed 519 limits unless there is significant penetration of ASDs for HVAC applications or a large percentageof the load is electronic (some type of filtering could be needed in these cases).
- Retrofitting with electronic ballasts should not have significant impacts on building harmonic levels if ballasts with less than 30% current distortion are used.

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Exercises for commercial facility evaluations

- Simple circuit to evaluate effects of different load combinations
- Harmonic source representations for different types of loads
  - electronic loads
  - lighting
  - asds
- Neutral currents, transformer derating, interaction evaluations

IEEE P519A
Concerns for Residential Systems

October, 1998

Harmonic concerns for circuits supplying residential customers

- Characteristics of nonlinear loads
  - electronic loads
  - ASD heat pumps and air conditioners
  - compact fluorescents
  - electric vehicle battery chargers
- System frequency response characteristics
- How to apply limits

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Evaluate response to CFLs as an example

- CFLs are being promoted as part of energy conservation programs at many electric utilities.
- A recent study has concluded that low CFL penetration levels can cause the feeder voltage distortion to <u>exceed</u> 5%.
- Previous studies have indicated that further investigation needs to be done.

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Introduction - cont.

- Measurements were performed to identify harmonic characteristics for different CFLs
- Transient models utilized to develop a detailed representation of typical loads.
- Harmonic simulations used to examine cumulative effect of CFLs.

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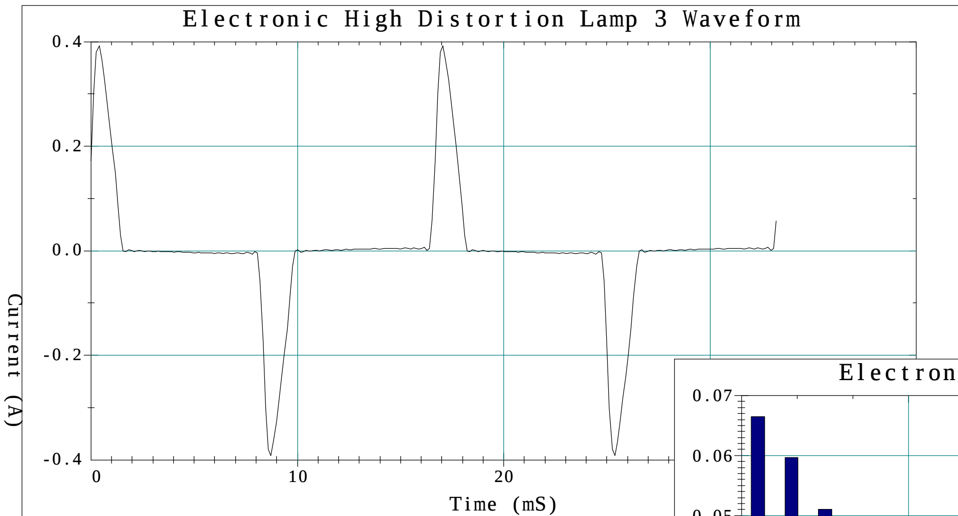
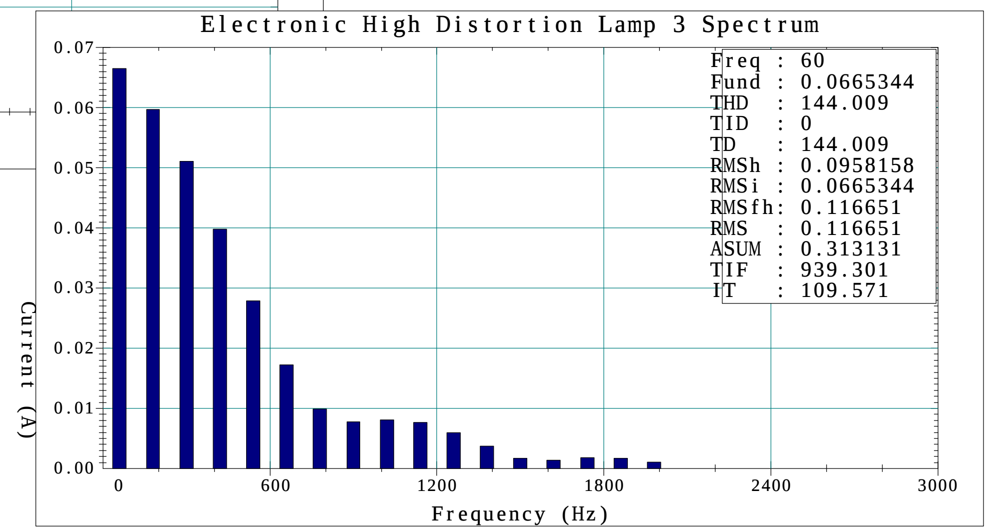
High Distortion Electronic Ballast CFLs





Harmonic Current Distortion of 140%

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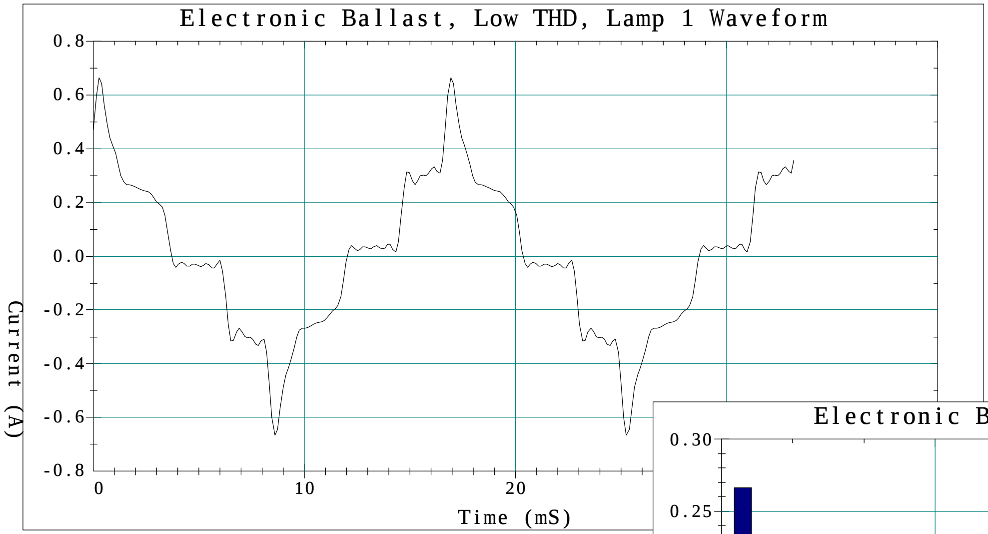
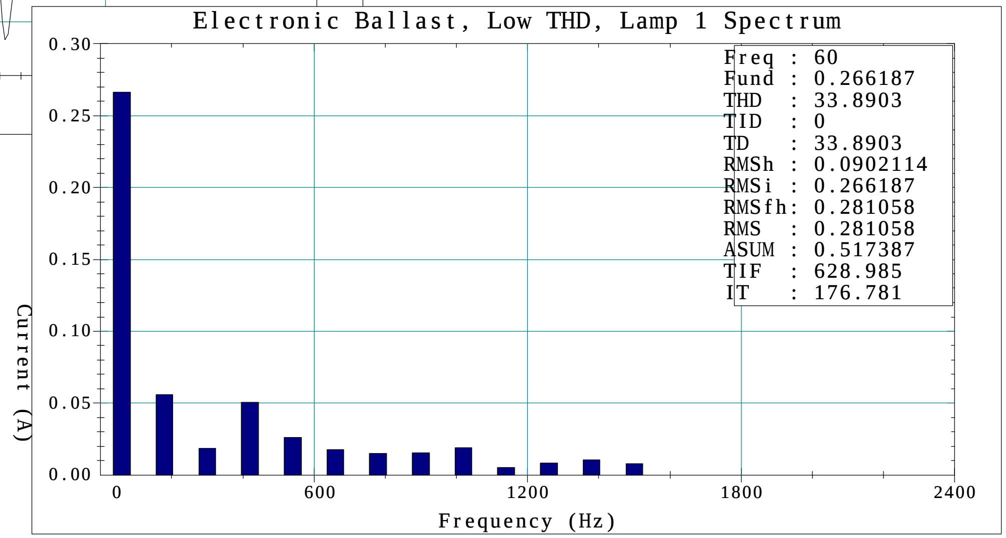
Low Distortion Electronic Ballast CFLs



Harmonic Current Distortion of 30%



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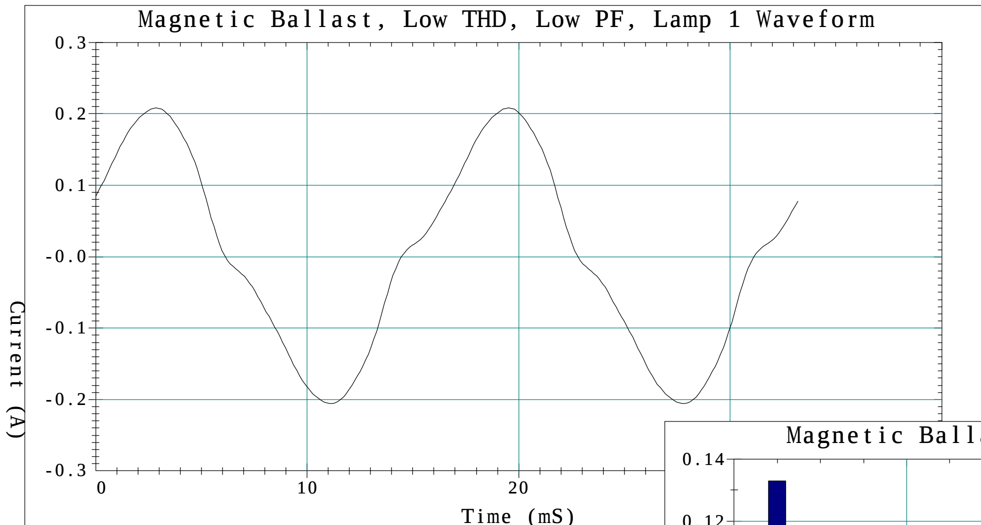
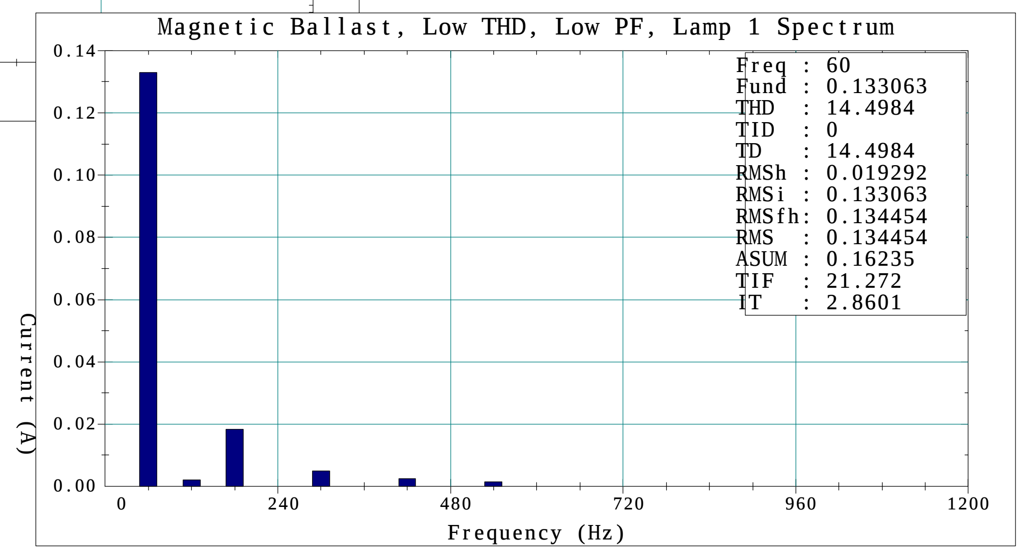
Magnetic Ballast CFLs





Harmonic Current Distortion of 20%

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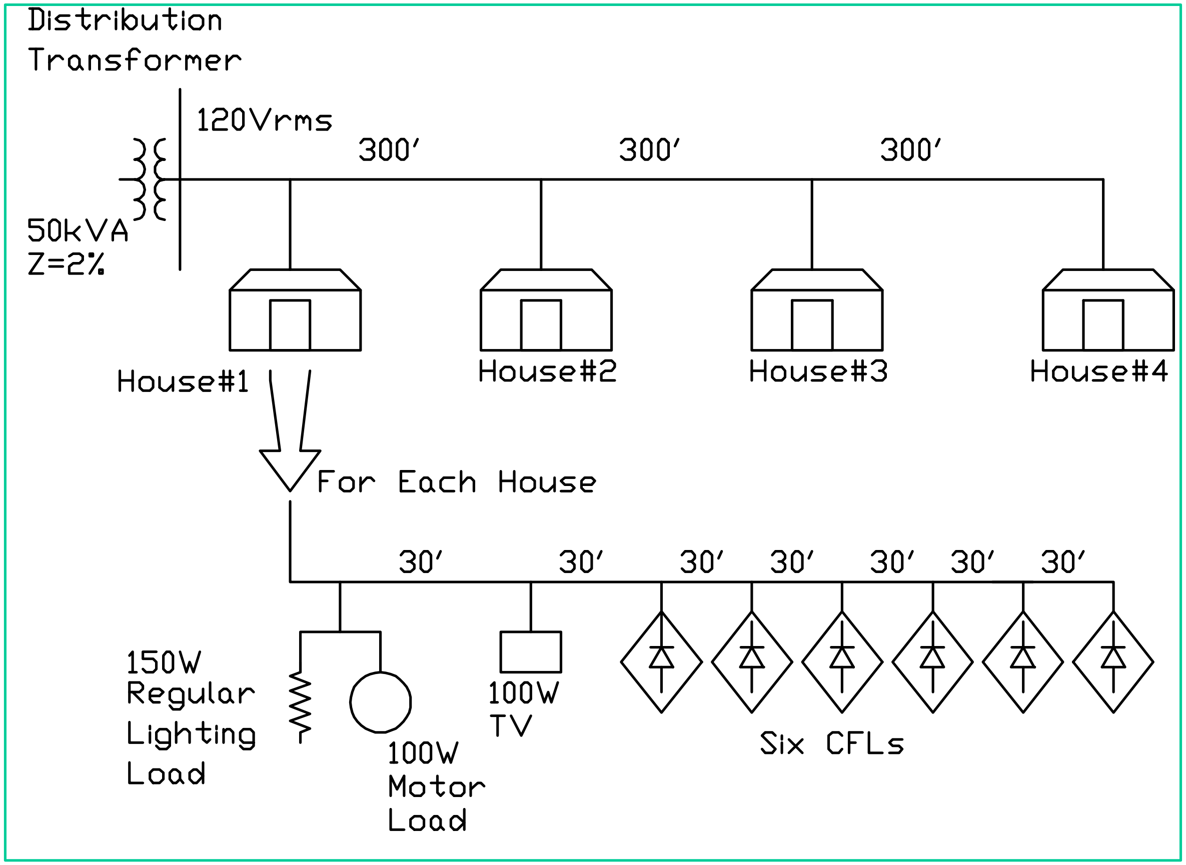
Residential Circuit Example

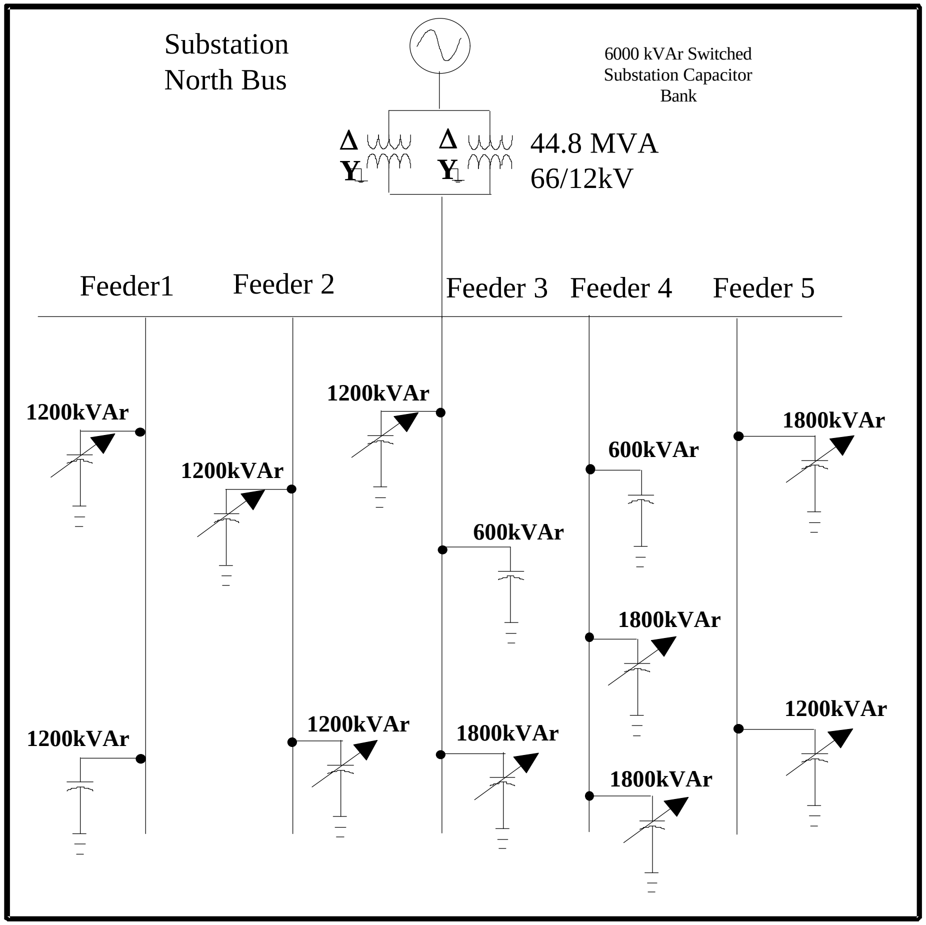


Assumed Harmonic Spectrum

Harmonic	Magnitude	Angle
1	100.0%	-11.5
3	82.0%	-38
5	53.4%	-62.5
7	31.6%	-85.1
9	16.6%	-103.3
11	8.2%	-111
13	1.5%	-99.1
15	1.0%	-88.4
17	0.6%	-95.5
19	0.5%	-109.5
21	0.3%	-120.5
23	0.1%	-107.5
25	0.1%	-67.4

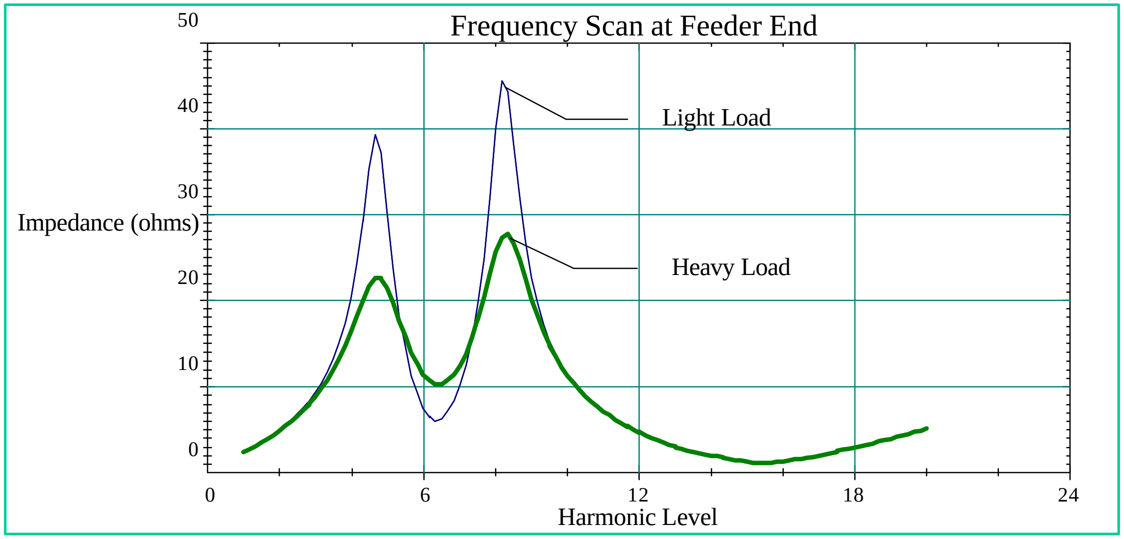
High Distortion Electronic Ballast CFLs Including Cancellation Effects

Distribution System Studied



31% of loads are commercial

System Frequency Response



This case was selected to represent worst case realistic circuit conditions due to the system resonance at the fifth harmonic.

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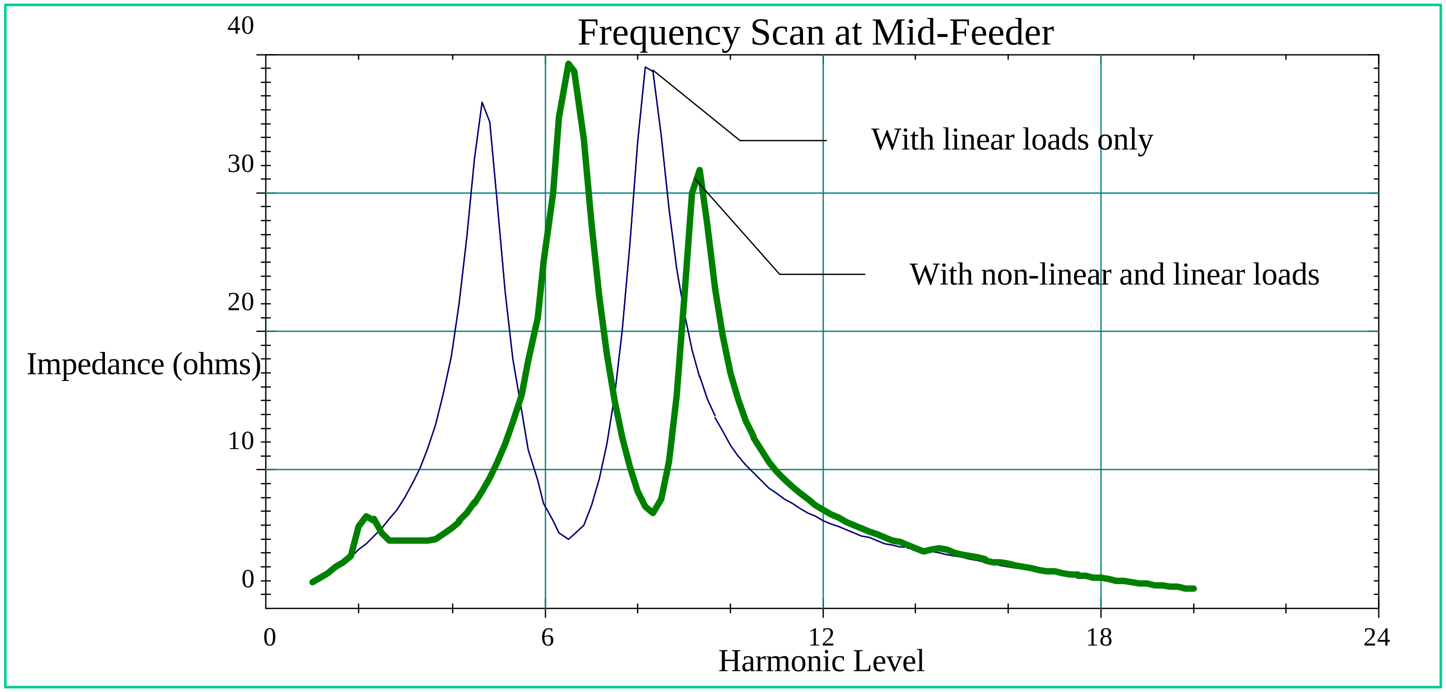
System Frequency Response Comparison



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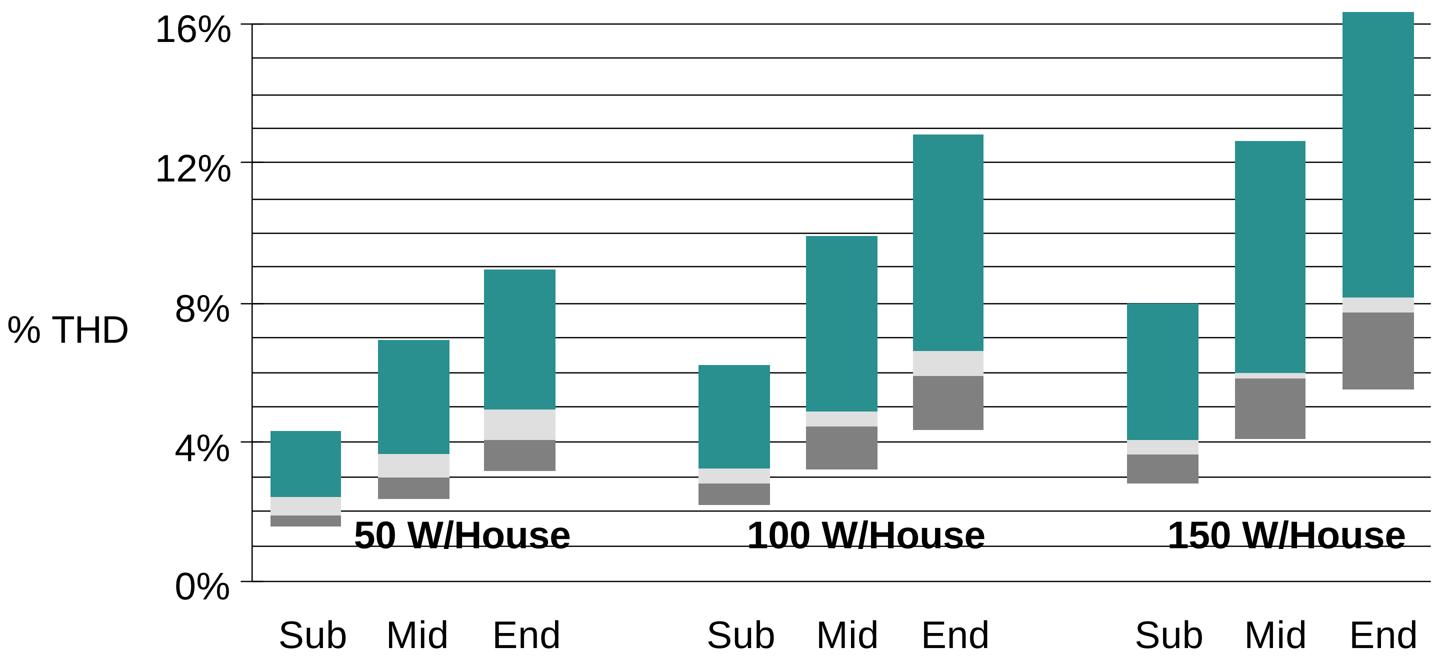
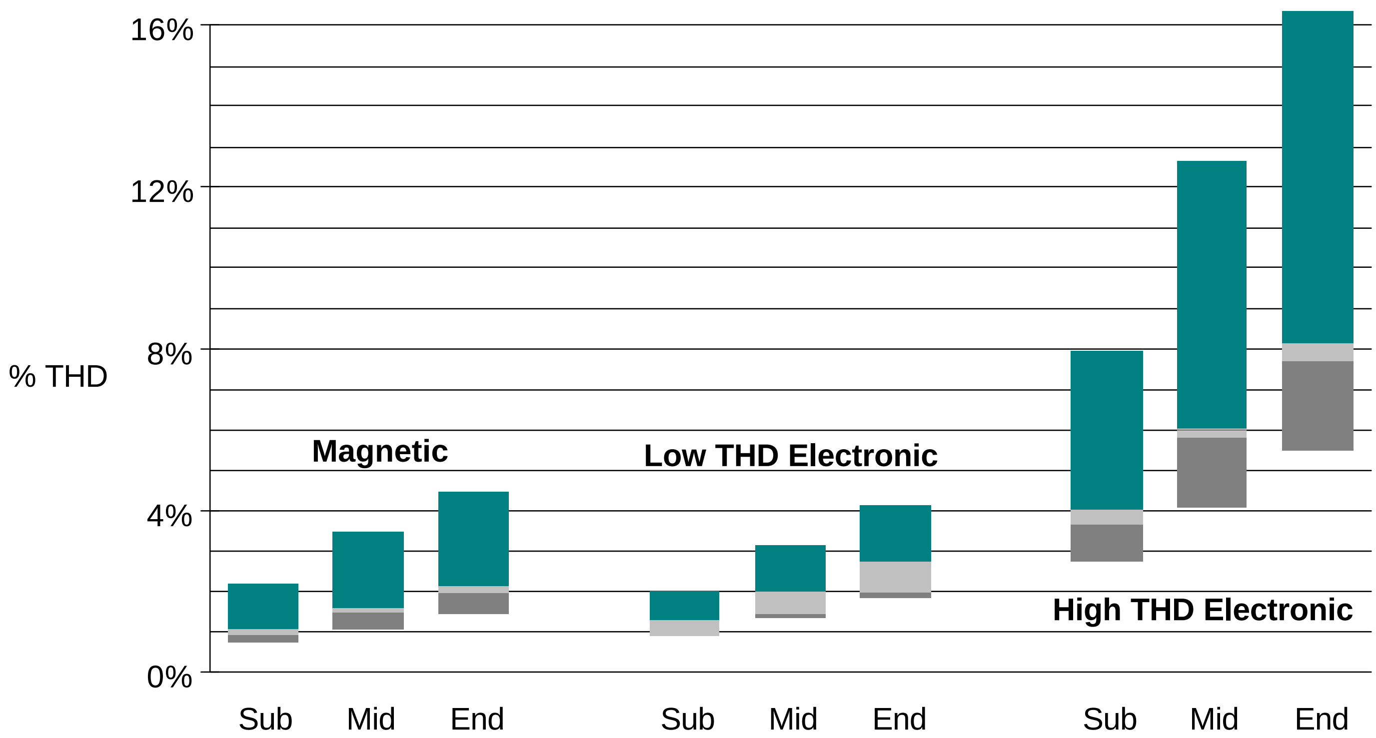
Effect of CFL Penetration



Effect of CFL Type



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Summary of potential impacts

- High penetration levels of CFLs that use high distortion electronic ballasts can result in unacceptable voltage distortion levels.
- CFLs with lower current distortion levels (30% or less) should not cause problems on the feeder.
- Distortion levels are dependent on system conditions (capacitance, representation of electronic loads, etc.)

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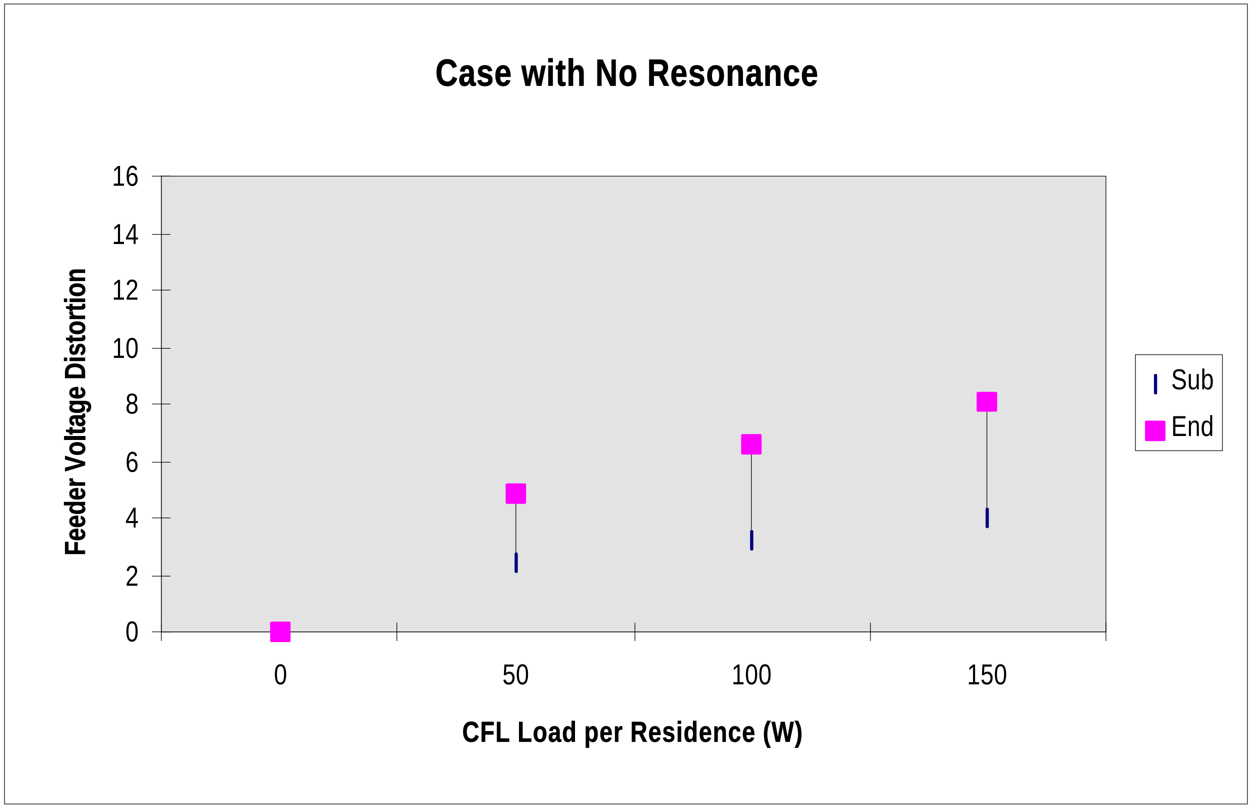
Summary of Voltage Distortion



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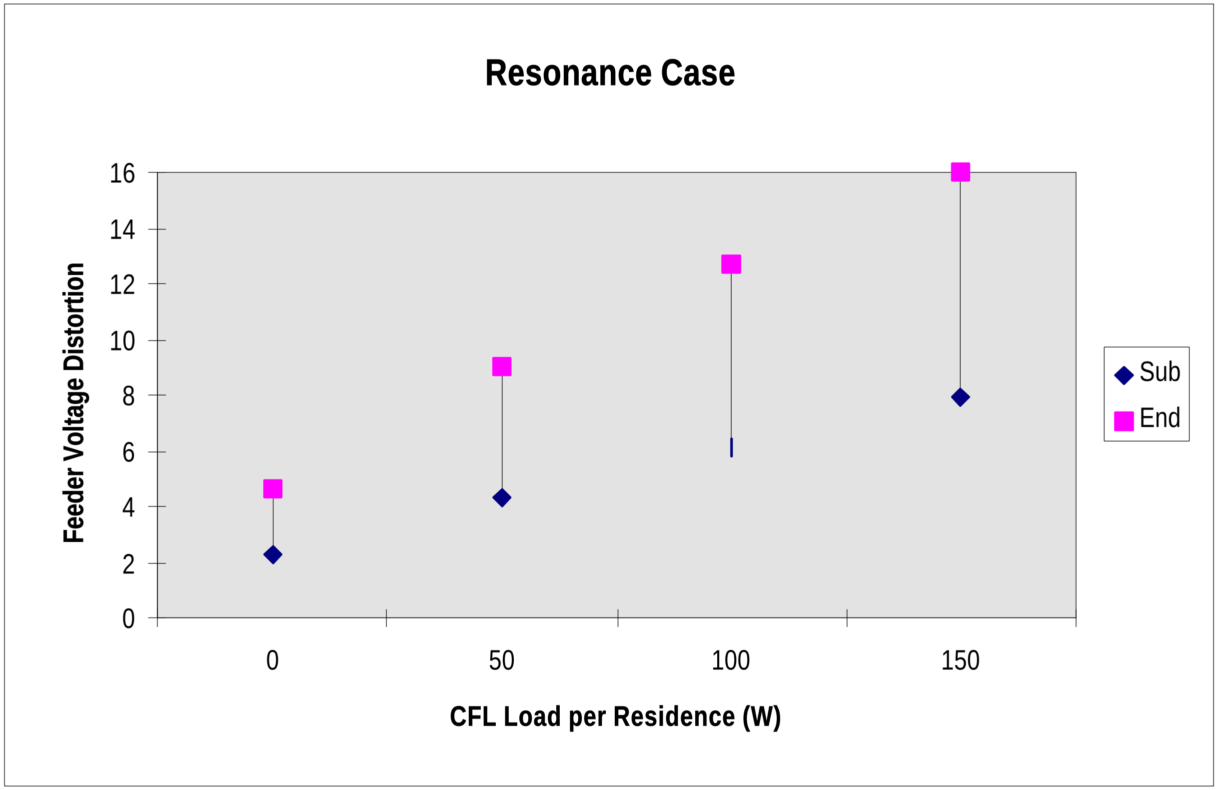
Summary - cont.



How to apply limits

- Limit harmonics from individual loads (IEC 1000-3-2)
- Limit harmonics per resonance (very difficult to enforce)
- Prevent resonance conditions on the distribution system or control harmonics on the distribution system

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IEC Approach

- Limit harmonic currents for individual equipment (type testing).
- IEC 1000-3-2 for equipment up to 16 amps.
- IEC 1000-3-4 for equipment up to 75 amps (under development).
- This should limit overall harmonic distortion levels to acceptable values.
- Procedure for evaluating customers supplied at medium voltage and high voltage (1000-3-6).

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IEC 1000-3-2 (General Loads)

- Equipment current limits for equipment up to 16 amps.
- Designed for 380 volt systems (L-L).
- Class A equipment is general purpose loads.

Harmonic Order	Maximum Permissible Harmonic Current (in Amperes)
Odd Harmonics	
3	2.3
5	1.14
7	0.77
9	0.4
11	0.33
13	0.21
15-39	0.15 x (15/n)
Even Harmonics	
2	1.08
4	0.43
6	0.3
8-40	0.23 x (8/n)

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IEC 1000-3-2 (Lighting Loads)

- Class C equipment:

Harmonic Order	Maximum value expressed as a percentage of the fundamental input current of luminaires
2	2%
3	30% x PF
5	10%
7	7%
9	5%
11-39	3%

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IEC 1000-3-2 (Power Supply Loads)

- Class D equipment (special waveform).
- Note that relative limits only apply up to 300 watts. Absolute limit applies up to the 16 amp maximum.

Harmonic Order	Relative Limit (mA/W)	Maximum permissible harmonic current (A)
3	3.4	2.3
5	1.9	1.14
7	1	0.77
9	0.5	0.4
11	0.35	0.33
13-39	linear extrapolation: 3.85/n	see table for Class A equipment

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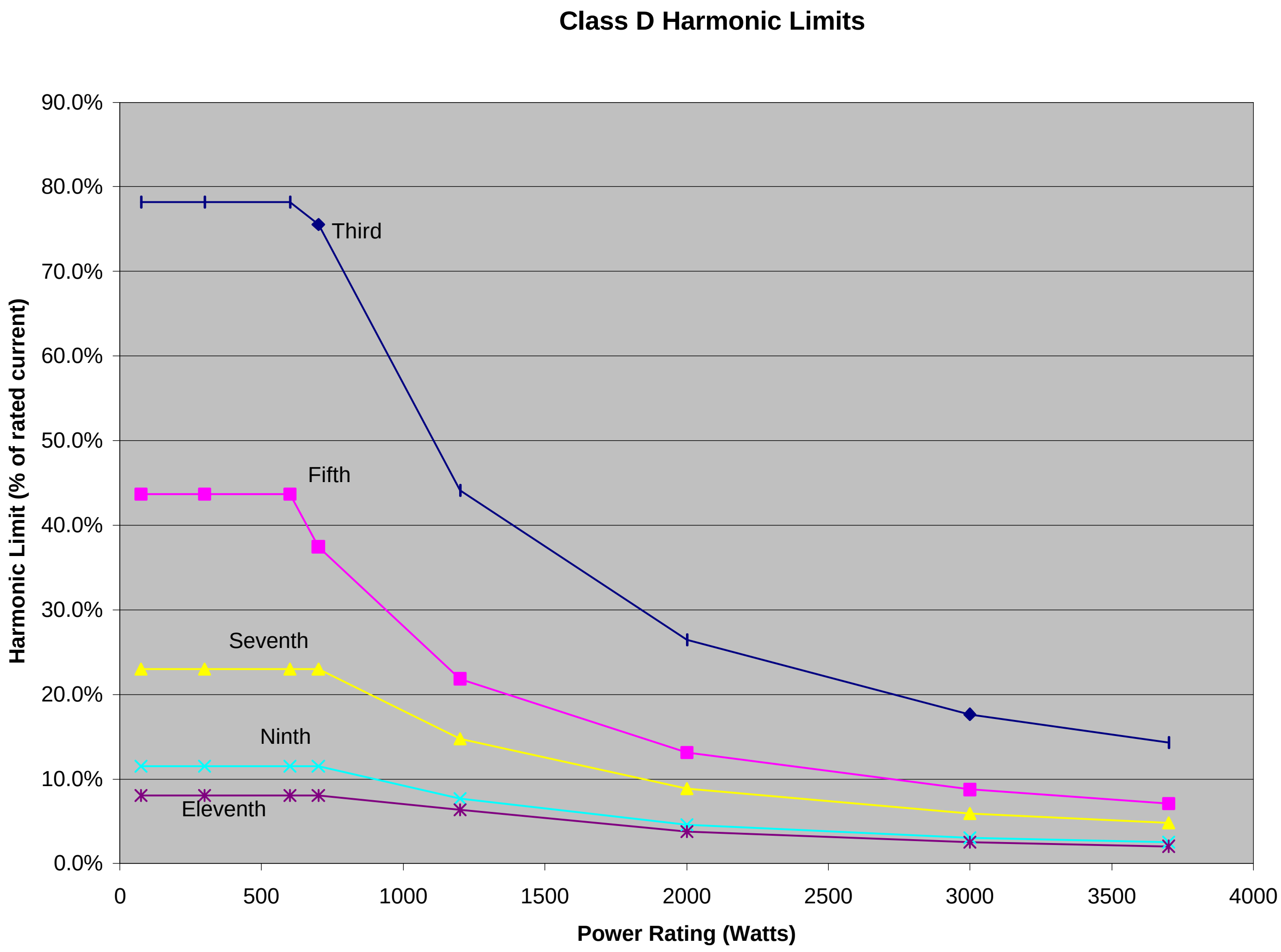
Limits for electronic loads



IEC 1000-3-4 (Loads up to 75 Amps)

- Under development.
- Limits dependent on short circuit ratio.
- Initial draft set of limits under discussion.

	I1/Ic < 1/35	I1/Ic < 1/170
Harmonic Order	In/I1 (%)	In/I1 (%)
3	21.6	50.4
5	10.7	25
7	7.2	16.9
9	3.8	8.8
11	3.1	7.2
13	2	4.6
15	0.7	1.6
17	1.2	2.8
19	1.1	2.6

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Summary-
handling residential harmonics

- Where to apply limits?
- What should the limits be?
- Resonance concerns
- Controlling harmonics on the distribution system
- Effect of new load types (electric vehicle chargers)

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Exercises for residential evaluation

- Example circuit, capacitor configurations
- Representation for residential customers
  - without nonlinear loads
  - with nonlinear loads
- Characteristics of other large harmonic sources
  - asds
  - electric vehicle chargers

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IEEE P519A
Utility Considerations

October, 1998

System Response Characteristics

- Voltage distortion is a result of the voltage drop created across the equivalent power system impedance.
- At 60 Hz, power systems are primarily inductive. The equivalent inductance can be calculated:

$$L_{eq} = \frac{X_{sc}}{2\pi * f}$$

X_{sc}= system short circuit reactance

f = power system fundamental frequency (60 Hz)

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Utility Considerations

- Controlling system voltage distortion levels
- Resonance considerations
- Utility equipment applications (e.g. SVC)
- Economic Considerations
- Telephone Interference
- Using rates to control harmonics?

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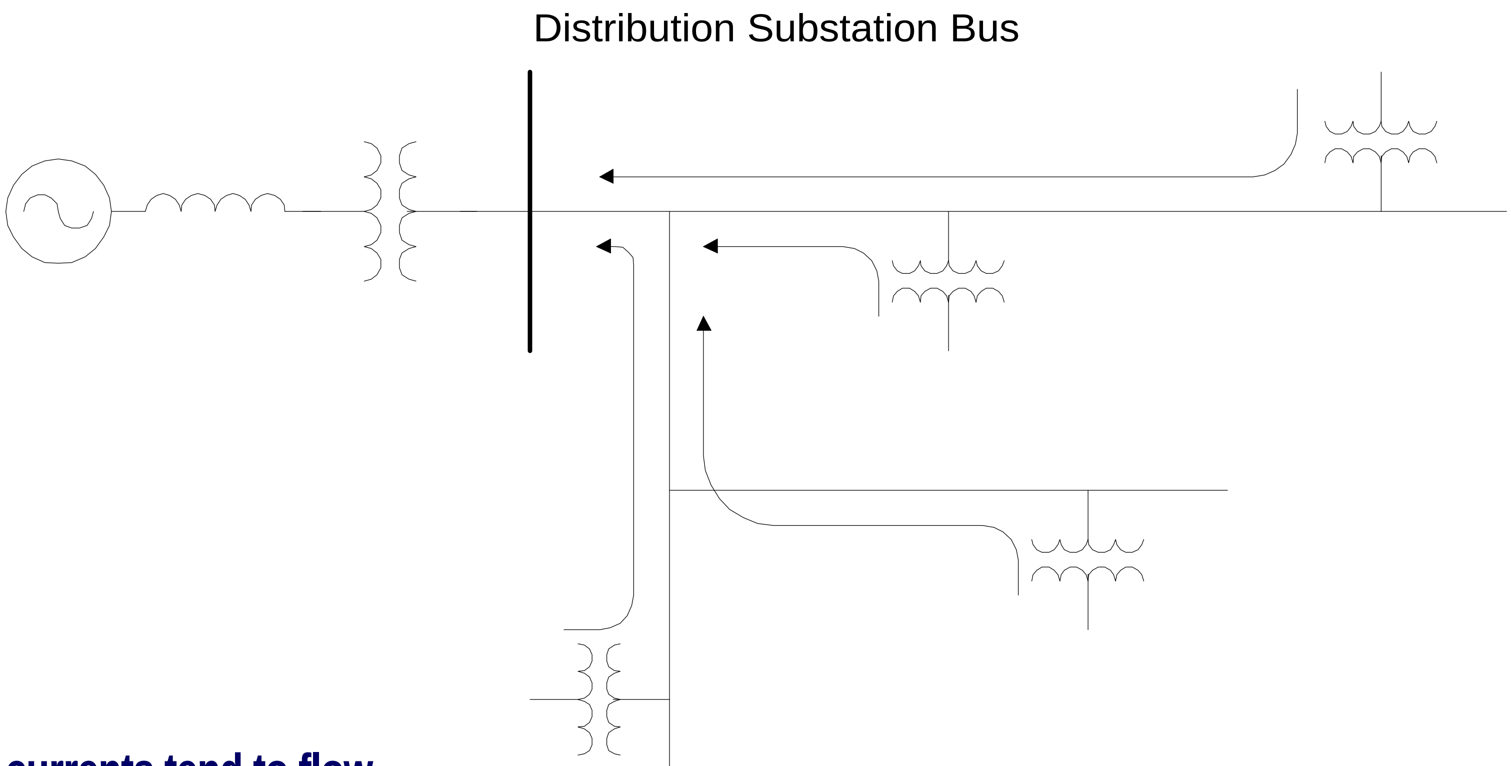
Distribution System Response



Harmonic currents tend to flow
from the harmonic source (nonlinear load)
into the utility source because it is the lowest impedance.

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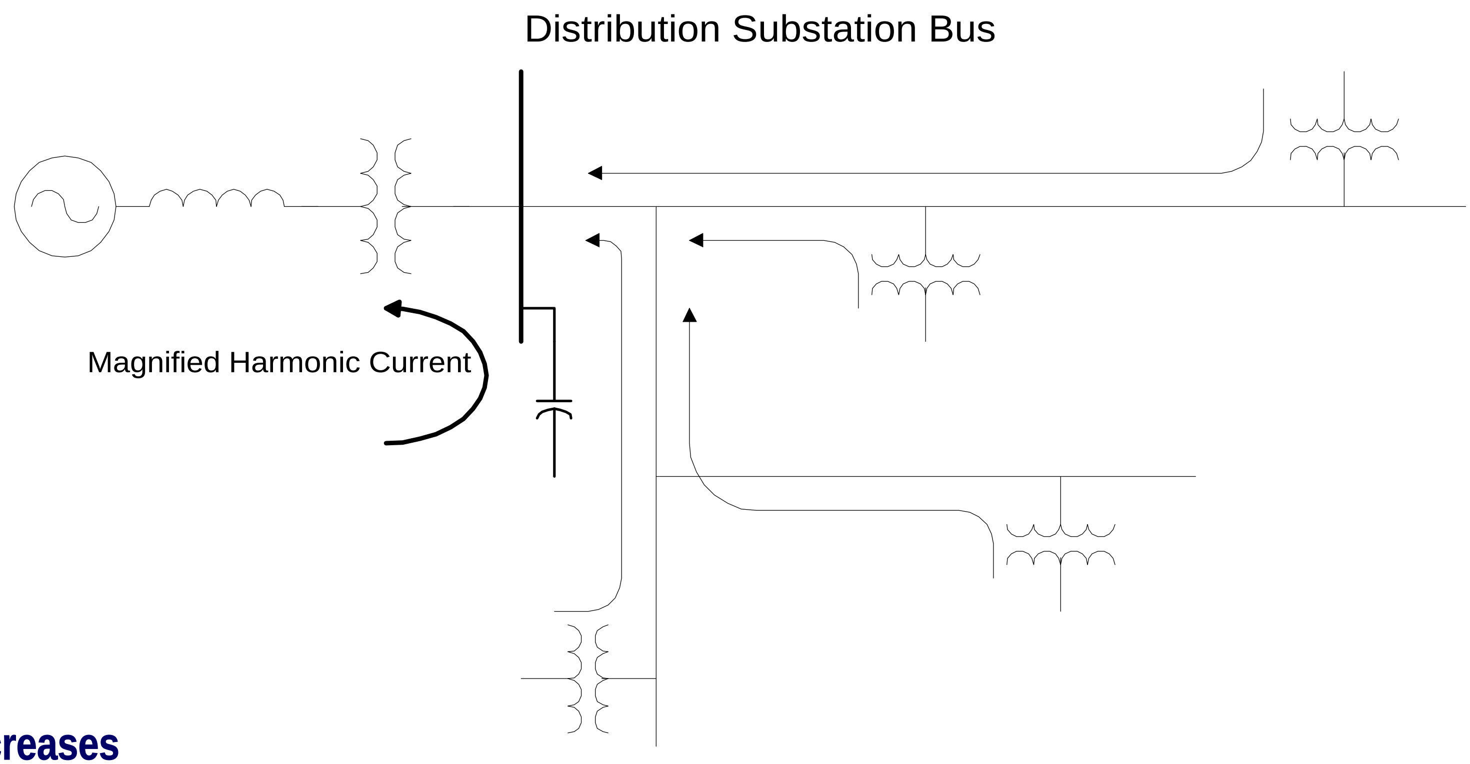
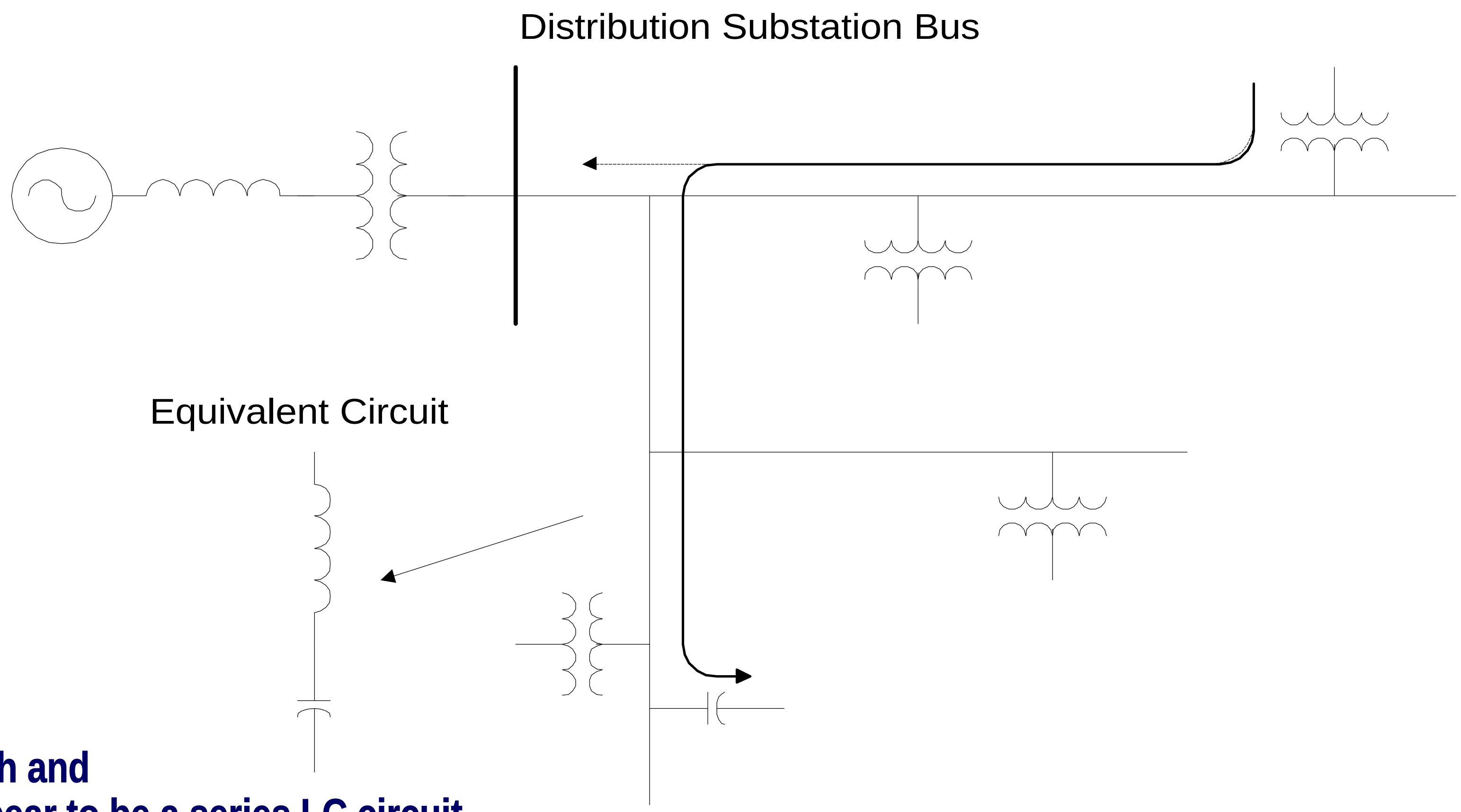
Effect of Capacitors - Parallel Resonance



Capacitor increases harmonic current flow into the substation.

Effect of Capacitors - Series Resonance



Feeder branch and capacitor appear to be a series LC circuit.

Some Modeling Guidelines

- Substation transformer with short circuit equivalent on the high side.
- Overhead distribution lines can be modeled with series impedances. Cables must include shunt capacitance.
- Include all capacitor bank locations in the model.
- Model transformers and low side buses for customers with low voltage power factor correction or filters.
- Include simple resistive representation for load or resistance with a series inductance to represent step down transformers.
- Three phase model is needed to evaluate positive and zero sequence harmonic components together. Otherwise, positive sequence representation usually adequate.

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Utility Equipment Applications

- Apply harmonic limits based on studies of the impact on the overall system voltage distortion levels and other impacts (e.g. telephone interference)
- Economic evaluation of harmonic controll alternatives

Economics of controlling harmonic distortion levels

- System perspective for the economic analysis
- Alternatives
  - control at individual loads
  - control at customer level
  - control on the system
- Minimize total costs

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How Can Harmonics be Controlled?

- Control at the equipment level (IEC 1000-3-2).
- Control at the customer level (IEEE 519 - current).
- Control on the utility system (IEEE 519 - voltage).

Some combination of these will probably be necessary.

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Future of Harmonic Control

- Harmonics will be controlled at individual nonlinear loads with better power supplies and active compensation.
- Harmonics will be controlled at the customer level with active devices that can provide var control, harmonic control, and some power conditioning (e.g. voltage sag ride through support).
- Harmonics will be controlled on the distribution system along with vars using active filter technology.