Overview on Power Quality, Harmonics Analysis & Solutions

43rd ANNUAL
NATIONAL CONVENTION

Resource Speaker:

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Deputy Governor – Metro East

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SMX Convention Center

Objectives of this Technical Presentation

- 1.) Describe the Power Quality Standard in terms of European (IEC), American (ANSI/NEMA/UL) and Philippines (PDC & PEC) in terms of terminology and limits.
- 2.) Equate Power Quality into Power Reliability
- 3.) Discuss the types and class of Power Quality Monitoring Instruments
- 4.) Harmonics Mitigation

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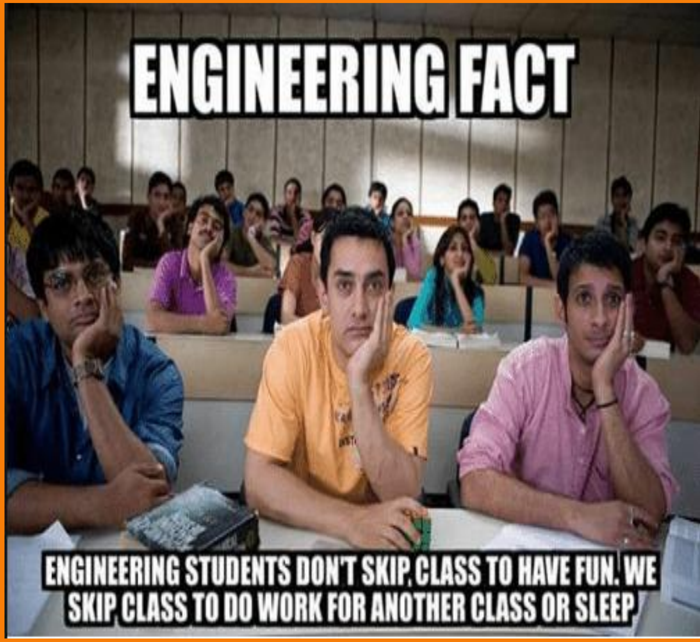
Fundamental Power Parameters

- Voltage
- Current
- Frequency
- Power (kW, kVAR & kVA)
- Power Factor
- Energy (kWh & kVARh)



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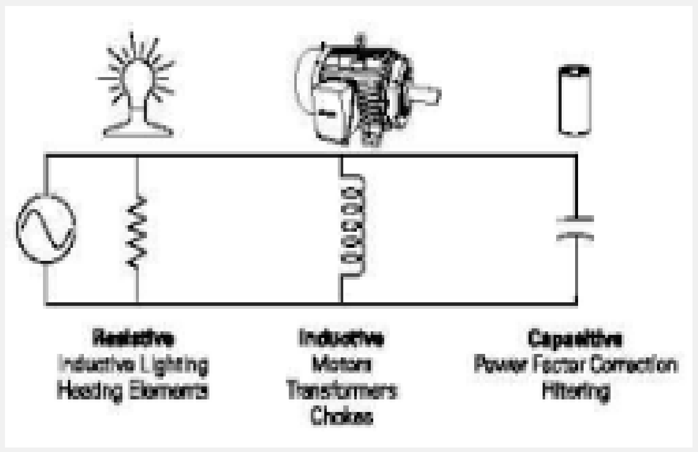
Electrical Loads Century Ago

- Customer loads were linear in nature (Lighting, heating and motor)
- They were not sensitive to power disturbance
- No Grid Connection



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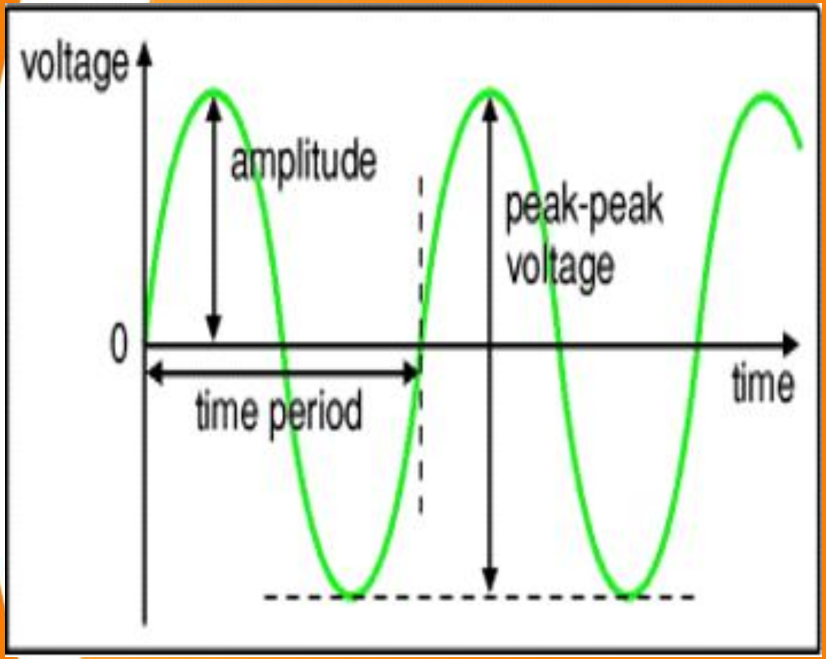
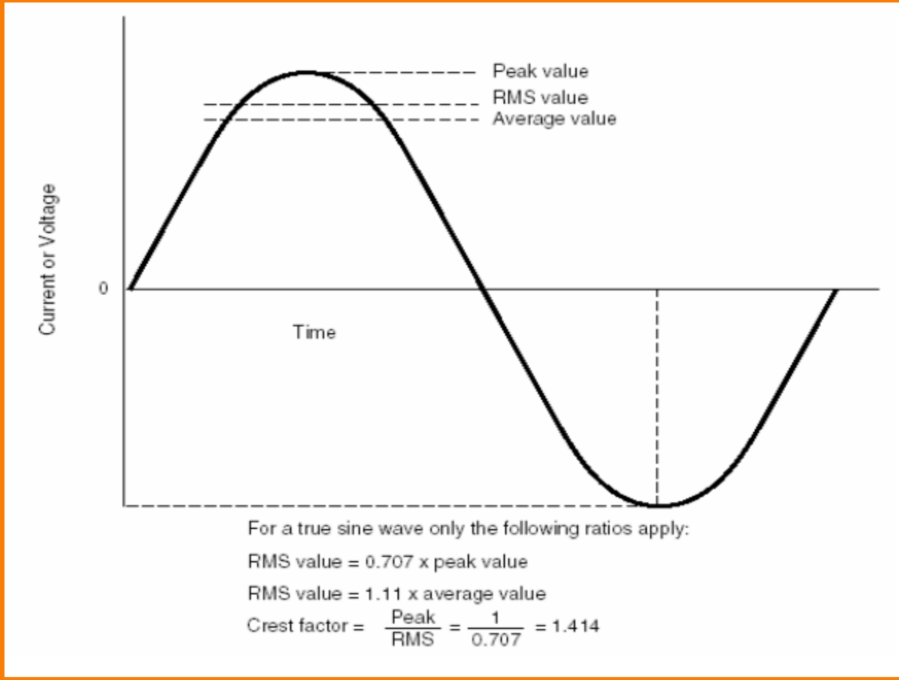
Ideal AC Sine Wave





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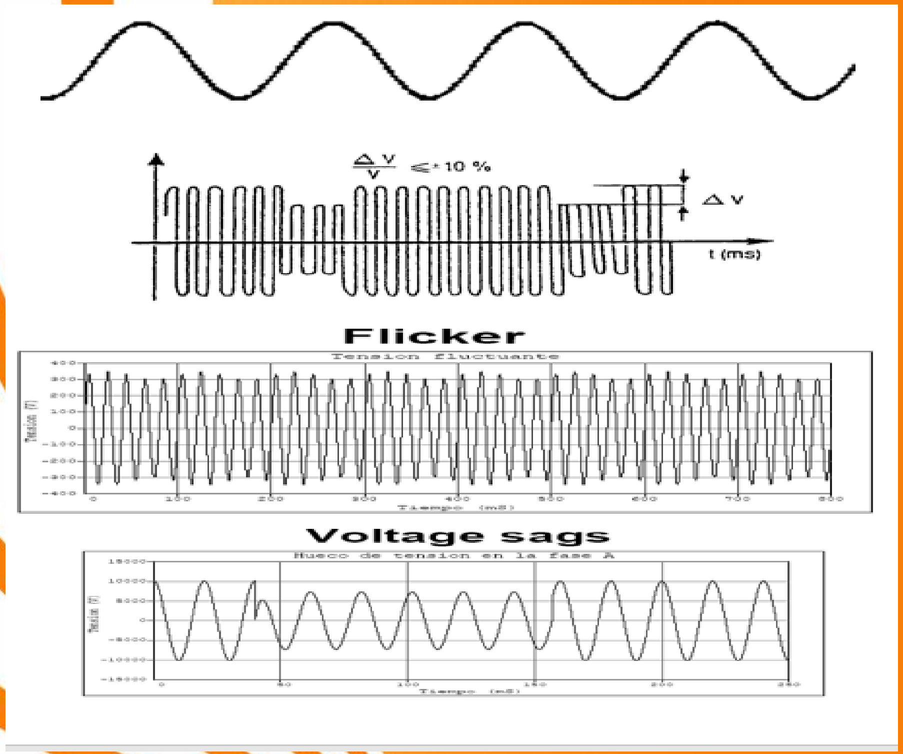
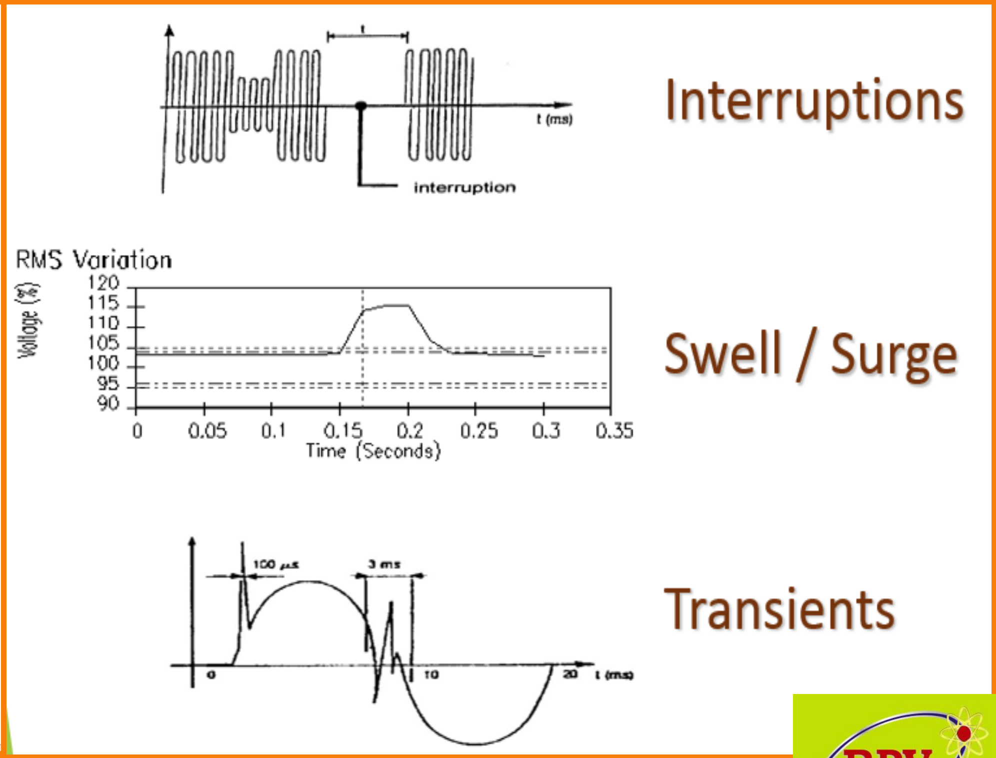
Electrical Loads in the 21st Century

- Customer load were both linear and non-linear (due to electronic type of loads)
- Non-linear loads (Electronics & micro processor based) are sensitive to power disturbances
- Luzon, Visayas & Mindanao Grid, Asia Grid & Worldwide Grid, Micro Grid & Smart Grid

Power Disturbance or the PQ Parameters

- Any deviation from a nominal value of the input AC Characteristics.





- Do you agree that Power Disturbance (PQ Parameters) may not be a Power Quality Problem ?

Power Quality Problem

"Any power problem manifested in voltage, current, or frequency deviations that results in the failure or mis-operation of customer equipment."

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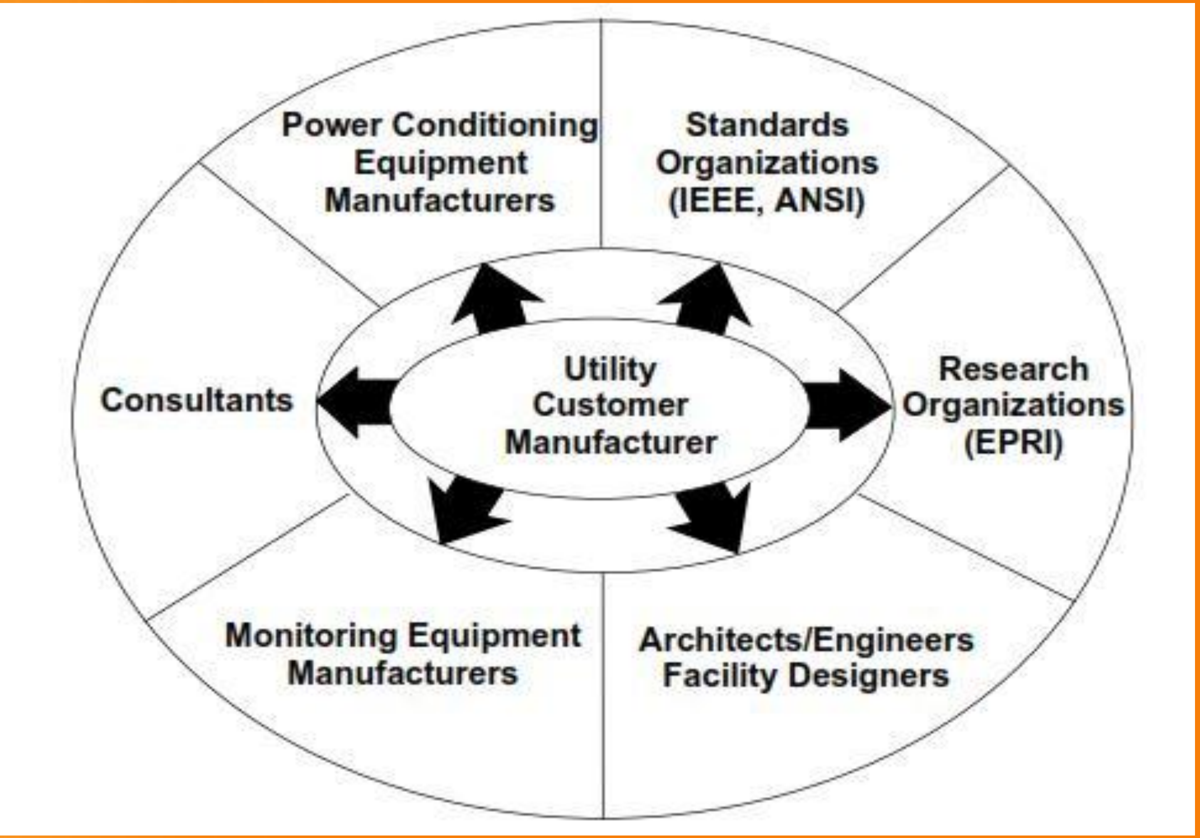
Players That Influence End-Use Power Quality



The Role of Standards

- Power quality problems ultimately impact the end user
- Power quality standards must provide guidelines, recommendations, and limits to help assure compatibility between end use equipment and the system where it is connected

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Power Quality Standards Organizations in USA

- 1.) Institute of Electrical & Electronics Engineers (IEEE)
- 2.) American National Standard Institute (ANSI)
- 3.) National Institute of Standards and Technology
- 4.) National Fire Protection Association (NFPA)
- 5.) National Electrical Manufacturers Associations (NEMA)
- 6.) Electric Power Research Institute (EPRI)
- 7.) Underwriters Laboratories (UL)

USA Power Quality Standards by Topic

Topic	Relevant standards
Grounding	IEEE 446, 141, 142, 1100; ANSI/NFPA 70
Powering	ANSI C84.1; IEEE 141, 446, 1100, 1250
Surge protection	IEEE C62, 141, 142; NFPA 778; UL 1449
Harmonics	IEEE C57.110, 519, P519a, 929, 1001
Disturbances	ANSI C62.41; IEEE 1100, 1159, 1250
Life/fire safety	FIPS Pub. 94; ANSI/NFPA 70; NFPA 75; UL 1478, 1950
Mitigation equipment	IEEE 446, 1035, 1100; 1250; NEMA-UPS
Telecommunication equipment	FIPS Pub. 94; IEEE 487, 1100
Noise control	FIPS Pub. 94; IEEE 518, 1050
Utility interface	IEEE 446, 929, 1001, 1035
Monitoring	IEEE 1100, 1159
Load immunity	IEEE 141, 446, 1100, 1159, P1346
System reliability	IEEE 493

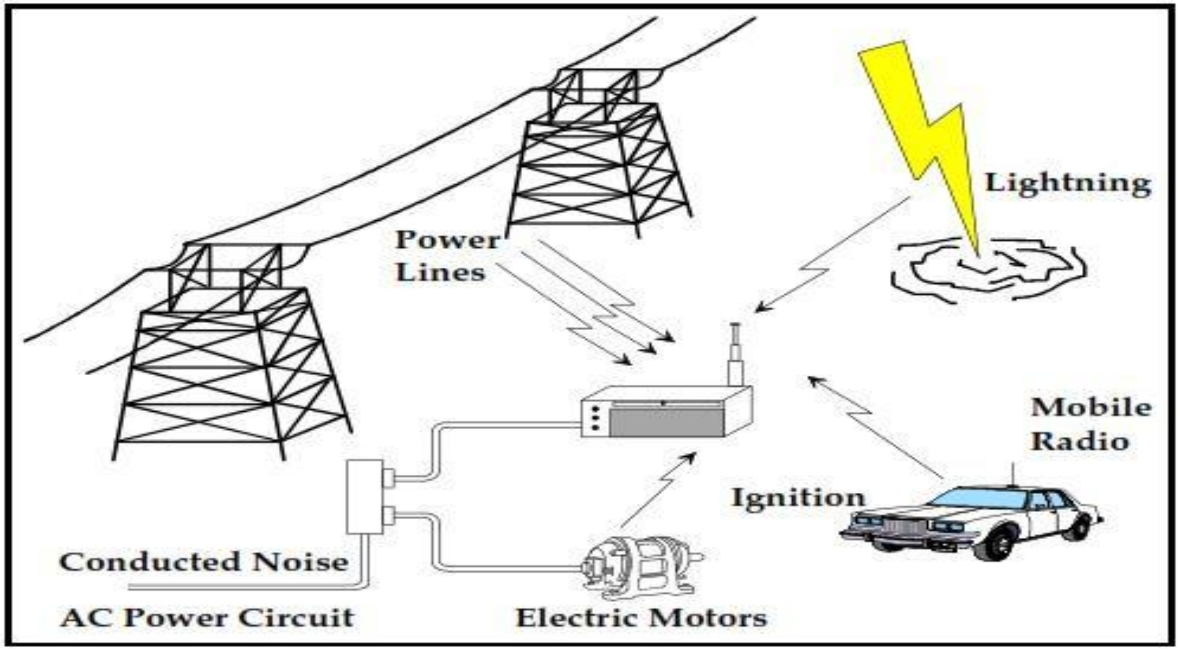
SOURCE: IEEE Standards 1159-1995 copyright © 1995. All rights reserved.

International PQ Standards

- 1.) International Electrotechnical Commission (IEC)
- 2.) The European Standards Community Organization (CENELEC) – Developed PQ Standards called Euronorms

International Electrotechnical Commission (IEC)

- IEC has defined category of standards called Electromagnetic Compatibility (EMC) Standards the deal with power quality issues.



IEC Power Quality Standards by Topic

Topic	Description	IEC number
General	-Fundamental principles -Definitions -Terminology	IEC Pub. 1000-1
Environment	-Description -Classification -Compatibility limits	IEC Pub. 1000-2
Limits	-Emission and immunity limits -Generic standards	EIC Limits 1000-3
Testing and measurement	Techniques for conducting tests	IEC Pub. 1000-4
Installation and mitigation	-Installation guidelines -Mitigation methods -Mitigation devices	IEC Guide 1000-5

Comparison of IEEE and IEC Power Quality Standards

Disturbance	IEEE standard	IEC standard
Harmonic environment	None	IEC 1000-2-1/2
Compatibility limits	IEEE 519	IEC 1000-3-2/4 (555)
Harmonic measurement	None	IEC 1000-4-7/13/15
Harmonic practices	IEEE 519A	IEC 1000-5-5
Component heating	ANSI/IEEE C57.110	IEC 1000-3-6
Under-Sag-environment	IEEE 1250	IEC 38, 1000-2-4
Compatibility limits	IEEE P1346	IEC 1000-3-3/5 (555)
Sag measurement	None	IEC 1000-4-1/11
Sag mitigation	IEEE 446, 1100, 1159	IEC 1000-5-X
Fuse blowing/upsets	ANSI C84.1	IEC 1000-2-5
Oversurge environment	ANSI/IEEE C62.41	IEC-1000-3-7
Compatibility levels	None	IEC 3000-3-X
Surge measurement	ANSI/IEEE C62.45	IEC 1000-4-1/2/4/5/12
Surge protection	C62 series, 1100	IEC 1000-5-X
Insulation breakdown	By product	IEC 664

SOURCE: EPRI's PEAC Corp. (*Courtesy of EPRI's "Signature."*)

Comparison of IEEE1159 - EN50160 Levels

	IEEE 1159				EN50160
No.	Categories	Typical Spectral Content	Typical Duration	Typical Voltage Magnitude	
	Short Duration Variations				
	Instantaneous				
7	Sag		0.5-30 Cycles	0.1-0.9 pu	<1 sec
8	Swell		0.5-30 Cycles	1.1-1.8 pu	No
	Momentary				
9	Interruption		0.5 Cycles-3s	<0.1 pu	<1 sec
10	Sag		30 Cycles-3s	0.1-0.9 pu	No
11	Swell		30 Cycles-3s	1.1-1.4 pu	No
	Temporary				
12	Interruption		3 s-1 min	<0.1 pu	No
13	Sag		3 s-1 min	0.1-0.9 pu	No
14	Swell		3 s-1 min	1.1-1.2 pu	No
	Long Duration Variations				
15	Interruption, Sustained		>1 min	0.0 pu	Yes
16	Undervoltages		>1 min	0.8-0.9 pu	Yes 10 min
17	Overvoltages		>1 min	1.1-1.2 pu	Yes 10 min

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Philippine Standard on Power Quality

1.) Philippine Distribution Code

- Chapter 3.2

2.) Philippine Grid Code

- Chapter 3.2

3.) Philippine Electrical Code (PEC 2017)

4.) Philippine National Standard (PNS)

- Refer to Appendix F of PEC 2017 (PNS for Electrical Products)

PDC Chapter 3

- 3.0 Performance Standard for Distribution and Supply
  - 3.1 Purpose and Scope
    - 3.1.1 Purpose
    - 3.1.2 Scope and Application
  - 3.2 Power Quality Standards for Distributors
    - 3.2.1 Power Quality Problems
    - 3.2.2 Frequency Variations
    - 3.2.3 Voltage Variations
    - 3.2.4 Harmonics
    - 3.2.5 Voltage Unbalance
    - 3.2.6 Flicker Severity
    - 3.2.7 Transient Voltage Variation
  - 3.3 Reliability Standards for Distributors
    - 3.3.1 Criteria for Establishing Distribution Reliability Standards
    - 3.3.2 Distribution Reliability Indices
    - 3.3.3 Inclusions and Exclusions of Interruption Events
    - 3.3.4 Submission of Distribution Reliability Reports and Performance Targets

3.1 PURPOSE AND SCOPE

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3.1.1 **Purpose**

a) To ensure the quality of electric power in the Distribution System:

b) To ensure that the Distribution System will be operated in a safe and efficient manner and with a high degree of reliability;

c) To specify Customer Services for the protection of the End-Users in both the captive and contestable markets; and

d) To specify safety standards for the protection of personnel in the work environment.

3.1.2 **Scope of Application**

This Chapter applies to all Distribution System Users including

a) Distributors;

b) Suppliers;

c) Embedded Generators; and

d) End-Users.

3.2 POWER QUALITY STANDARDS FOR DISTRIBUTORS

3.2.1 Power Quality Problems

3.2.1.1 For the purpose of this Article. Power Quality shall be defined as the quality of the voltage, including its frequency and the resulting current , that are measured in the Distribution System during normal conditions.

3.2.1.2 A power Quality problem exist when at least one of the following condition is present and significantly affect the normal operation of the system:

(a)The System Frequency has deviated from the nominal value of 60 Hz:

(b)Voltage magnitudes are outside their allowable range of variation:

(c)Harmonic Frequencies are present in the System

(d)There is imbalance in the magnitude of the phase voltages:

(e)The phase displaced between the voltages is not equal to 120 degrees:

(f) Voltage fluctuations cause Flicker that is outside the allowable Flicker Severity limits: or

(g)High-frequency Over voltages are preset in the Distribution System.

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3.2.2 Frequency Variations

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3.2.2.1 The nominal Frequency shall be 60 Hz.

3.2.2.2 The Distributor shall design and operate its System to assist the System Operator in maintaining the fundamental Frequency within the limits of 59.7 Hz and 60.3 Hz during normal conditions.

3.2.3 Voltage Variations

3.2.3 Voltage Variations

3.2.3.1 For the purpose of this section. Voltage Variation shall be defined as the deviation of the root-mean-square (RMS) value of the voltage from its nominal value, expressed in percent. Voltage Variation will either be of short duration.

3.2.3.2 Short Duration Voltage Variation

3.2.3.2 A Short Duration Voltage Variation shall be defined as a variation of the RMS value of the voltage from nominal voltage for a time greater than one-half cycle of the power Frequency but not exceeding one minute. A Short Duration Voltage Variation is a Voltage Swell if the RMS value of the voltage increases to between 110 percent and 180 percent if the nominal value. A Short Duration Voltage Variation is a Voltage Sag (or Voltage Dip) if the RMS value of the voltage decreases to between 10 percent and 90 percent of the nominal value.

3.2.3.3 Long Duration Voltage Variation

3.2.3.3 A Long Duration Voltage Variation shall be defined as a variation of the RMS value of the voltage from nominal voltage for a time greater than one minute. A Long Duration Voltage Variation is an Undervoltage if the RMS value of the voltage is less than or equal to 90 percent of the nominal voltage. A Long Duration Voltage Variation is an Overvoltage if the RMS value of the voltage is greater than or equal to 110 percent of the nominal value.

3.2.3.4 The Distribution shall ensure that no Undervoltage or Overvoltage is present at the Connection Point of any User during normal operating conditions. The ERC may require the Distribution to comply with a more stringent voltage variation limits, which shall be determined from technical and economic studies.

3.2.3.5 The Distributor shall ensure that the Distribution System has sufficient capacity so that Voltage Sags when starting large induction motor will not adversely affect any User facilities or Equipment.

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3.2.4 Harmonics

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3.2.4.1 For the purpose of this Section, Harmonics shall be defined as sinusoidal voltages and current having Frequencies that are integral multiples of the fundamental Frequency.

3.2.4.2 The Total Harmonic Distortion (THD) shall be defined as the ratio of the RMS value of the harmonic content to the RMS value of the fundamental quality, expressed in percent.

3.2.4.3 The Total Demand Distortion (TDD) shall be defined as the ratio of the RMS value of the harmonic content to the RMS value of the rated or maximum fundamental quality, expressed in percent.

3.2.4.4 At any User System, the THD of the voltage shall not exceed five percent (5%) during normal operating conditions.

3.2.4.5 At any User System, the TDD of he current shall not exceed five percent (5%) during normal operating conditions

3.2.5 Voltage Unbalance

3.2.5 Voltage Unbalance

3.2.5.1 For the purpose of this Section, Voltage Unbalance shall be defined as the maximum deviation from the average of the three phase voltages divided by the average of the three phase voltages, expressed in percent.

3.2.5.2 The maximum Voltage Unbalance at the Connection point of any User, excluding the Voltage Unbalance passed on from the Grid, shall not exceed 2.5 percent during normal operating conditions.

3.2.6 Flicker Severity

3.2.6 Flicker Severity

3.2.6.1 For the purpose of this Section, Flicker shall be defined as the impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time.

3.2.6.2 in the assessment if the disturbance caused by a Flicker source with a short duty cycle, the Short Term Flicker Severity shall be computed over a 10minute period.

3.2.6.3 In the assessment if the disturbance caused by a Flicker source with a long and variable duty cycle, the Long Term Flicker Severity shall be derived from the Short Term Flicker Severity levels.

3.2.6.4 The Flicker Severity at the Connection Point of any User shall not exceed 1.0 unit for short term and 0.8 units for long term.

3.2.7 Transient Voltage Variations

3.2.7 Transient Voltage Variations

3.2.7.1 For the purpose of this Section, Transient Voltage shall be defined as the high-frequency Overvoltage that are generally shorter in duration compared to the Short Duration Voltage Variations.

3.2.7.2 Infrequent short-duration peaks may be permitted to exceed the levels specified in Section 3.2.4 for TDD and THD provided that such increase do not compromise he service to other End-Users or cause damage to any Equipment in the Distribution System.

Articles in PEC 2017 related to Power Quality

- 1.) Article 2.50 – Grounding & Bonding
- 2.) Article 2.80 – Surge Arrester (Above 1000V)
- 3.) Article 2.85 – Surge Protective Device (Below 1000 V)
- 4.) Article 2.90 – Lighting Protection System
- 5.) Article 7.1 – Legally Required Standby System

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Two (2) Performance Class of Power Quality Meters or Analyzers based on IEEE P1159.1 &61000-4-30

The 2nd edition of IEC 61000-4-30

Another important upcoming change is the new edition of the standard, which is IEC 61000-4-30 edition 2. The driver for this second edition was that the IEC has observed the problems and difficulties provoked by the first edition and main difference will be the addition of another Class (which is Class S), which make the device easier and cheaper to manufacture as the requirements will not be that strict.

- Class A
  …for contractual applications that may require resolving disputes, verifying compliance with standards, etc.
- Class B
  …for qualitative surveys, trouble-shooting applications and other applications where low uncertainty is not required.
- Class S
  …for statistical surveys, and contractual applications where there is no disputes.

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Fixed Monitoring from Class S to Class A

- Built in analysis to international power quality standards such as EN50160, IEEE1159, G5/4 and GOST
- Automatic alerts for preventive maintenance
- From simple compliance chart to sophisticated expert analysis screens

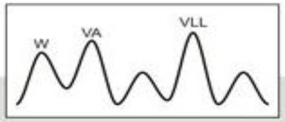



Fixed Type Class B Power Quality Meter

- **High Low Event Recording for V, A, Hz, VA, W, VAr, PF**

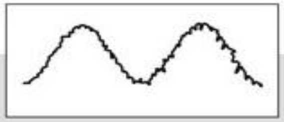
  Protection of 3 phase system against single phasing, low & high voltage, over load, highly lagging and leading PF, Hz etc. Power Navigator can trap such events for future reference.

  Identify & record unbalance voltage and currents and helps the user to identify the root cause. Unbalance over-burdens the electrical system and affects in the form of over loading of cables, motors and switchgear.



- **Harmonics up to 31st level and THD**

  Presence of THD will urge the user to identify the polluting loads and take necessary action to mitigate harmonics thru' an appropriate harmonic filter and save energy and also to improve plant & equipments efficiency.



- **Data Logging with Time Stamp**

  The information is needed in all types of businesses to determine performance, quality, efficiency, cost reduction, fuel consumption monitoring and many other critical factors. This feature provides important and accurate data for analysis.

  1 Minute to 12 hours interval programmable. Data interval and parameter can be selected through RS485 communication.

Optional Programmable Data Logging

Table 1

No of Parameters	No of Records	
	1MB	8MB
1	121920	982080
2	81280	654720
4	48768	392839
9	24384	196416
14	16256	130944
29	8128	65472

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Fixed Class A Power Quality Recorder

Current Transformers

Get a **special offer** when you add optional split core or flexible CT form factors to your purchase

Premium

Flexible & Split Core Current Transformers

Our premium CTs are available in press-open split core and flexible Rogowski coil styles. These CTs offer the highest accuracy and convenient

Standard

Split Core Current Transformers

Our standard CTs are available in split core and hinged styles. These CTs feature a solid design at an affordable price.

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System Accuracy

System Accuracy 1.09%

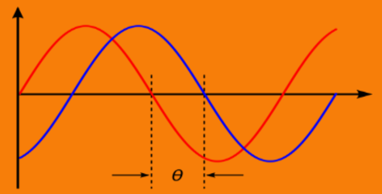
Power Meter 0.6%

+

CT 0.5%

+

Phase Shift 0.76%



EN 50160 Summary Report

EN50160 Compliance Report

3 צפון | Tue, Nov 07, 2006

EN50160 Compliance Report
26-08-06 - 16-09-06

Power Frequency

From	To	In-service time, %	Compliance +/-1%, % of time	Compliance +4/-6%, % of time	Min Frequency Hz	Max Frequency Hz	Standard Compliance
26-08-06	26-08-06	77.85	100.00	100.00	49.56	50.17	Ok
27-08-06	02-09-06	100.00	100.00	100.00	49.59	50.21	Ok
03-09-06	09-09-06	100.00	100.00	100.00	49.48	50.16	Ok
10-09-06	16-09-06	100.00	99.96	100.00	49.10	50.23	Ok
Annual report							
26-08-06	16-09-06	7.25	99.99	100.00	49.10	50.23	Ok

Voltage Variations

From	To	In-service time, %	Compliance +/-10%, % of time	Compliance +10/-15%, % of time	V1 Min	V1 Max	V2 Min	V2 Max	V3 Min	V3 Max	Standard Compliance
26-08-06	26-08-06	77.78	100.00	100.00	23060	23719	22990	23663	23057	23748	Ok
27-08-06	02-09-06	100.00	100.00	100.00	22998	23671	22929	23596	23011	23703	Ok
03-09-06	09-09-06	100.00	100.00	100.00	23021	23701	22989	23608	23050	23712	Ok
10-09-06	16-09-06	100.00	100.00	100.00	23002	23792	22949	23728	23010	23805	Ok

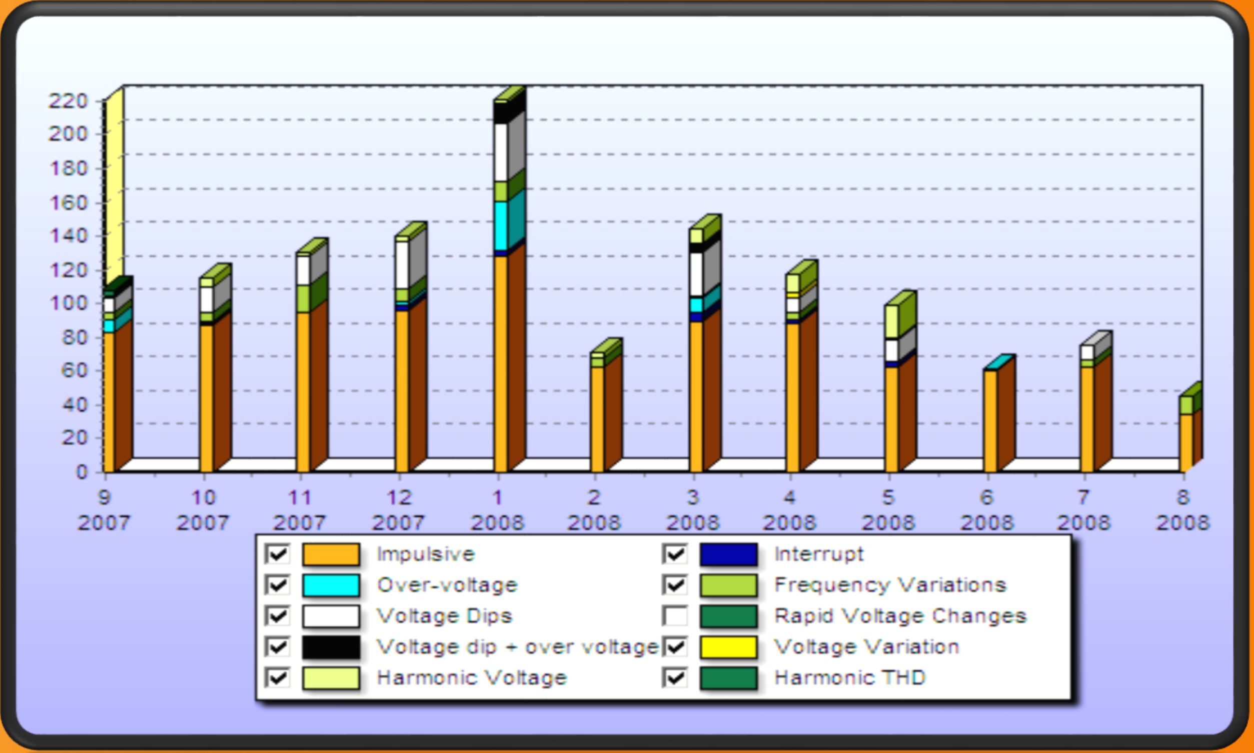
Rapid Voltage Changes

From	To	Polyphase Incidents	V1 Incidents	Max V1 Variation , %Un	V2 Incidents	Max V2 Variation, %Un	V3 Incidents	Max V3 Variation, %Un	Standard Compliance
26-08-06	26-08-06	0	0	0.00	0	0.00	0	0.00	Ok
27-08-06	02-09-06	0	0	0.00	0	0.00	0	0.00	Ok
03-09-06	09-09-06	0	0	0.00	0	0.00	0	0.00	Ok
10-09-06	16-09-06	0	0	0.00	0	0.00	0	0.00	Ok

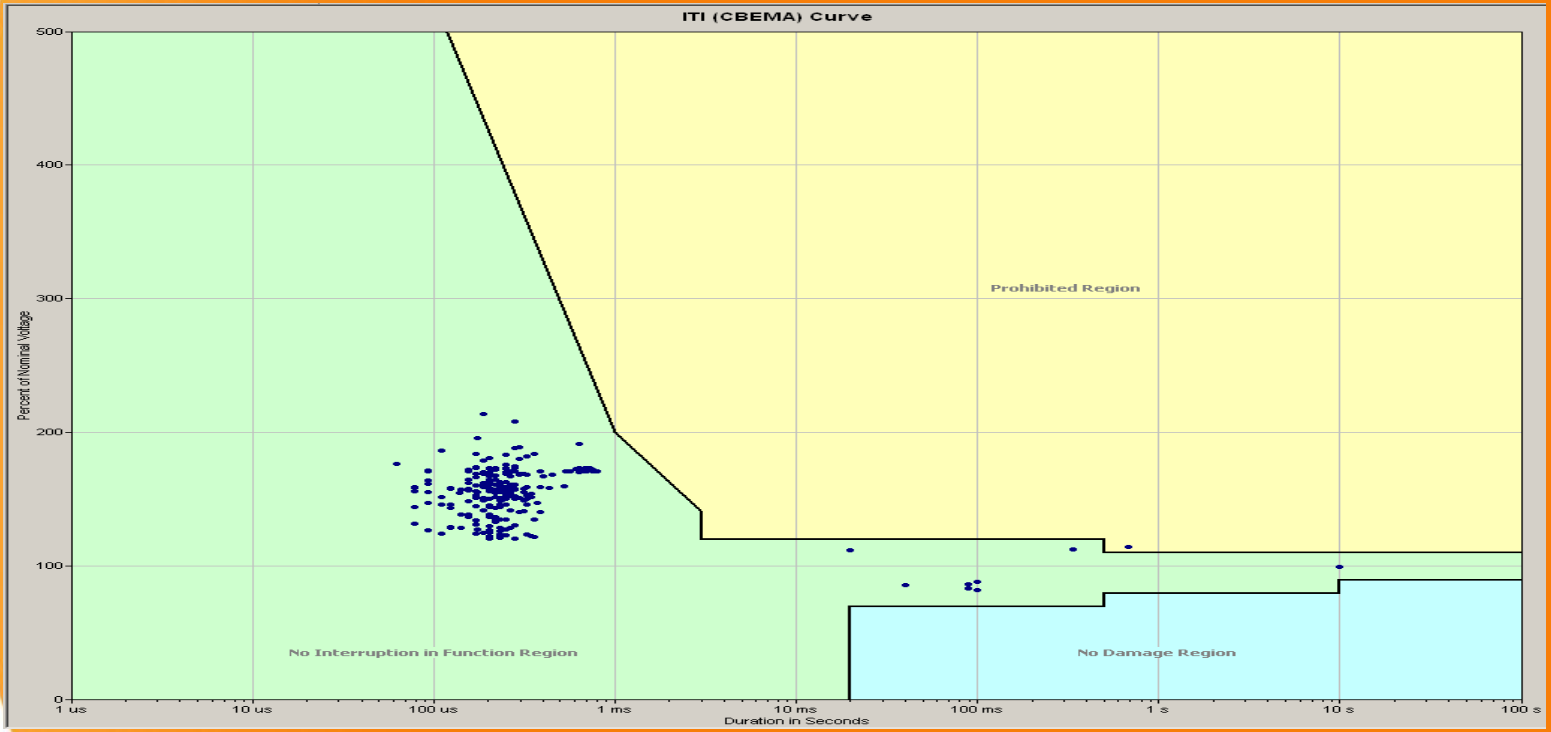
List of Events

Category	No. of Events	Worst Case					
		Event No.	Date	Time	Value	Duration	
Frequency Variations	**67**	1809	19/07/2006	17:10.9	48.44	16:3 m	
Voltage Dips	**122**	1986	19/07/2006	14:39.2	69,180	890.0 ms	
Long interruption	**1**	1979	24/12/2006	25:55.9	3,778	5:10 hrs	
Transient Overvoltage	133	2263	15/03/2007	55:18.3	180,131	.6 ms	
Transient Undervoltage	142	2024	02/01/2007	46:43.8	143,127	.6 ms	
THD	3	1998	24/12/2006	12:16.9	0.73	24:43 min	
Individual Harmonic H5	9	2271	31/03/2007	28:28.9	2.2	2:16 hrs	
Individual Harmonic H15	2	1984	24/12/2006	13:01.6	0.6	19:60 min	
Individual Harmonic H17	2	1986	24/12/2006	13:01.6	1.14	23:59 min	
Individual Harmonic H19	3	1987	24/12/2006	12:16.9	1.39	24:43 min	
Individual Harmonic H23	3	1992	24/12/2006	12:16.9	1.11	24:43 min	
Individual Harmonic H25	3	1994	24/12/2006	12:16.9	1.17	24:43 min	
Individual Harmonic H4	3	1980	24/12/2006	12:16.9	1.97	24:43 min	
Total	**493**						

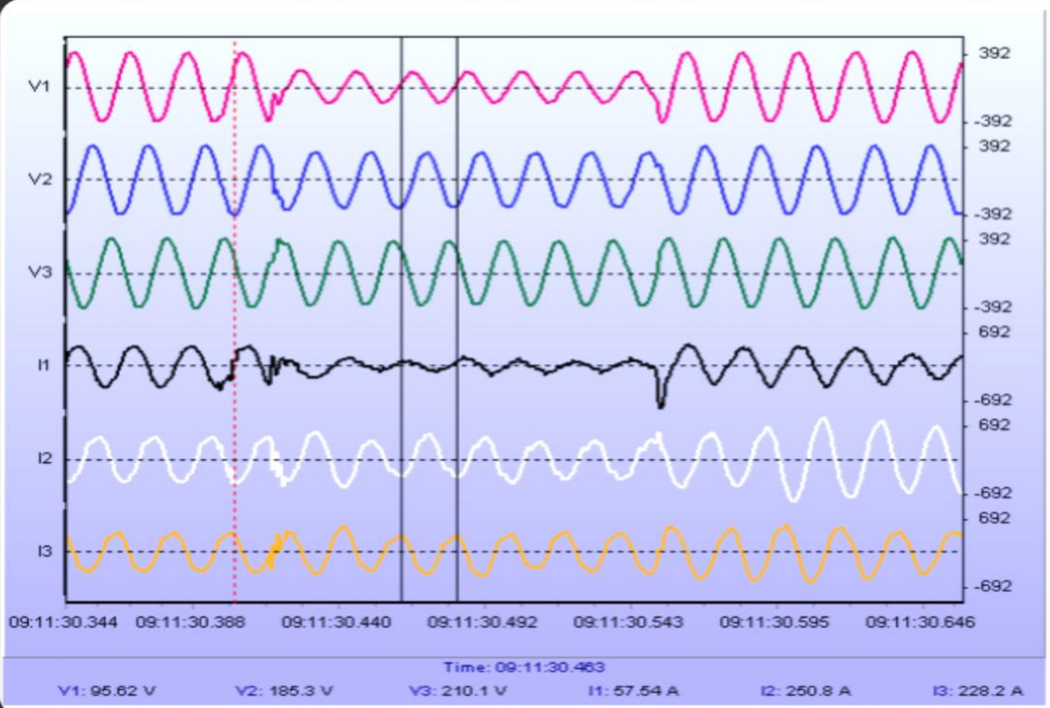
EN50160 Compliance Trends



ITI (CBEMA) Curve

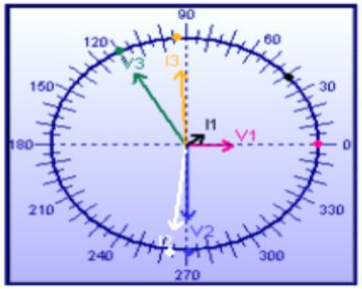


Deep Analysis of a Dip



PQ Event Description: Voltage Dips
Event No.: PQ750

	Min Peak	Max Peak	Angle
V1	-143.8	143.8	0 °
V2	-256.9	256.9	-88.3 °
V3	-296	294.6	118.9 °
I1	-97.82	108.8	38.6 °
I2	-287.1	405.3	-96.2 °
I3	-360.4	273	93 °



☐ Triangle

Symmetrical Components		
	V	I
Positive Sequence	157.3 V	155.8 A
Negative Sequence	66.1 V	115.4 A
Zero Sequence	0.5 V	5.3 A
Negative Sequence Unbalance	42.04%	74.04%
Zero Sequence Unbalance	0.3%	3.41%

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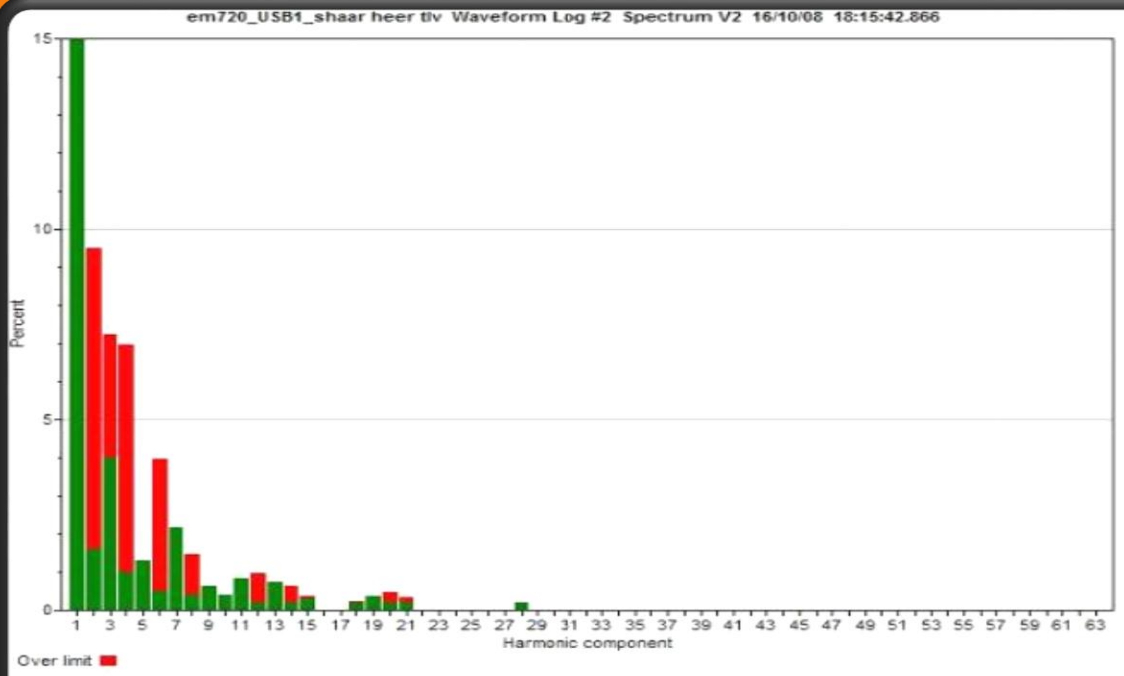
High Individual Harmonics



Harmonics

	HD%	V		HD%	V
H02	9.53	21.0	H03	7.24	16.0
H04	6.99	15.4	H05	1.33	2.9
H06	3.97	8.8	H07	2.20	4.8
H08	1.48	3.3	H09	0.64	1.4
H10	0.42	0.9	H11	0.86	1.9
H12	0.99	2.2	H13	0.75	1.6
H14	0.63	1.4	H15	0.40	0.9
H16	0	0	H17	0	0
H18	0.23	0.5	H19	0.38	0.8
H20	0.48	1.1	H21	0.34	0.8
H22	0	0	H23	0	0
H24	0	0	H25	0	0
H26	0	0	H27	0	0
H28	0.23	0.5	H29	0	0
H30	0	0	H31	0	0
H32	0	0	H33	0	0
H34	0	0	H35	0	0
H36	0	0	H37	0	0
H38	0	0	H39	0	0
H40	0	0	H41	0	0
H42	0	0	H43	0	0
H44	0	0	H45	0	0
H46	0	0	H47	0	0
H48	0	0	H49	0	0
H50	0	0	H51	0	0
H52	0	0	H53	0	0
H54	0	0	H55	0	0
H56	0	0	H57	0	0
H58	0	0	H59	0	0
H60	0	0	H61	0	0
H62	0	0	H63	0	0

Voltage V2

RMS: 223.1 V
H01 RMS: 220.5 V

TOTAL HARMONICS

THD: 14.9%
Odd Harmonics: 7.8%
Even Harmonics: 12.6%
Interharmonics: 1.2%

Crest Factor: 1.42
Form Factor: 1.10

Frequency: 50.26 Hz

Class B/S Portable/Handheld Power & Energy Analyzer

Configure the ELITEpro XC as its own wifi hotspot and view real-time data using a wifi-enabled smartphone, laptop, or tablet.

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Class A Power Quality Analyzer

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Power Quality Audit - Integrating Principles

1. Understand the problem
2. Find the real cause before you find the best solution
3. The solution must be always cost effective
4. Be open and work closely with the customer
5. Be Pro-Active, Not Reactive
6. Do not go after magic solutions
7. Educate utility and customers
8. Offer alternative PQ Services
9. Be aware of legal issues
10. Satisfy the customers - They are always right

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PQ Audit Check List

What sensitive electronic equipment is experiencing problems? (type, location, etc.)

- Nature of the problems? (data loss, lockups, component damage, flickering lights, etc.)
- When do the problems occur? (time of day, day of week, particular system operation, etc.)
- How long have problems occurred? (since installation, just recently, seasonally, etc.)
- Coincident problems occurring at the same time? (lights flicker, motors slow down, etc.)
- Possible problem sources at site? (arc welders, air conditioning, copy machines, etc.)
- Existing protection for equipment? (surge suppressor, isolation transformer, etc.)
- Has protection equipment helped the problems? (getting better, no change, getting worse, etc.)
- Has the wiring and grounding of the building been checked? (missing connections, improper connections, poor quality connections - high impedance, etc.)
- Has the quality of the supplied AC voltage been checked? (use True RMS meters)

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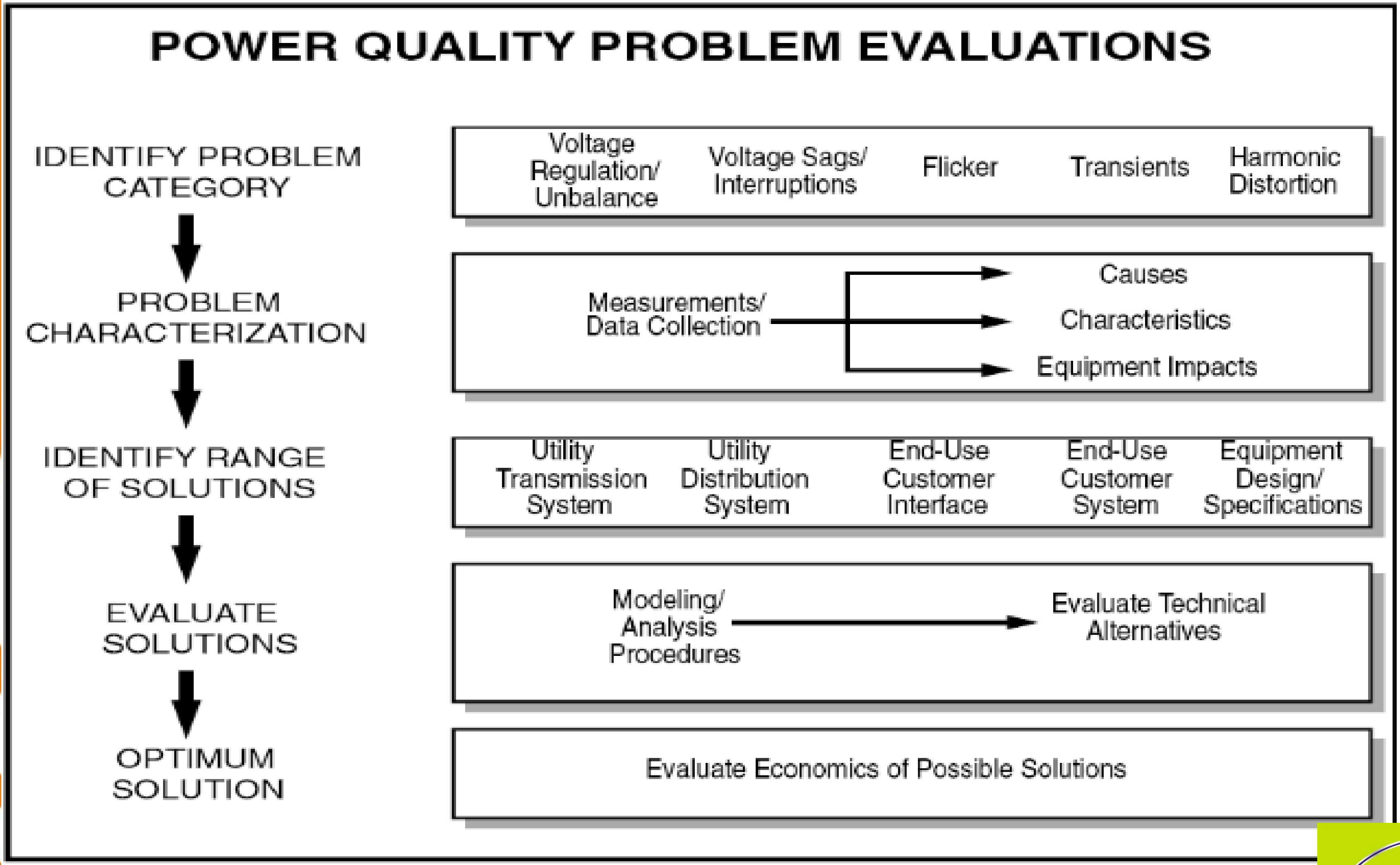
Basic steps involved in power quality evaluation



Loads that generate harmonics

- Switched mode power supplies (SMPS)
- Electronic fluorescent lighting ballasts
- Variable speed drives
- Un-interruptible power supplies (UPS)

These are all *non-linear* loads

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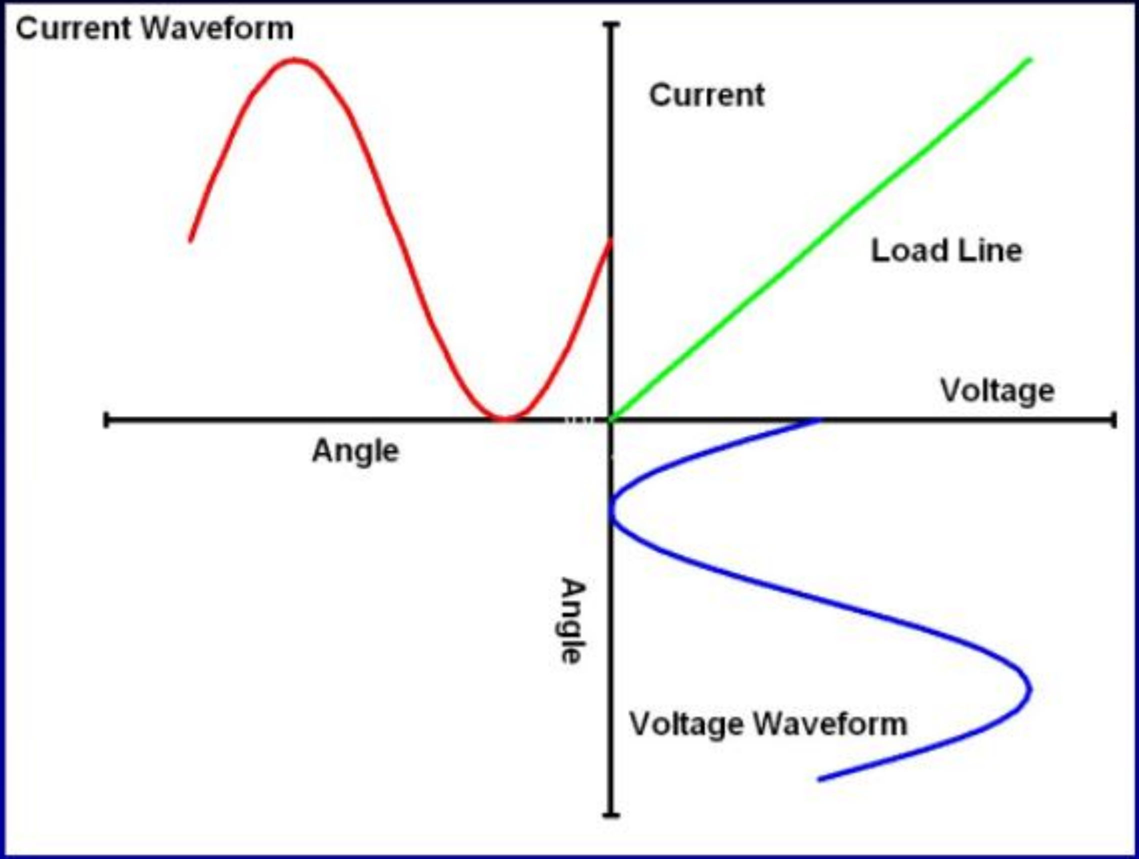
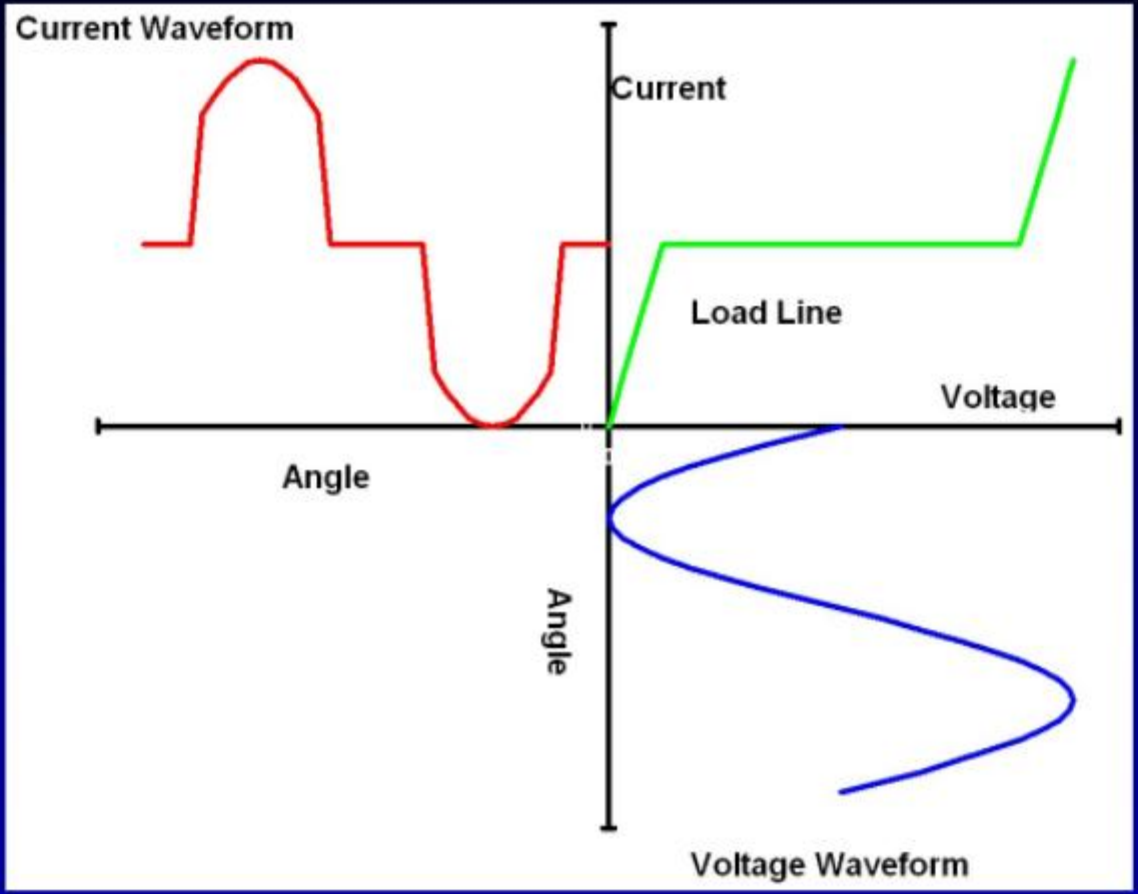
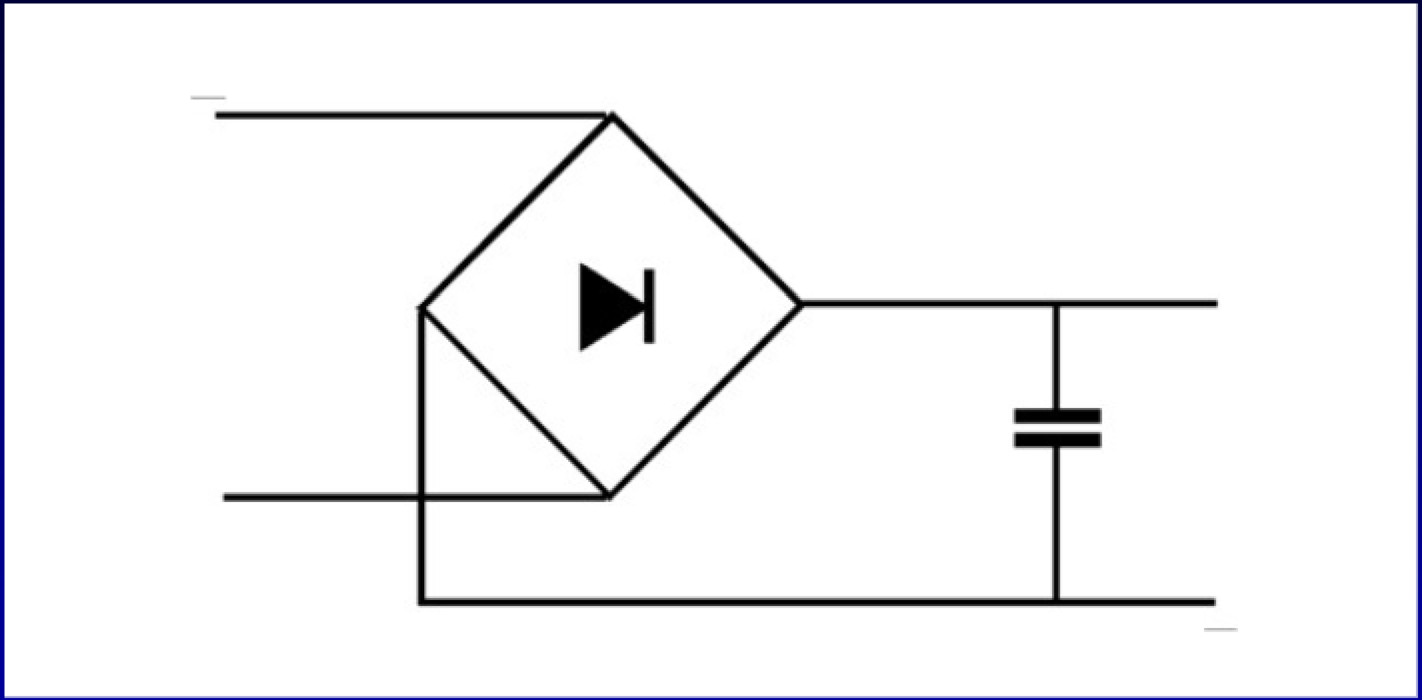
How harmonics are generated – linear load



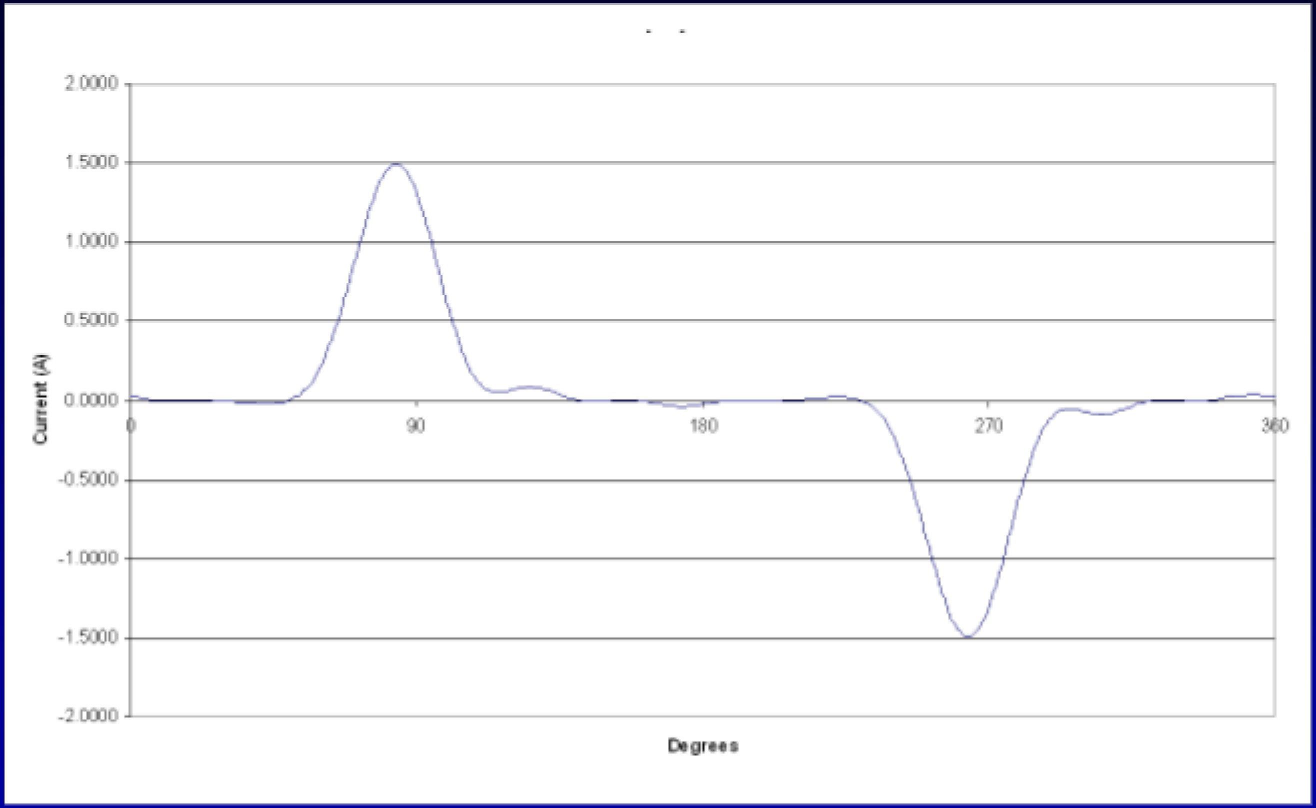
How harmonics are generated – non-linear load



A Common non-linear load



Current waveform for a typical Personal Computer



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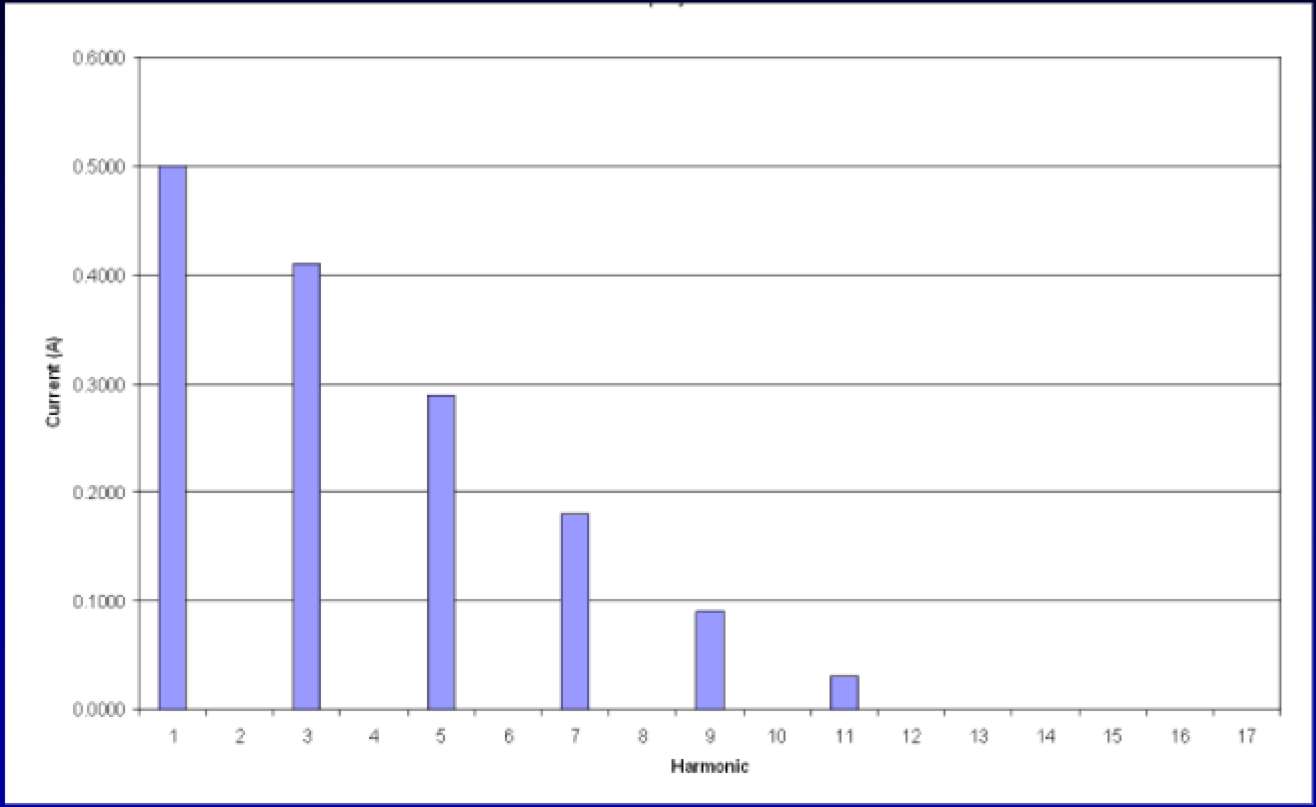
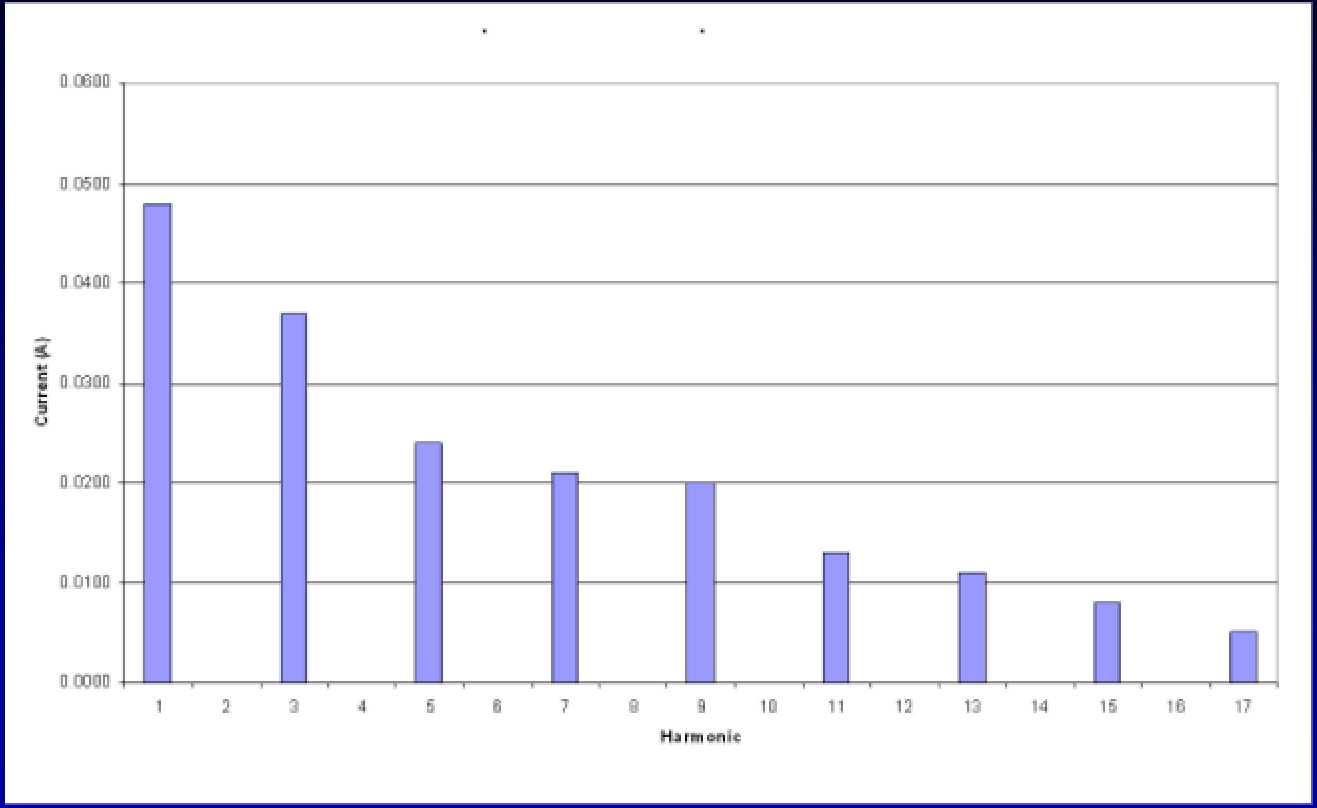
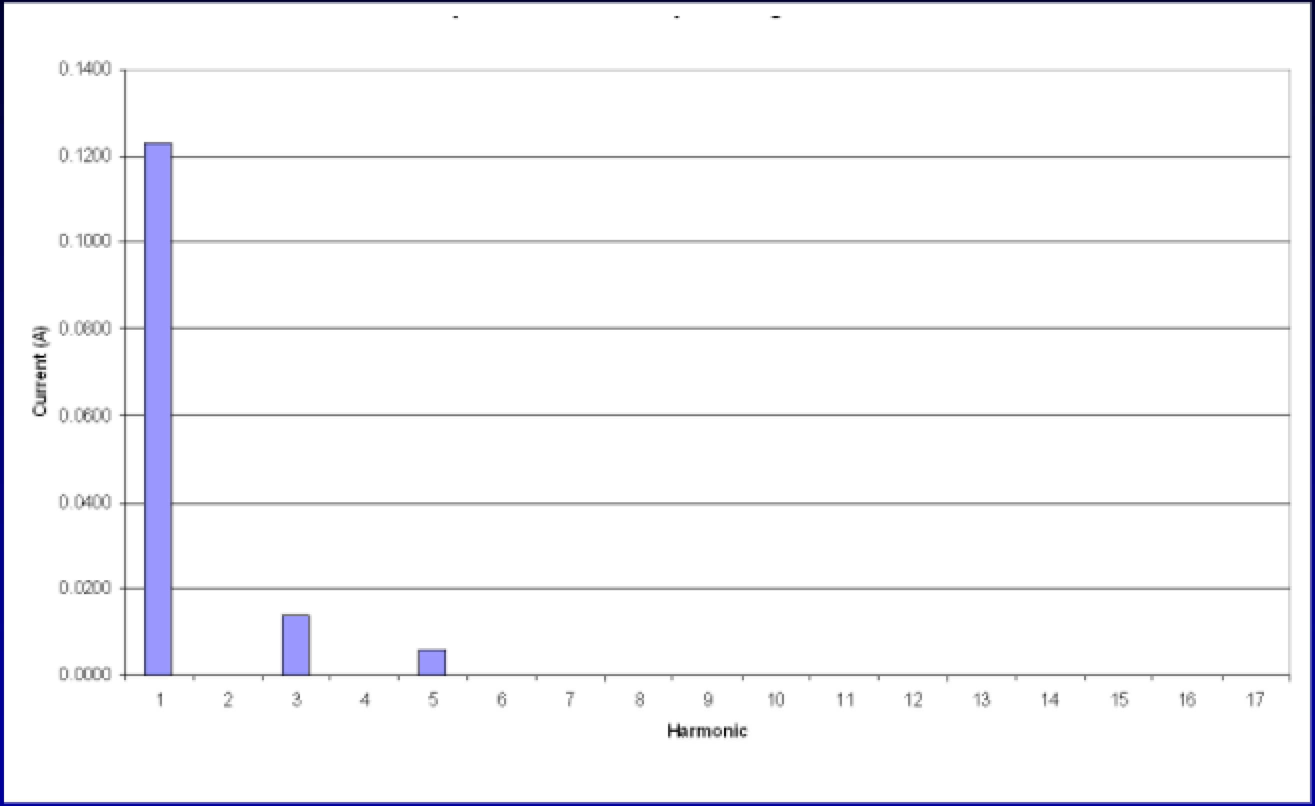
Harmonic profile of a typical Personal Computer



Harmonic profile for electronic fluorescent ballast



Harmonic profile for magnetic fluorescent ballast



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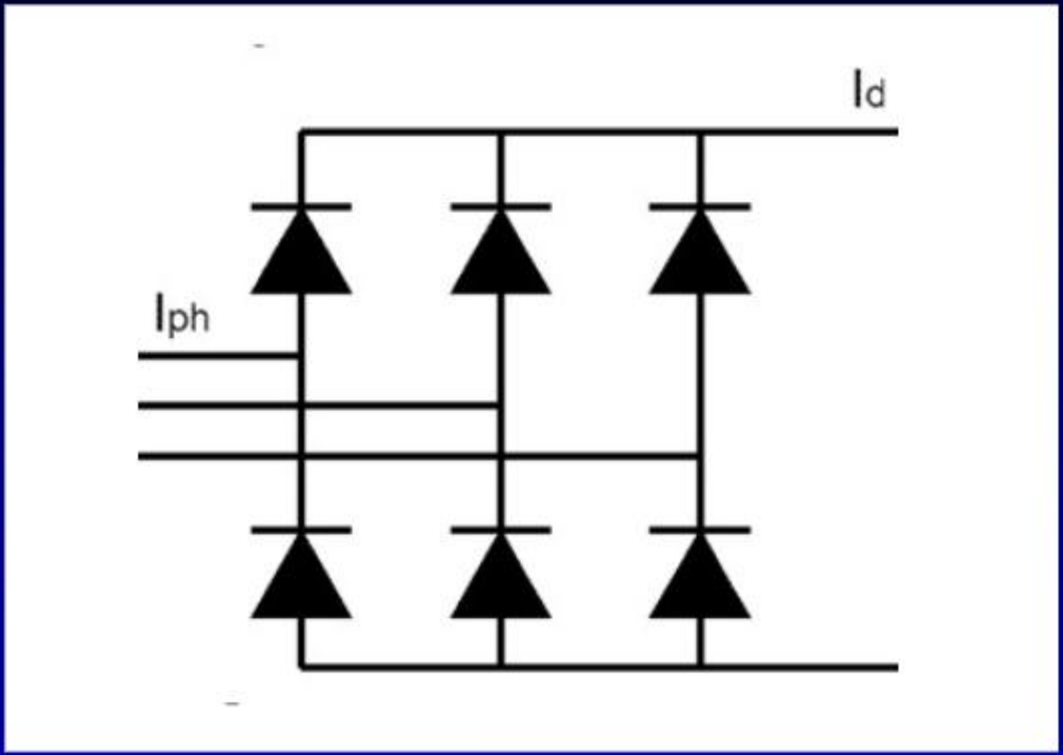
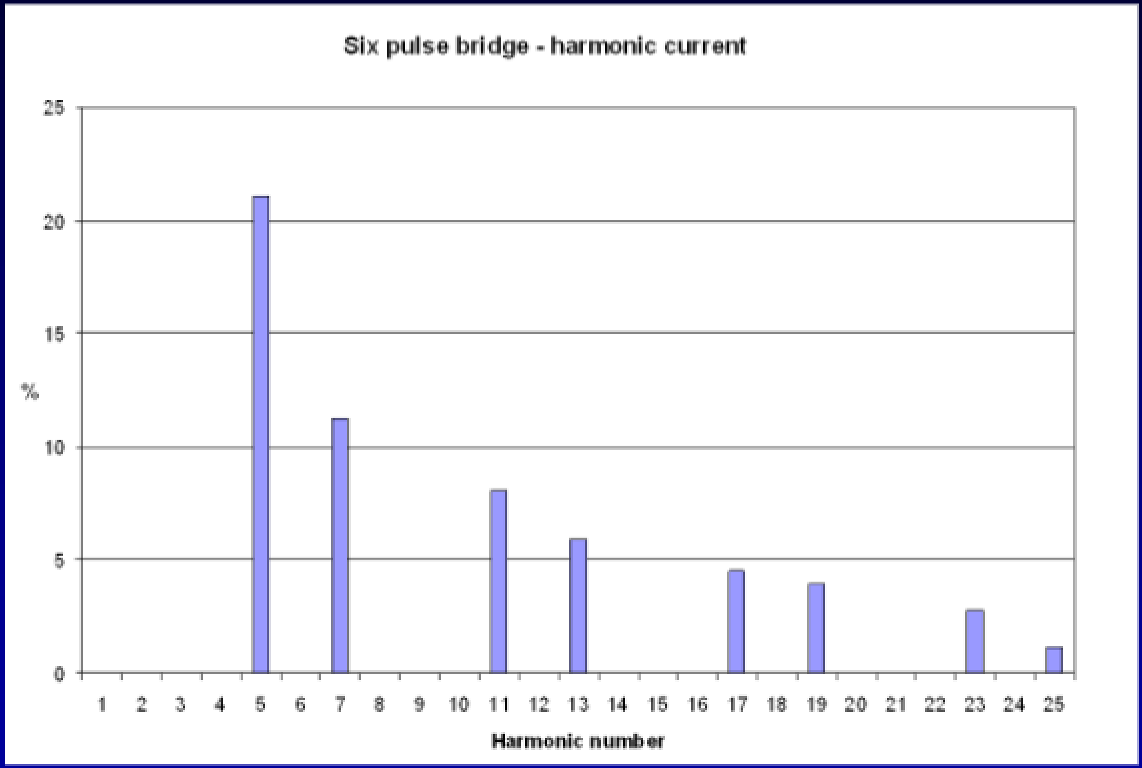
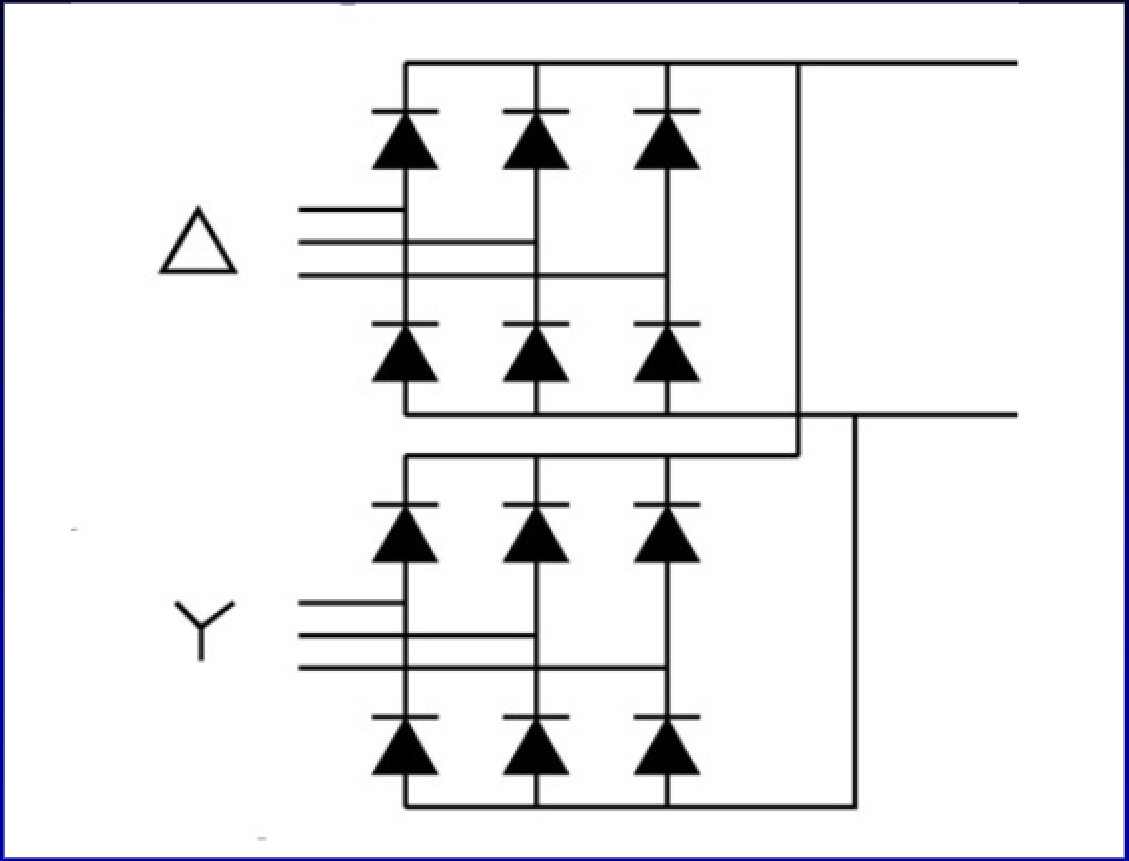
Six-pulse bridge



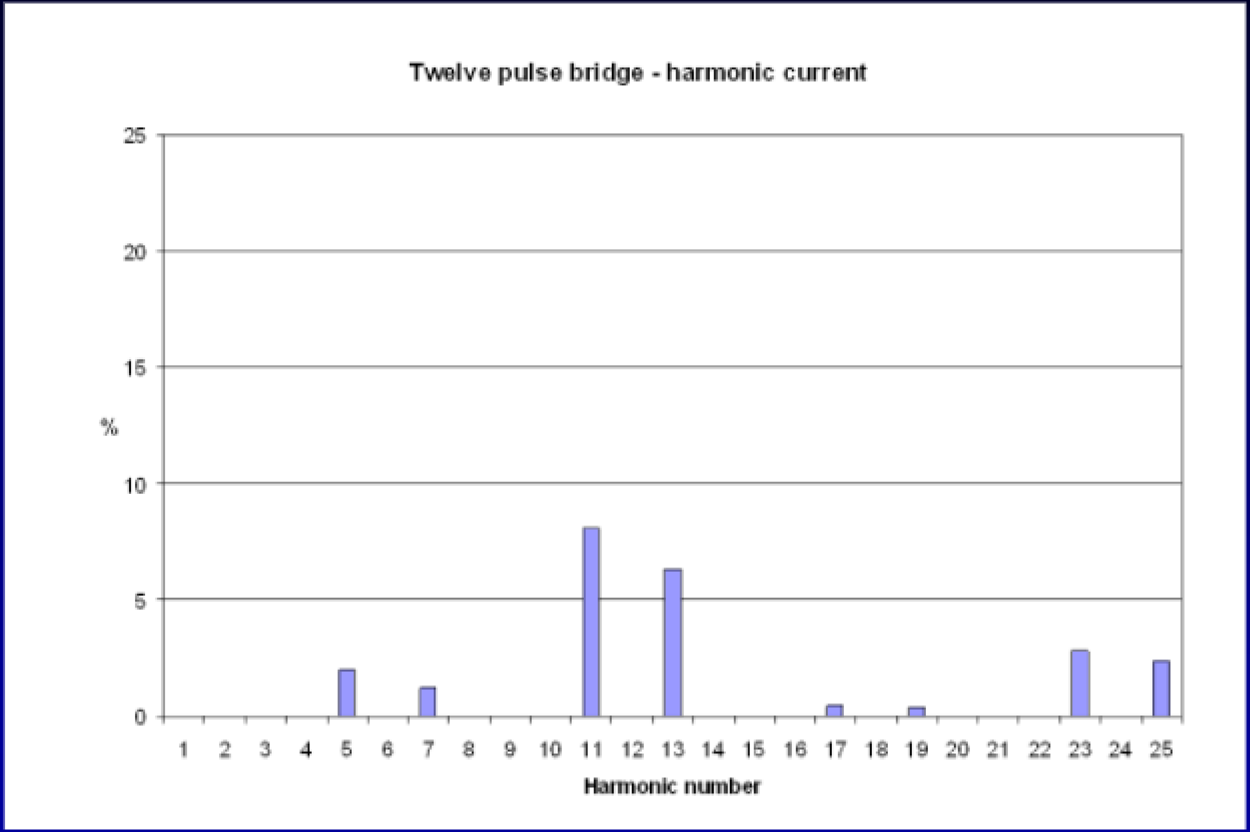
Typical harmonic profile - six-pulse bridge



Twelve-pulse bridge



Typical harmonic profile - twelve-pulse bridge

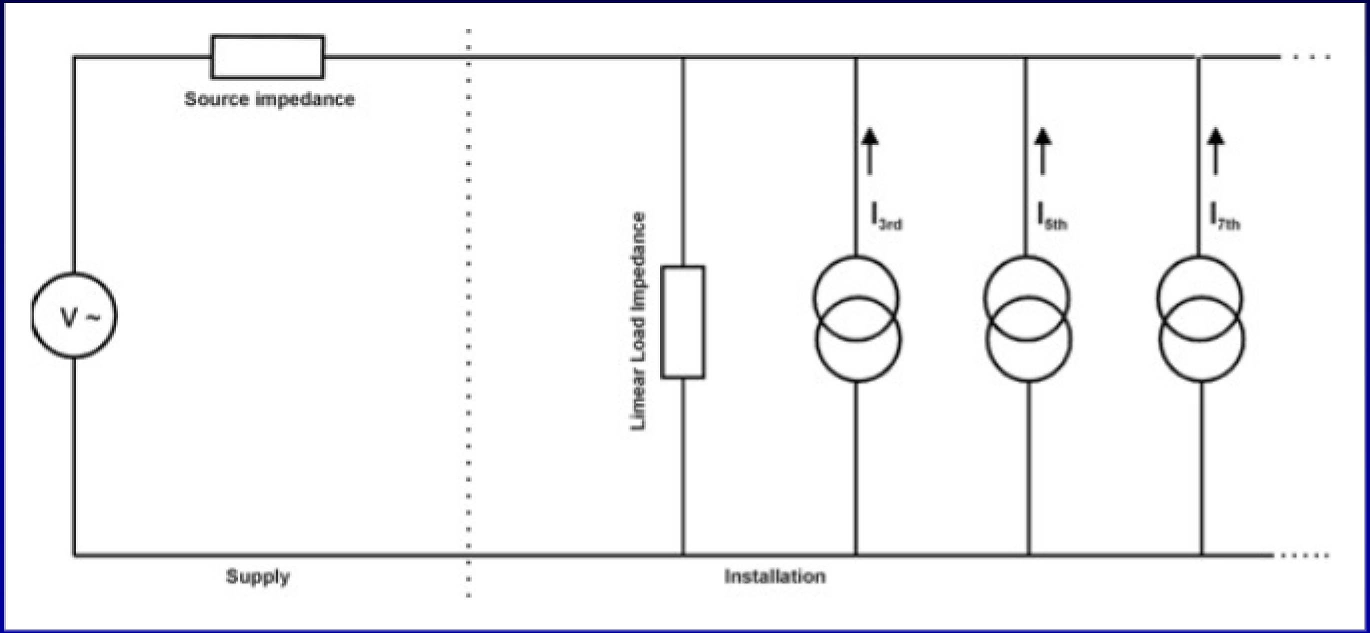


Why have harmonics become so important?

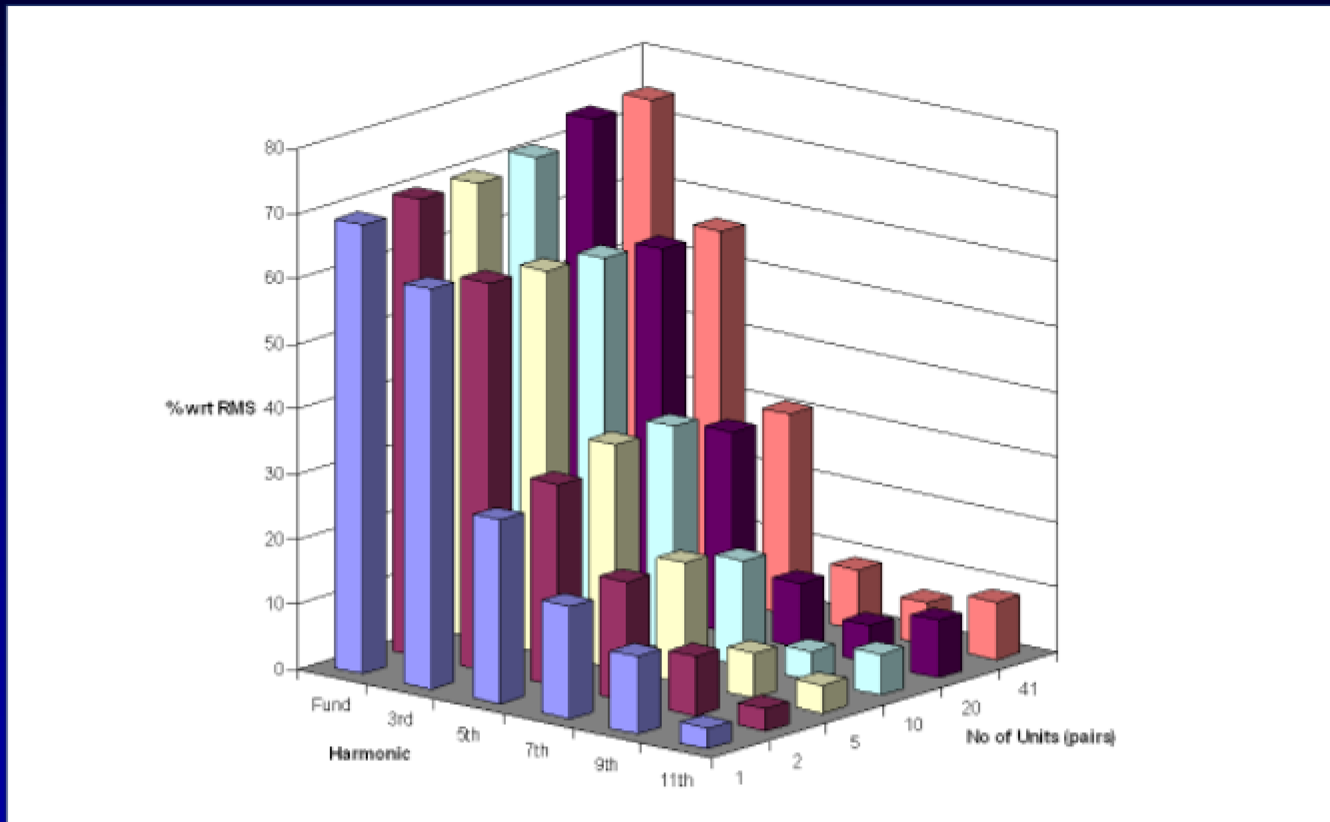
Harmonic generating equipment has been in use for decades

- Increase in the number of loads
- Change in the nature of loads
- Increase in those producing triple-Ns

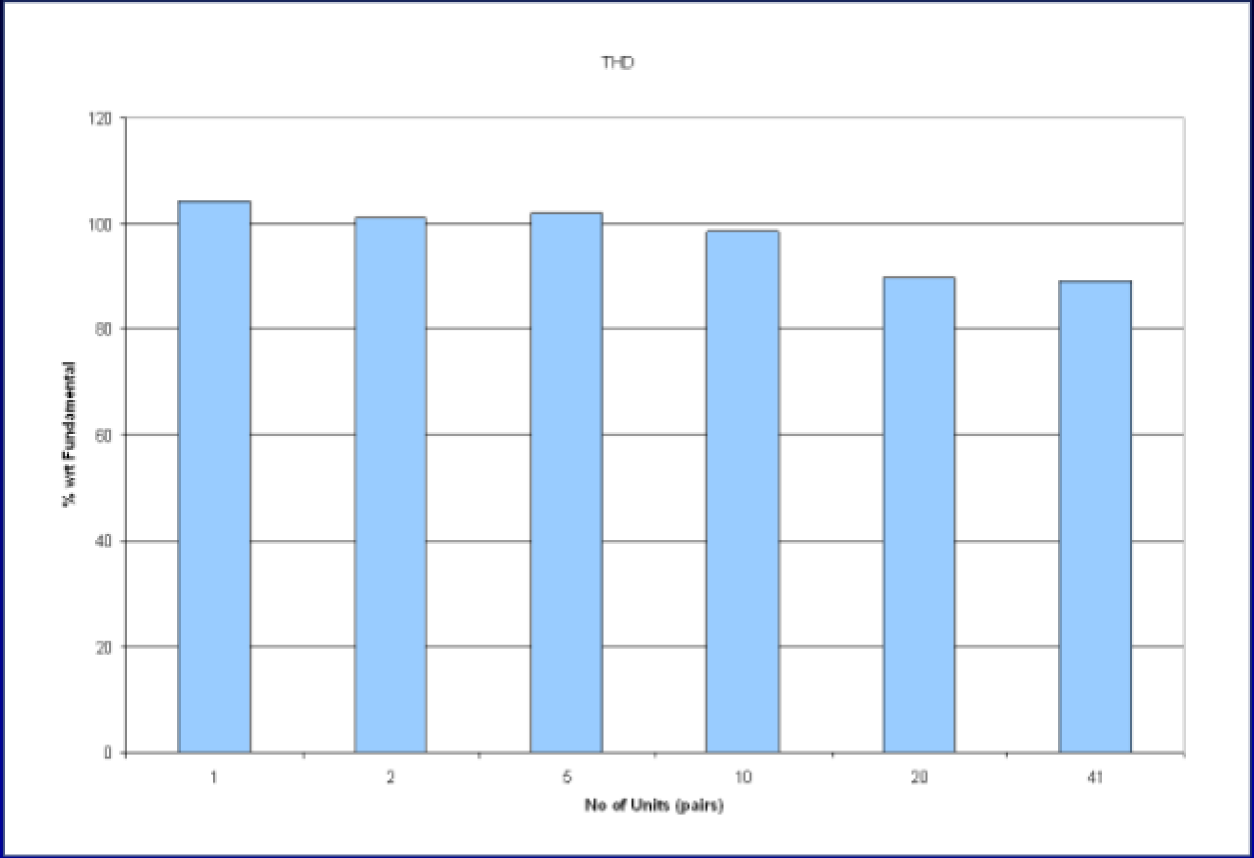
Equivalent circuit of a harmonic generating load



Harmonic Diversity



Harmonic Diversity - THDI



Problems caused by harmonics

- currents within the installation
  - overloading of neutrals
  - overheating of transformers
  - nuisance tripping of circuit breakers
  - over-stressing of power factor correction capacitors
  - skin effect
- voltages within the installation
  - voltage distortion & zero-crossing noise
  - overheating of induction motors
- currents in the supply

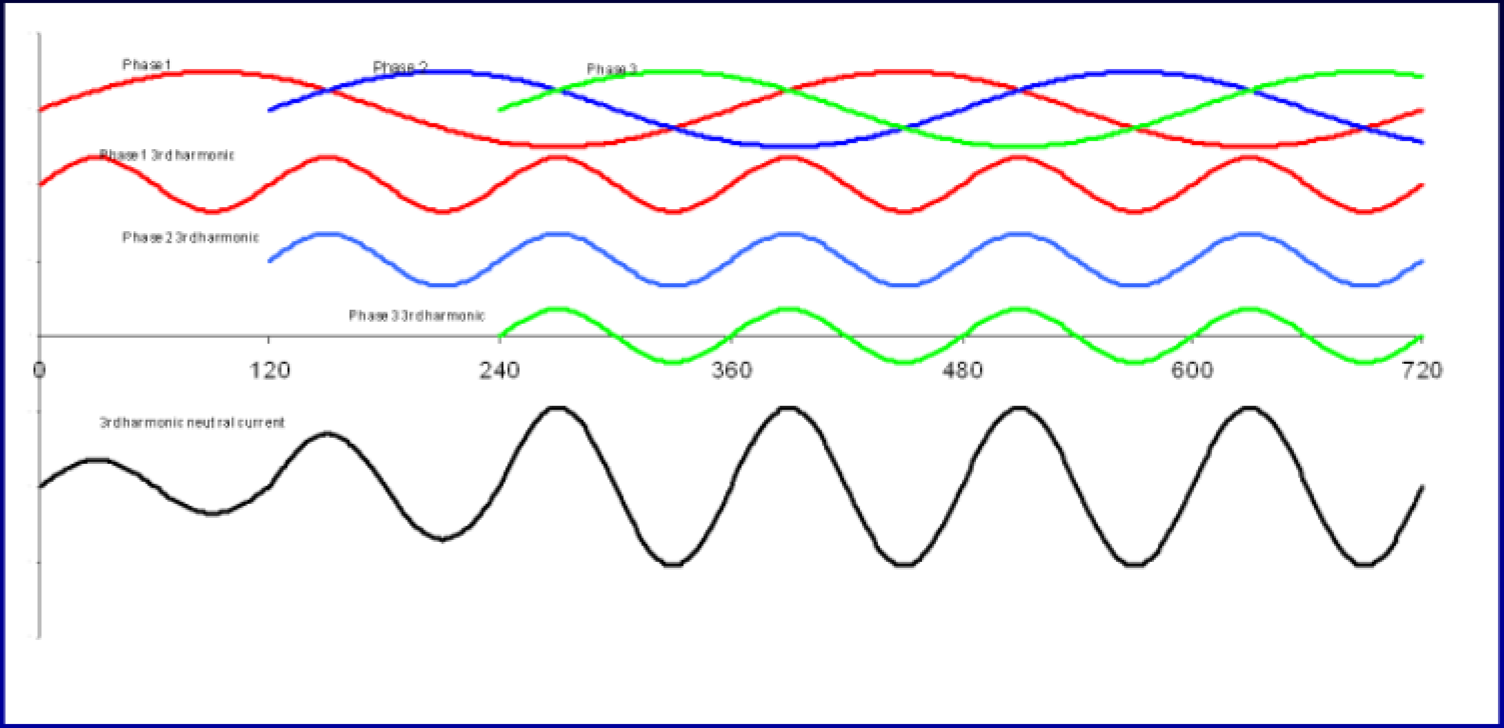
Overheating of neutrals

In balanced three phase systems the fundamental current cancels out

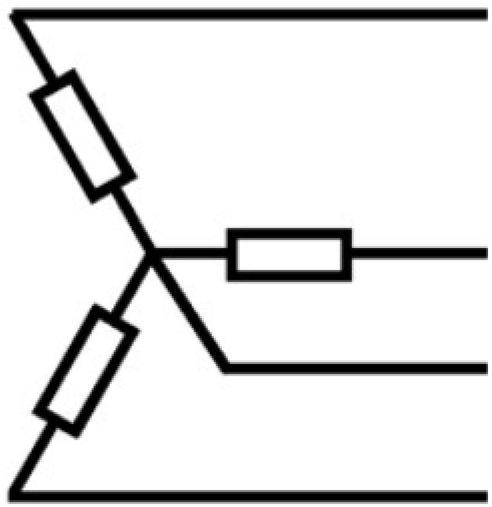
But *triple-N* harmonics ***add*** arithmetically *!*

Non triple-N harmonics cancel in the neutral

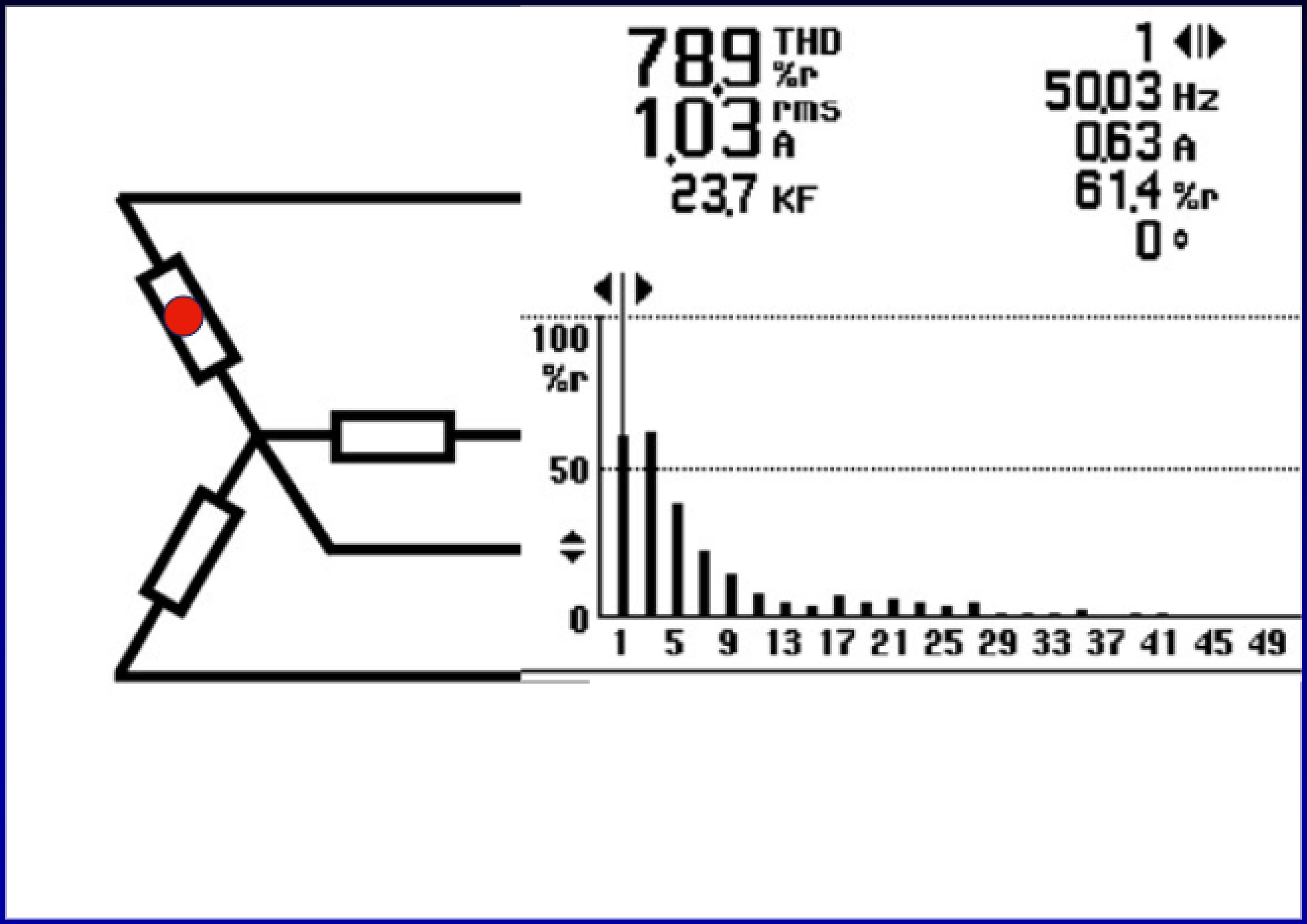
Harmonic neutral currents



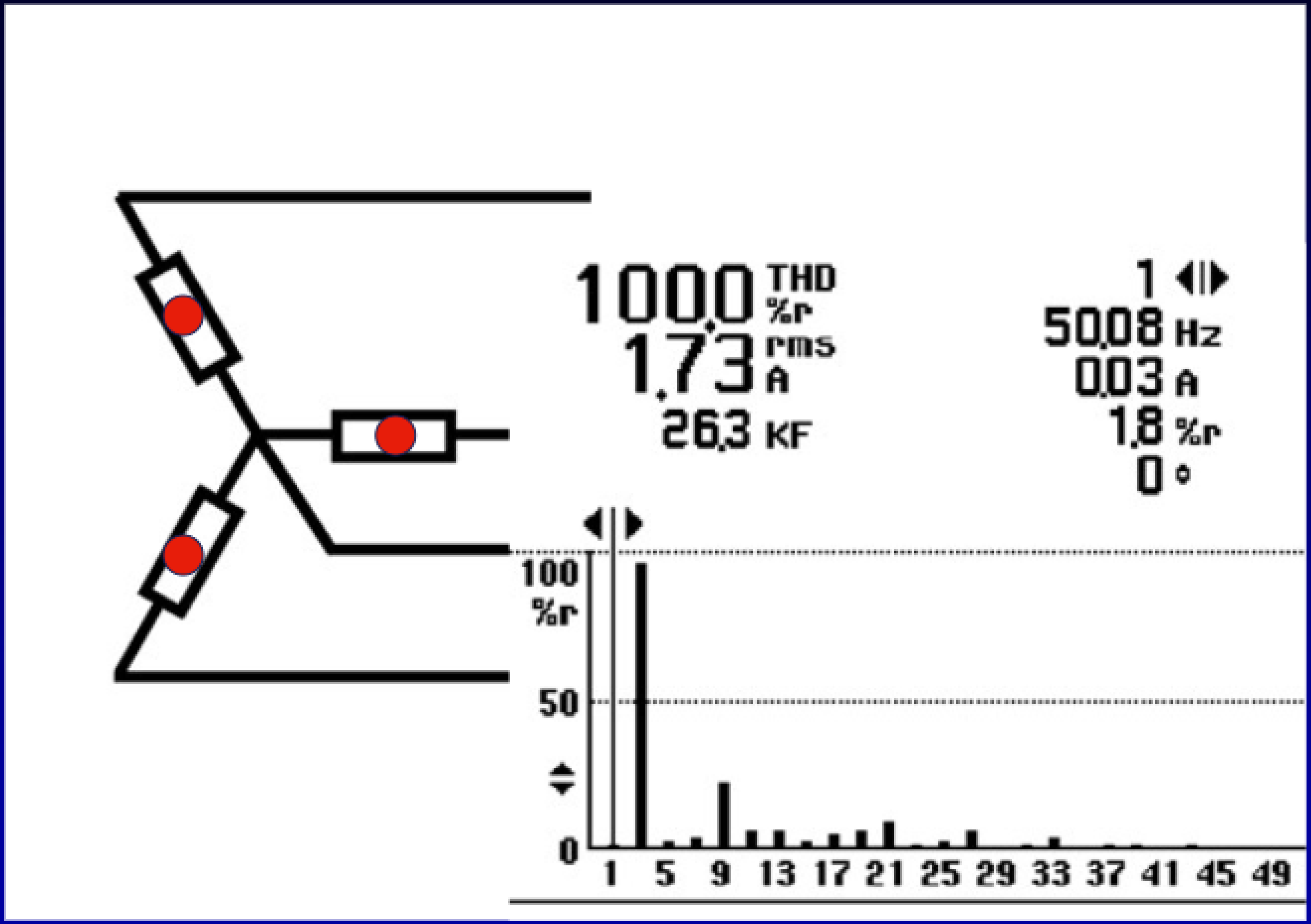
Neutral conductor sizing



Neutral conductor sizing



Neutral conductor sizing



Neutral conductor sizing

Neutral currents can easily approach *twice* the phase currents - sometimes in a *half-sized* conductor.

IEEE 1100-1992 recommends that neutral busbars feeding non-linear loads should have a cross-sectional area not less than 173% that of the phase bars.

Neutral cables should have a cross-sectional area that is 200% that of the phases, e.g. by using twin single core cables.

Effect of harmonics on transformers

Transformers supplying harmonic loads must be appropriately de-rated

- Harmonic currents, being of higher frequency, cause increased magnetic losses in the core and increased eddy current and skin effect losses in the windings
- Triple-n harmonic currents circulate in delta windings, increasing resistive losses, operating temperature and reducing effective load capacity

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Increased Eddy current losses in transformers

Increase in eddy current loss can be calculated by:

$$P_{eh} = P_{ef} \sum_{h=1}^{h=h_{max}} I_h^2 h^2$$

where:

P_{eh} is the total eddy current loss

P_{ef} is the eddy current loss at fundamental frequency

h is the harmonic order

I_h is the RMS current at harmonic h as a percentage of rated fundamental current

K-Rating of Transformers

Two rating or de-rating systems for transformers:-

- American system, established by UL and manufacturers, specifies harmonic capability of transformer - known as *K factor* .
- European system, developed by IEC, defines de-rating factor for standard transformers - known as *factor K* .

K-Rating of Transformers - US System

First, calculate the K factor of the load according to:

$$K = \sum_{h=1}^{h = h_{max}} I_h^2 h^2$$

where:

h is the harmonic order

I_h is the RMS current at *h* in per unit of rated load current

K-Rating of Transformers - US System

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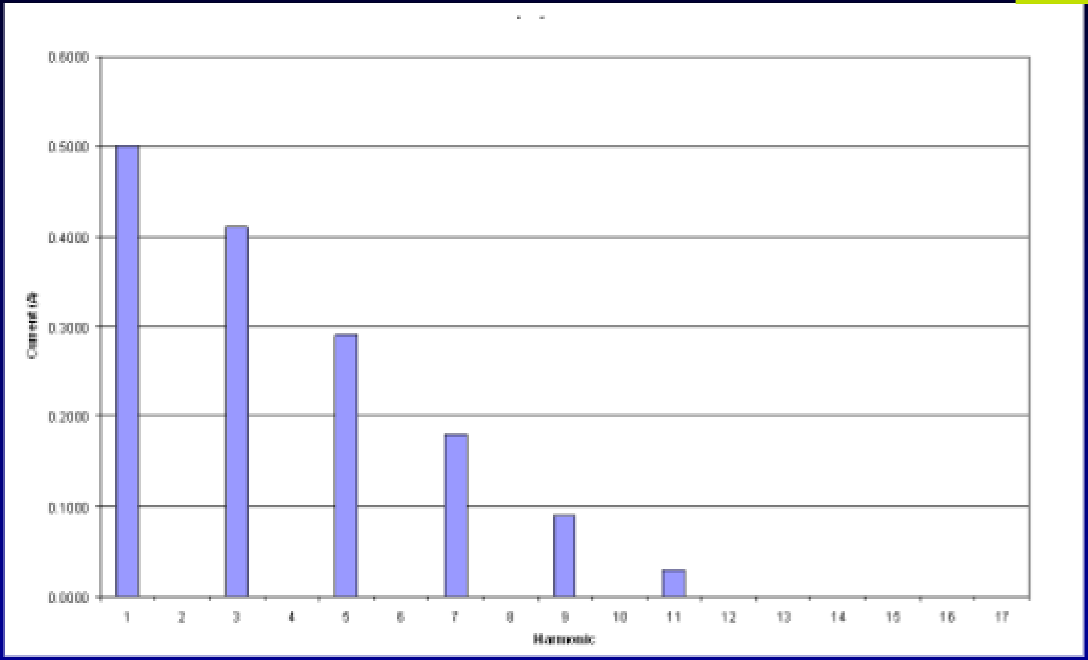


For this typical PC load, the K factor is 11.6

(See IEE 1100-1992 for a worked example)

K-Rating of Transformers - US System

Next, select a transformer with a higher K rating: standard ratings are 4, 9, 13, 20, 30, 40 and 50.

NB - for *non* K-rated transformers:

The K factor describes the increase in eddy current losses, not total losses.

K-Rating of Transformers - European System

In Europe, the transformer de-rating factor is calculated according to the formulae in BS 7821 Part 4. The factor K is given by:

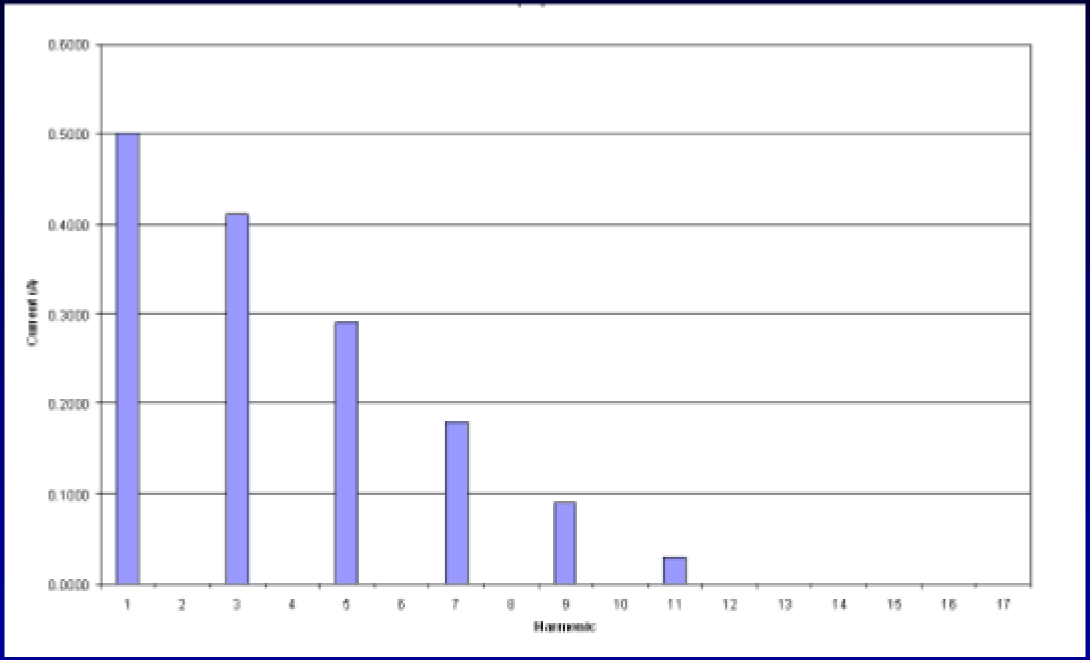
$$K = \left[1 + \frac{e}{1+e} \left(\frac{I_1}{I} \right)^2 \sum_{n+2}^{n=N} \left(n^q \left(\frac{I_n}{I_1} \right)^2 \right) \right]^{0.5}$$

e is ratio of eddy current loss (50 Hz) to resistive loss

n is the harmonic order

q is dependent on winding type and frequency, typically 1.5 to 1.7

K-Rating of Transformers - European System



For the same PC load, the de-rating factor is 78%

K-Rating or De-rating?

'K-rated' transformers are designed to supply harmonic loads by :

- using stranded conductors to reduce eddy current losses
- bringing secondary winding star point connections out separately to provide a 300% neutral rating

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K-Rating or De-rating?

'De-rating' a standard transformer has some disadvantages:-

- primary over-current protection may be too high to protect the secondary and too low to survive the in-rush current
- the neutral star point is likely to be rated at only 100% of the phase current
- it is less efficient
- future increases in loading must take the de-rating fully into account

Effect of harmonics on transformers

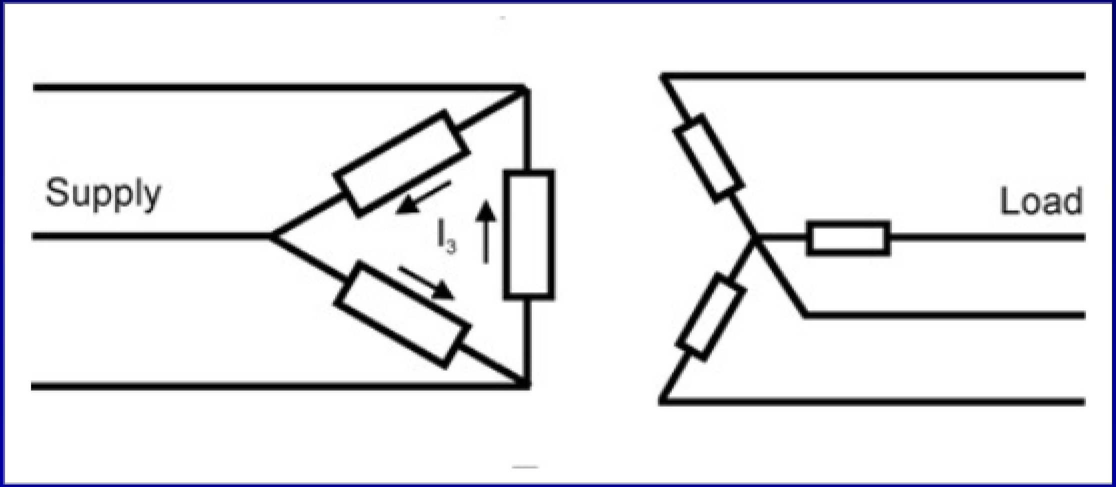
Transformers supplying harmonic loads must be appropriately de-rated

- Harmonic currents, being of higher frequency, cause increased magnetic losses in the core and increased eddy current and skin effect losses in the windings
- **Triple-n harmonic currents circulate in delta windings, increasing resistive losses, operating temperature and reducing effective load capacity**

Effect of triple-n harmonics in transformers

Triple-n harmonic currents circulate in delta windings - they do not propagate back onto the supply network.

- but the transformer must be specified and rated to cope with the additional losses.



Skin effect

Alternating current tends to flow on the outer surface of a conductor - skin effect - and is more pronounced at high frequencies.

- At the seventh harmonic and above, skin effect will become significant, causing additional loss and heating.
- Where harmonic currents are present, cables should be de-rated accordingly. Multiple cable cores or laminated busbars can be used.

Skin effect - penetration depth

$$d = \frac{1}{2\pi}\sqrt{\frac{\rho \times 10^5}{f}}$$

where:

d is the depth of penetration, mm

f is the frequency, Hz, and

ρ is the resistivity of the conductor

At the fundamental, 50 Hz	d = 9.32 mm
At the 11th harmonic, 550Hz	d = 2.81 mm

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Circuit breakers

Nuisance tripping can occur in the presence of harmonics for two reasons:

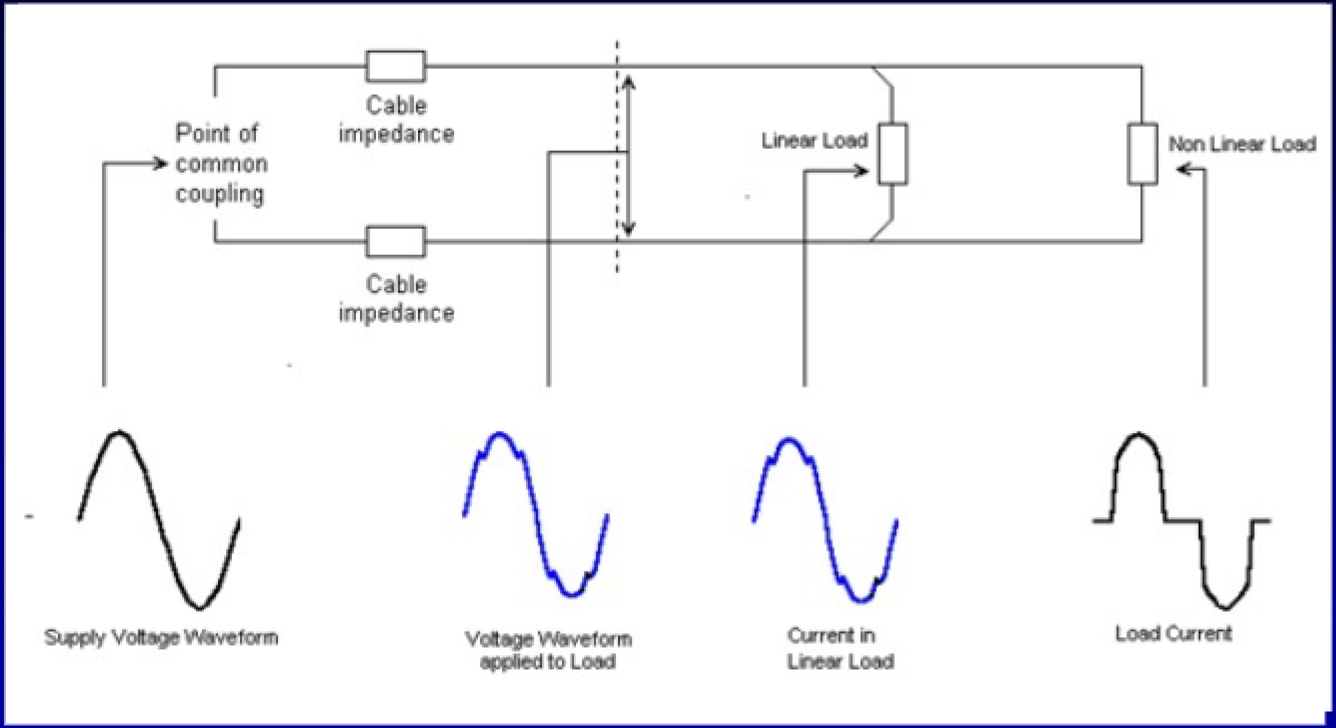
- Residual current circuit breakers are electromechanical devices. They may not sum higher frequency components correctly and therefore trip erroneously.

- The current flowing in the circuit will be higher than expected due to the presence of harmonic currents. Most portable measuring instruments do not read true RMS values.

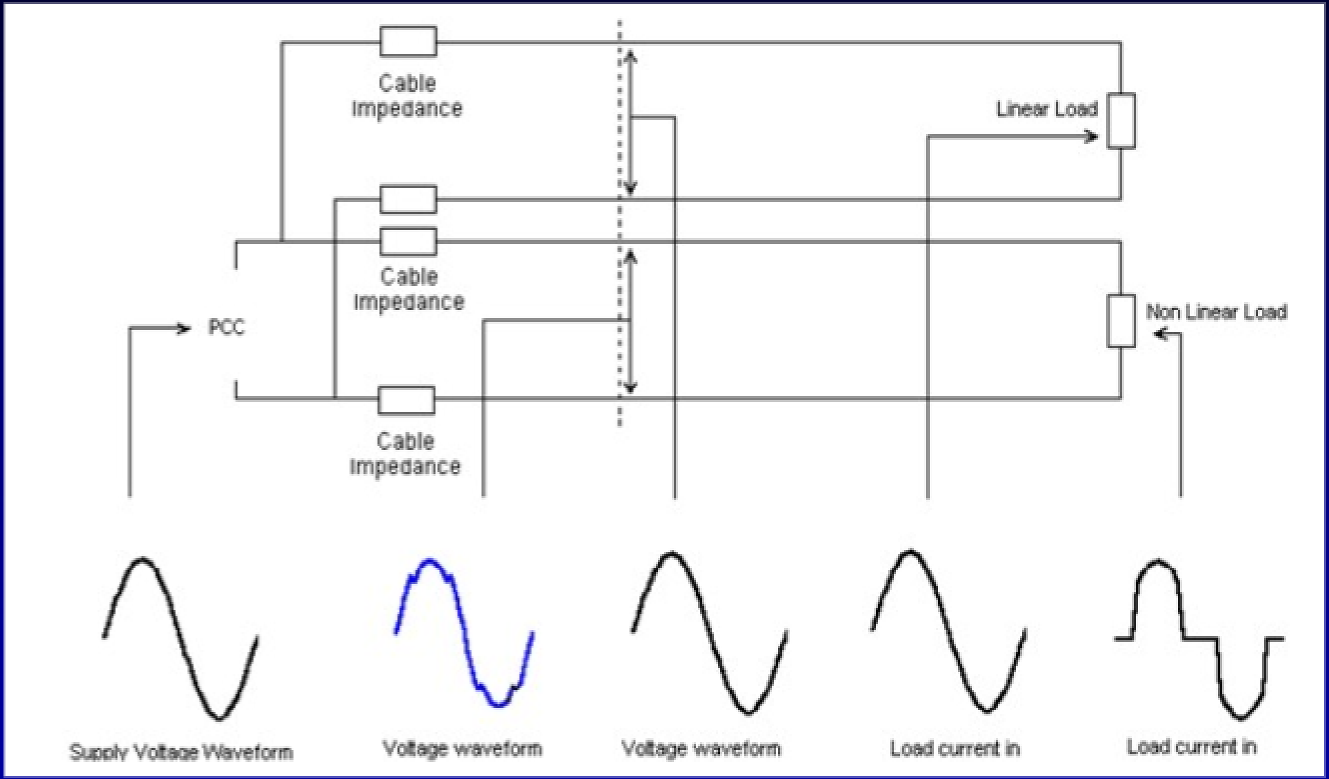
Problems caused by harmonics

- currents within the installation
  - overloading of neutrals
  - over-heating of transformers
  - over-stressing of power factor correction capacitors
  - skin effect
  - nuisance tripping of circuit breakers
- voltages within the installation
  - voltage distortion & zero-crossing noise
  - over-heating of induction motors
- currents in the supply

Voltage distortion



Reducing Voltage Distortion by Circuit Separation



Effect of harmonics on induction motors

- Increased magnetic and copper losses
- Each harmonic generates a field which may rotate forward (+), backward (-), or remain stationary (0)

1	2	3	4	5	6	7	8	9	10	11	12
+	-	0	+	-	0	+	-	0	+	-	0

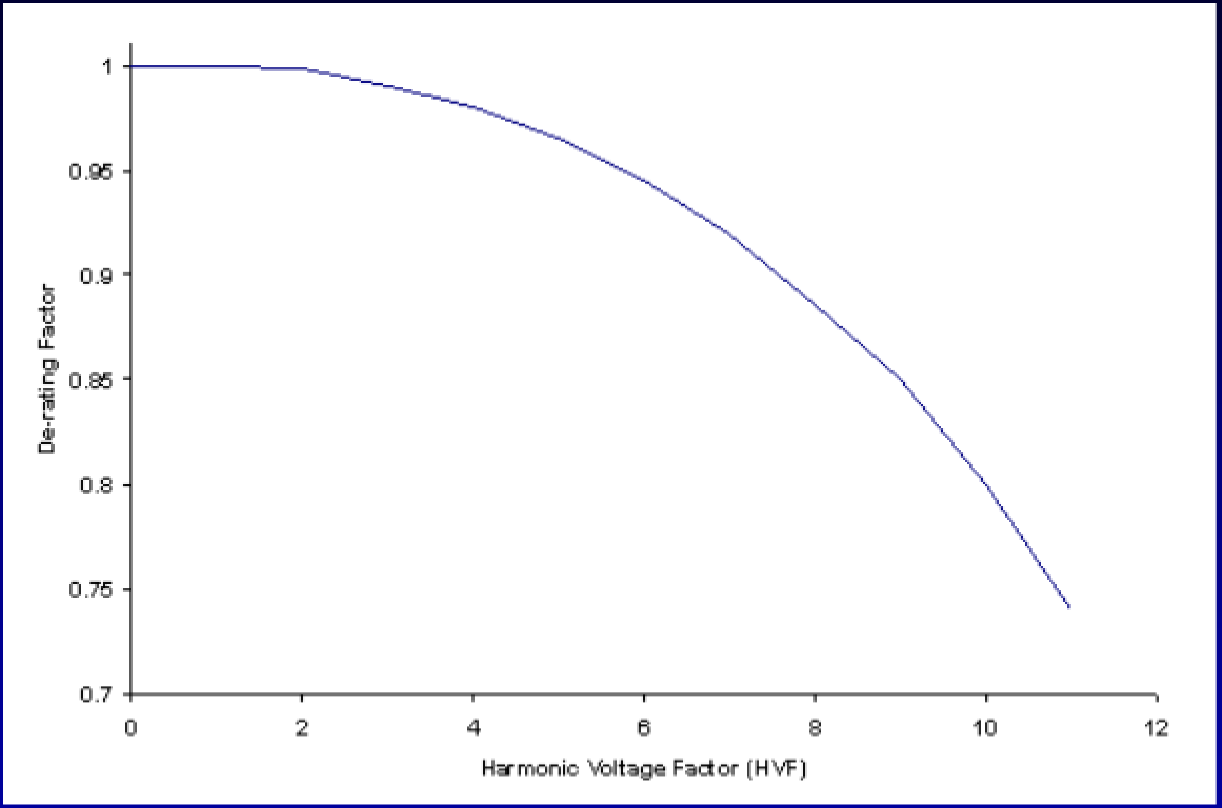
- Zero sequence harmonics produce a stationary field, causing over-heating and reduced efficiency

Effect of harmonics on induction motors

- The negative and positive sequence harmonics together cause torque pulsing, vibration and reduced service life
- Harmonics are induced in the rotor leading to overheating and torque pulsing

Stator harmonic	1	5	7	11	13	17	19
Rotor harmonic	-	6	6	12	12	18	18
Harmonic rotation	F	B	F	B	F	B	F

Motor de-rating curve for harmonic voltages



Harmonic voltage factor

The Harmonic Voltage Factor (HVF) is defined as:

$$HVF = \sqrt{\sum_{n=5}^{n=\infty} \frac{V_n^2}{n}}$$

where:

V_n is the RMS voltage at the nth harmonic as a percentage of the fundamental, and

n is the order of each odd harmonic, excluding triple-Ns

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Harmonic Standards

Electricity Association Engineering Recommendation G 5/4 (2001)

BS EN 61000

IEEE Std 519-1992 Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems

Harmonic solutions

Steps to be taken to reduce voltage distortion on the supply include, for example:

- Passive harmonic filters
- Isolation transformers
- Active harmonic conditioners

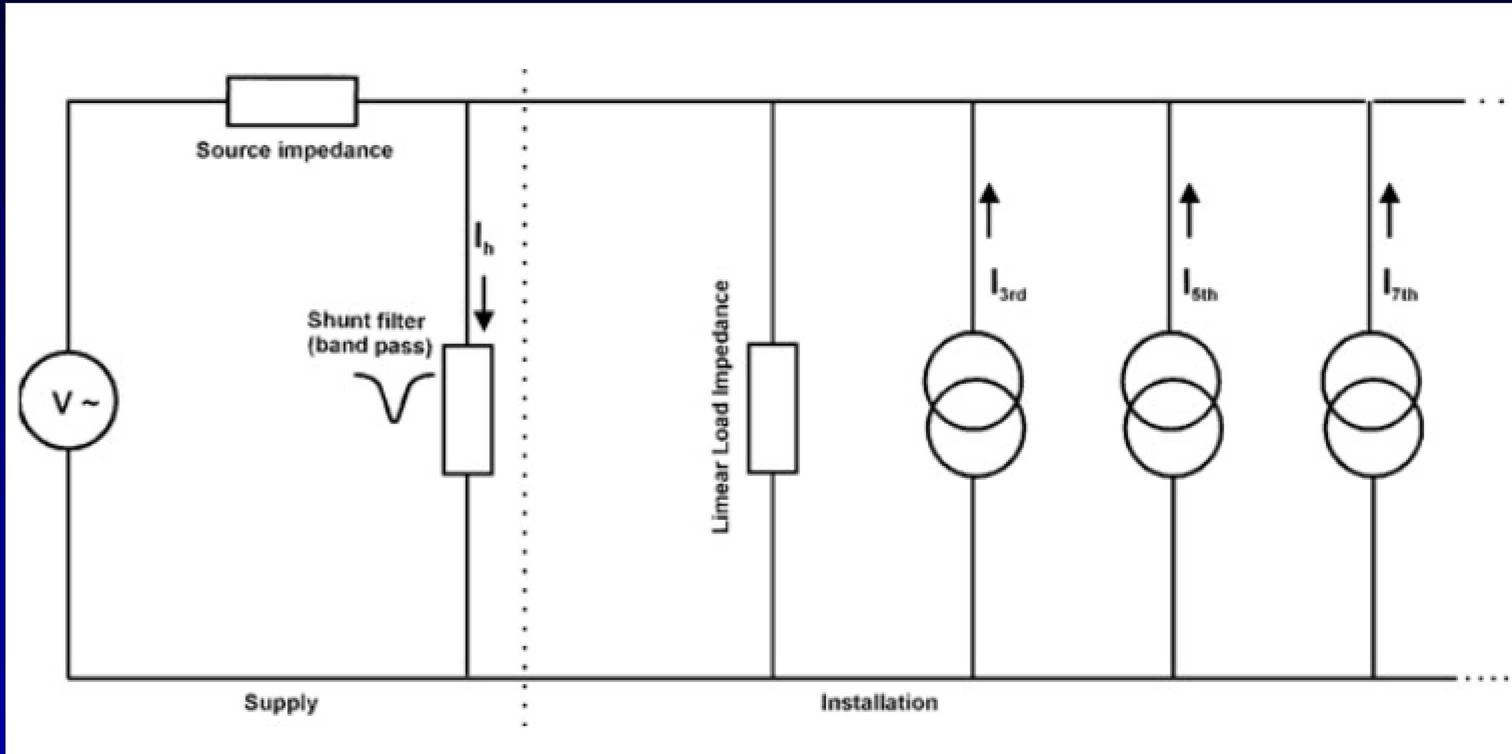
Passive harmonic filters

Filters are useful when

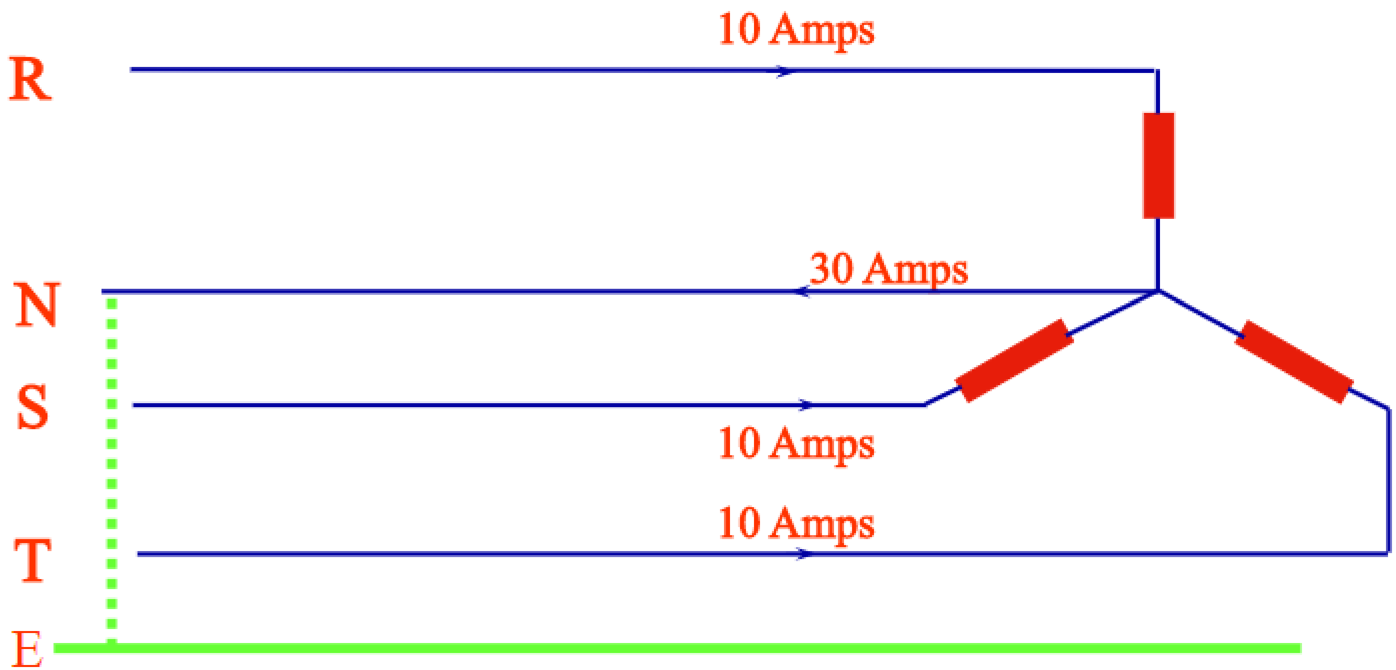
- the harmonic profile is well defined – such as motor controllers
- the lowest harmonic is well above the fundamental frequency

\- but filter design can be difficult and, especially for lower harmonics, the filters can be bulky and expensive

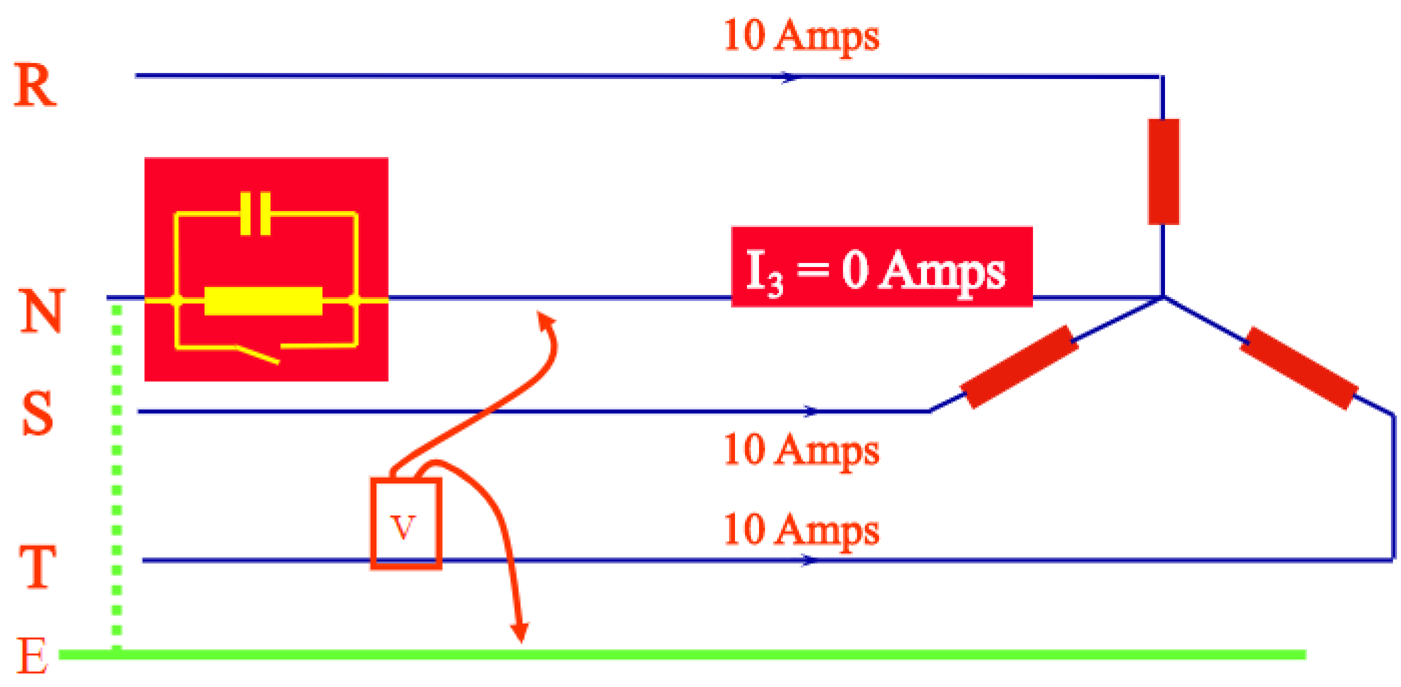
Passive harmonic filter



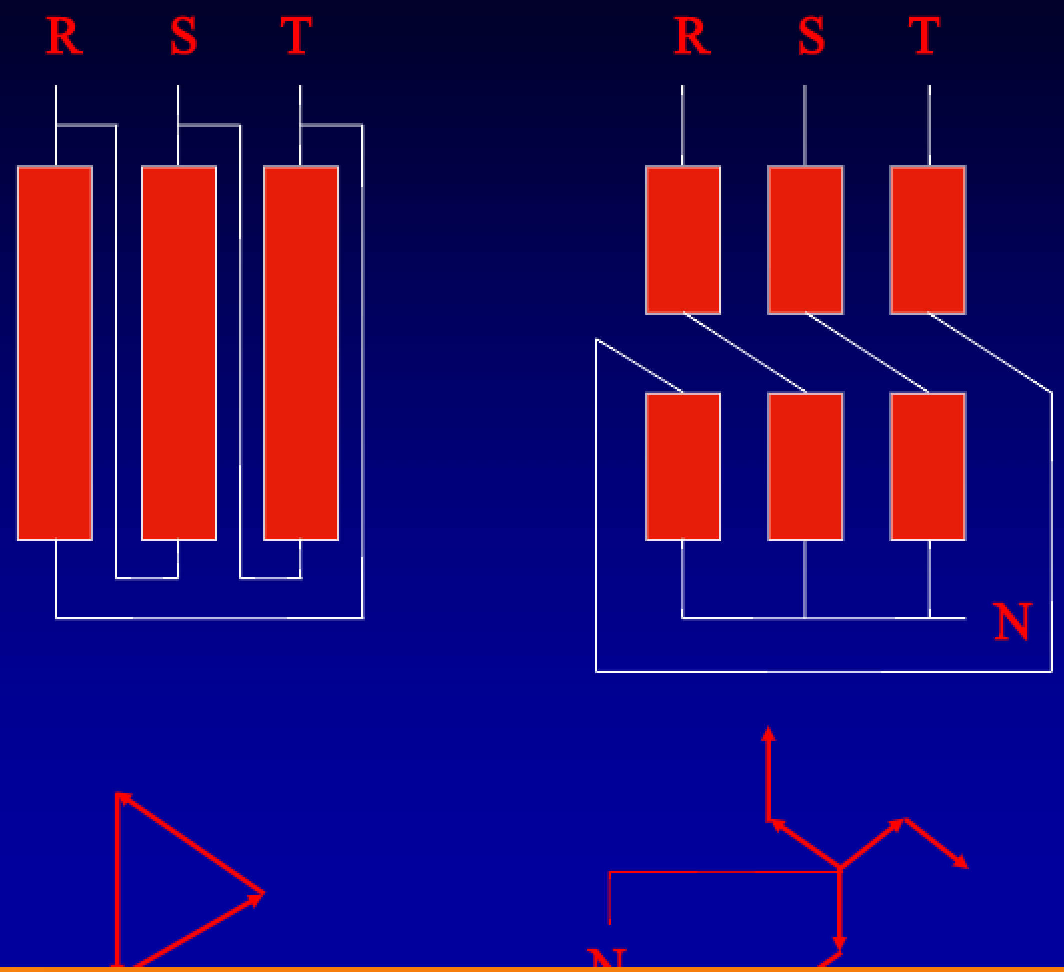
Third harmonic filters



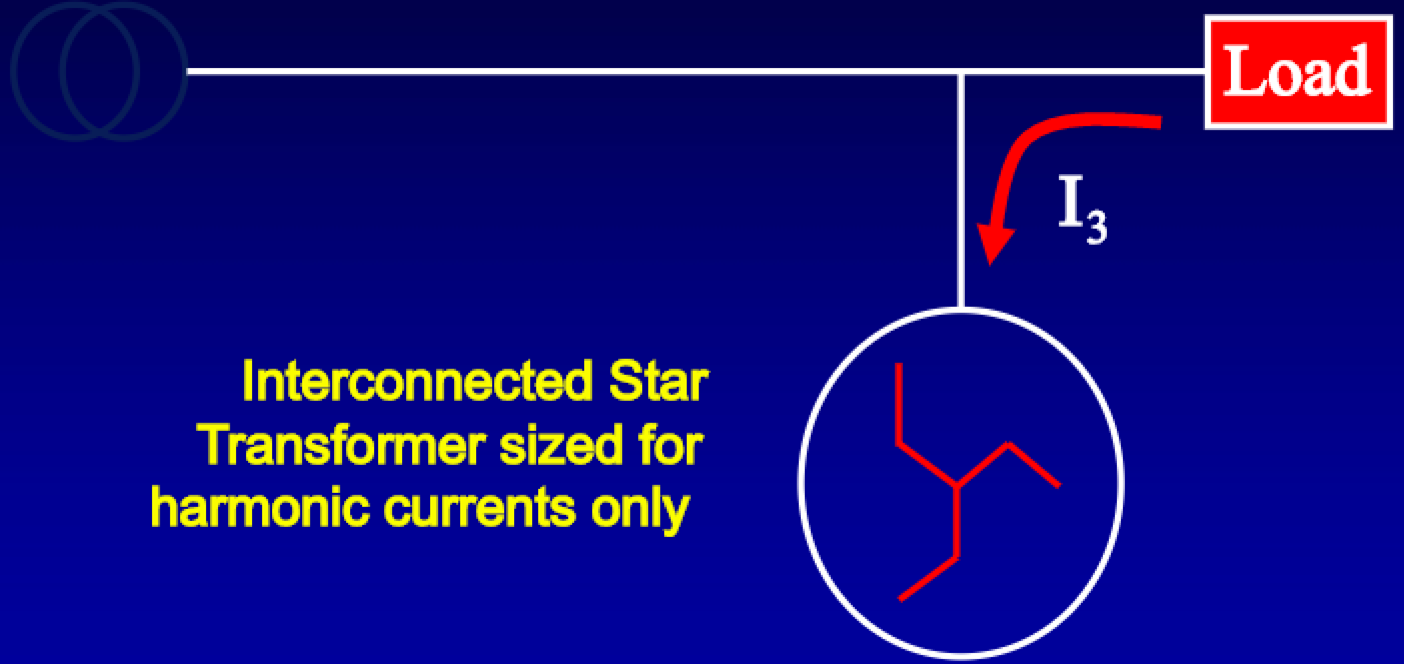
Third harmonic filters



Delta Interconnected-Star Transformer



Harmonic reduction transformers



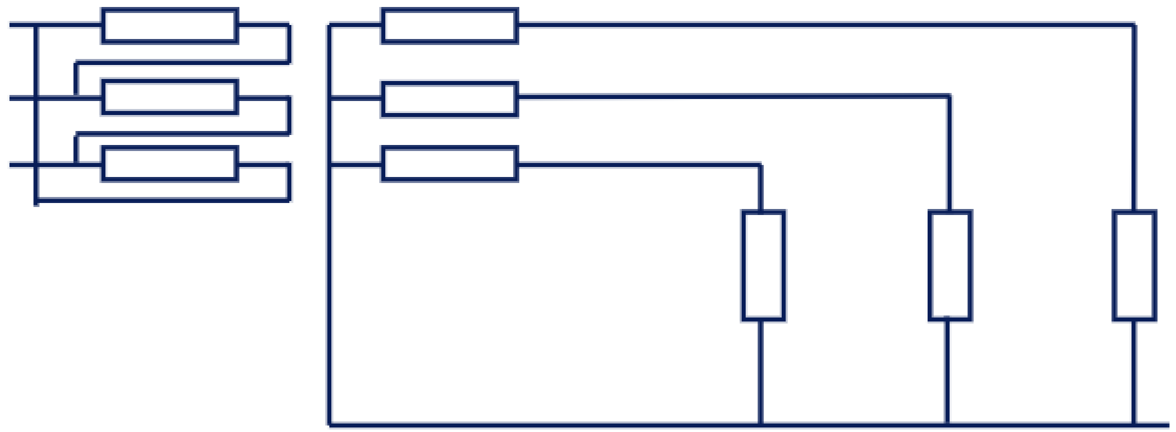
Interconnected Star Transformer sized for harmonic currents only

Isolating transformers

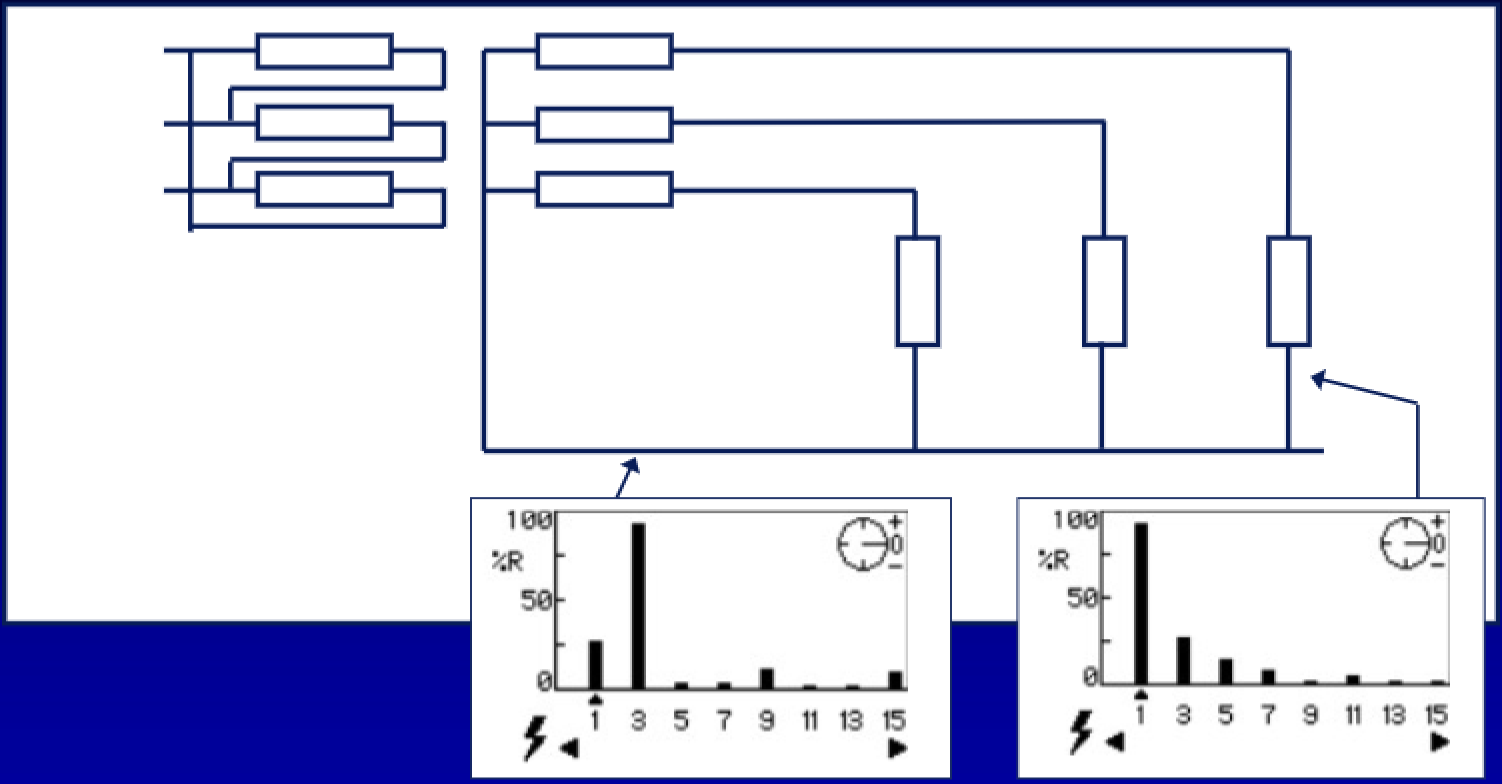
Delta-star isolating transformers reduce propagation of harmonic current into the supply.

- Transformers should be adequately rated to cope with the harmonics
- Although the transformer effectively establishes a new neutral, don't use half-sized neutrals
- Provide a well rated four wire feed so that the transformer can be isolated for service

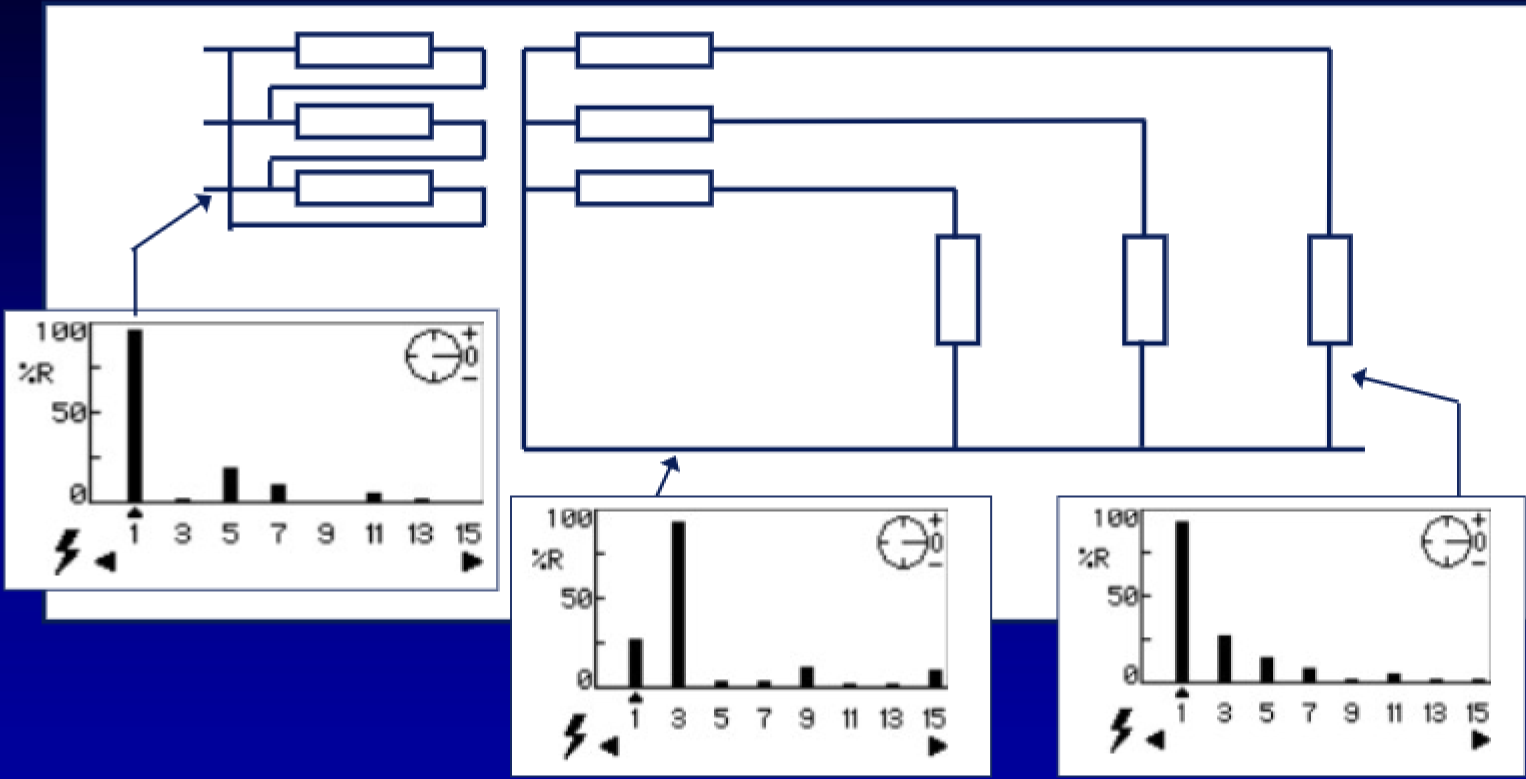
Isolating transformers



Isolating transformers



Isolating transformers



Active filters

- Where the harmonic profile is unpredictable or contains a high level of lower harmonics, active filters are useful
- Active harmonic conditioners operate by injecting a compensating current to cancel the harmonic current

Harmonic solutions

- Keep circuit impedances low
- Rate neutrals and multi-core cables generously - 1.73 to 2 times normal size
- Always use true RMS meters
- Provide a large number of separate circuits to isolate problem and sensitive loads
- Take harmonics into account when rating transformers
- Provide appropriate filtration where required

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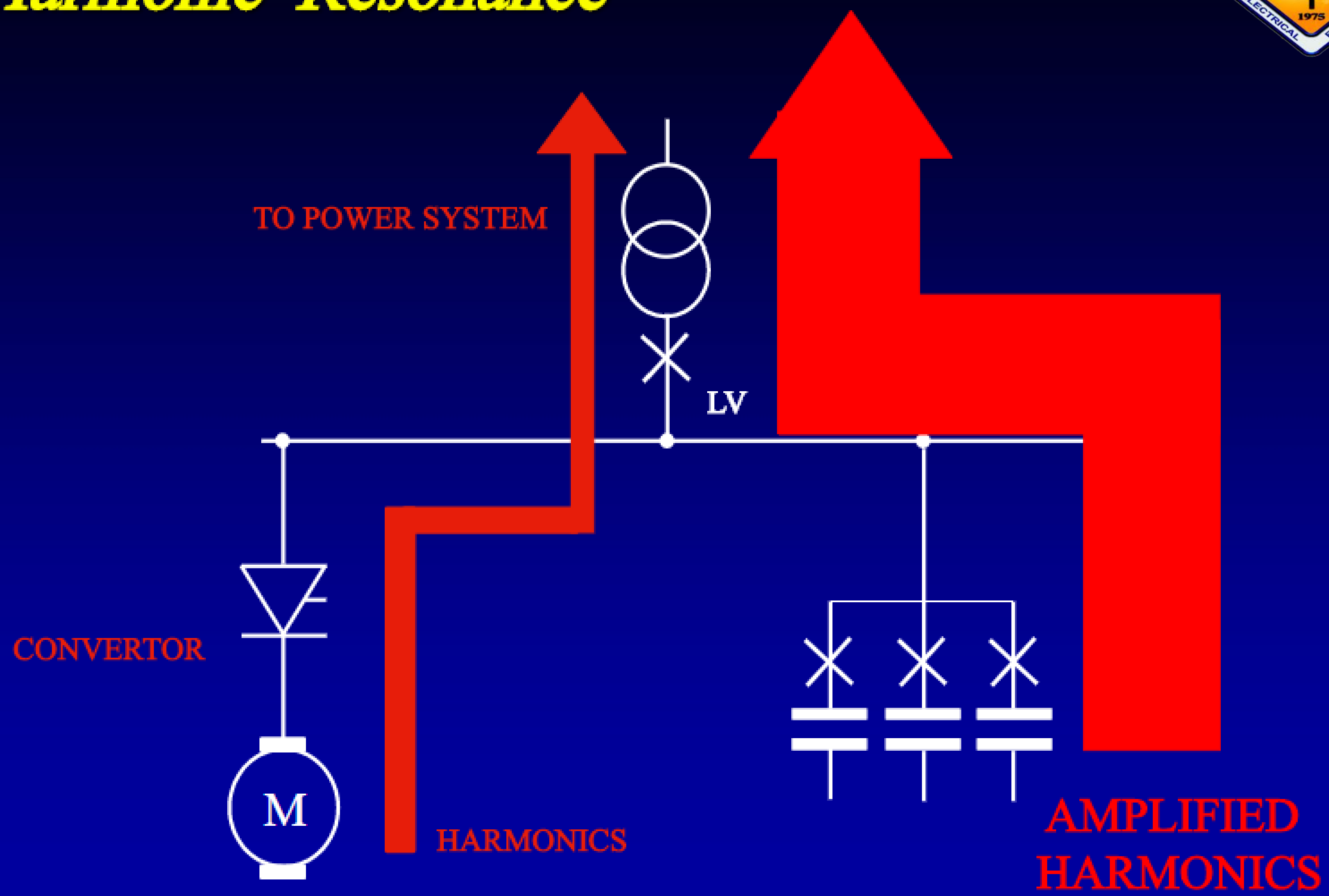
Power Factor Correction

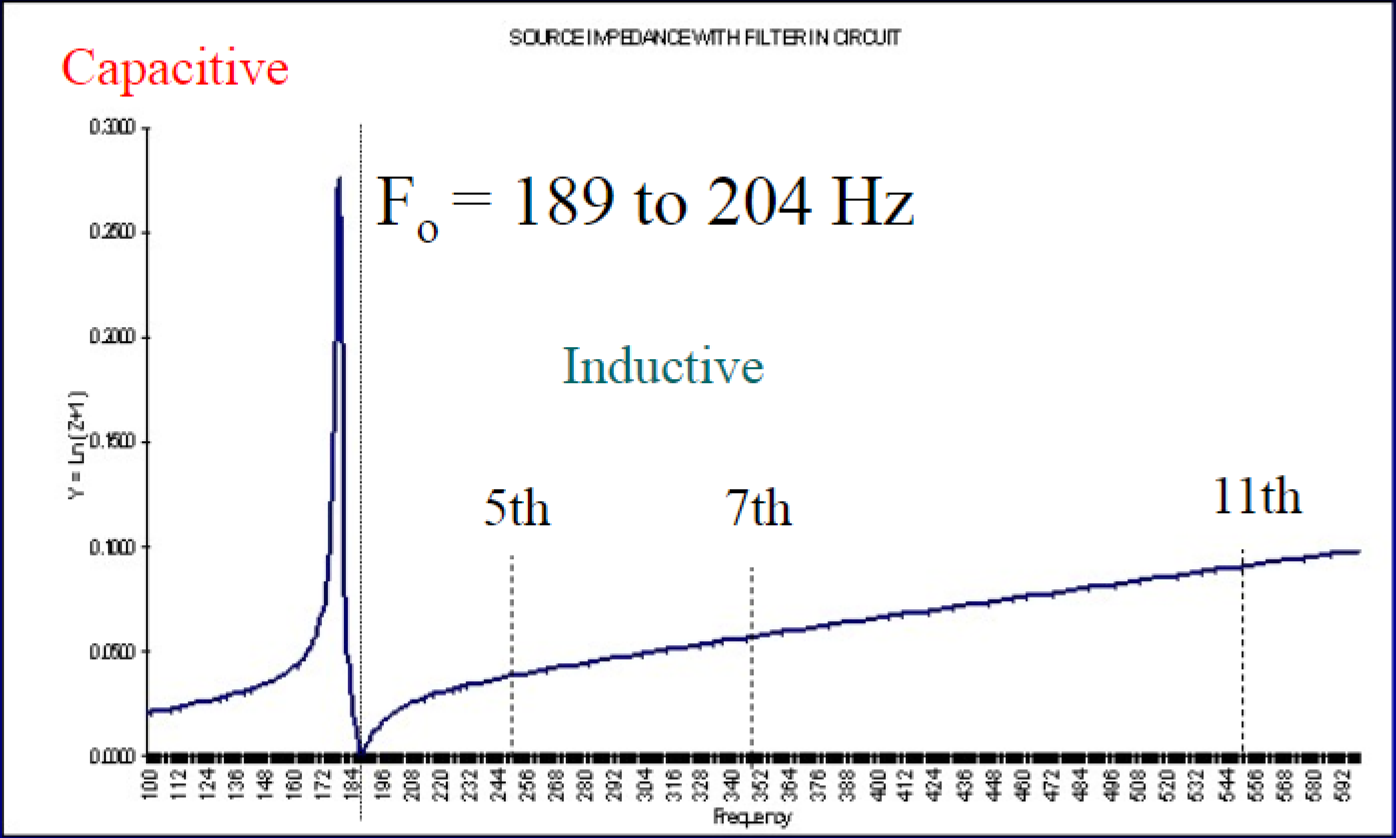
- Capacitor Discharge time required for standard Power Factor banks (1 minute)
- Rapidly switching loads require Zero crossing Thyristor or IGBT switched steps

e.g. Spot Welders
Lift motors
Cranes

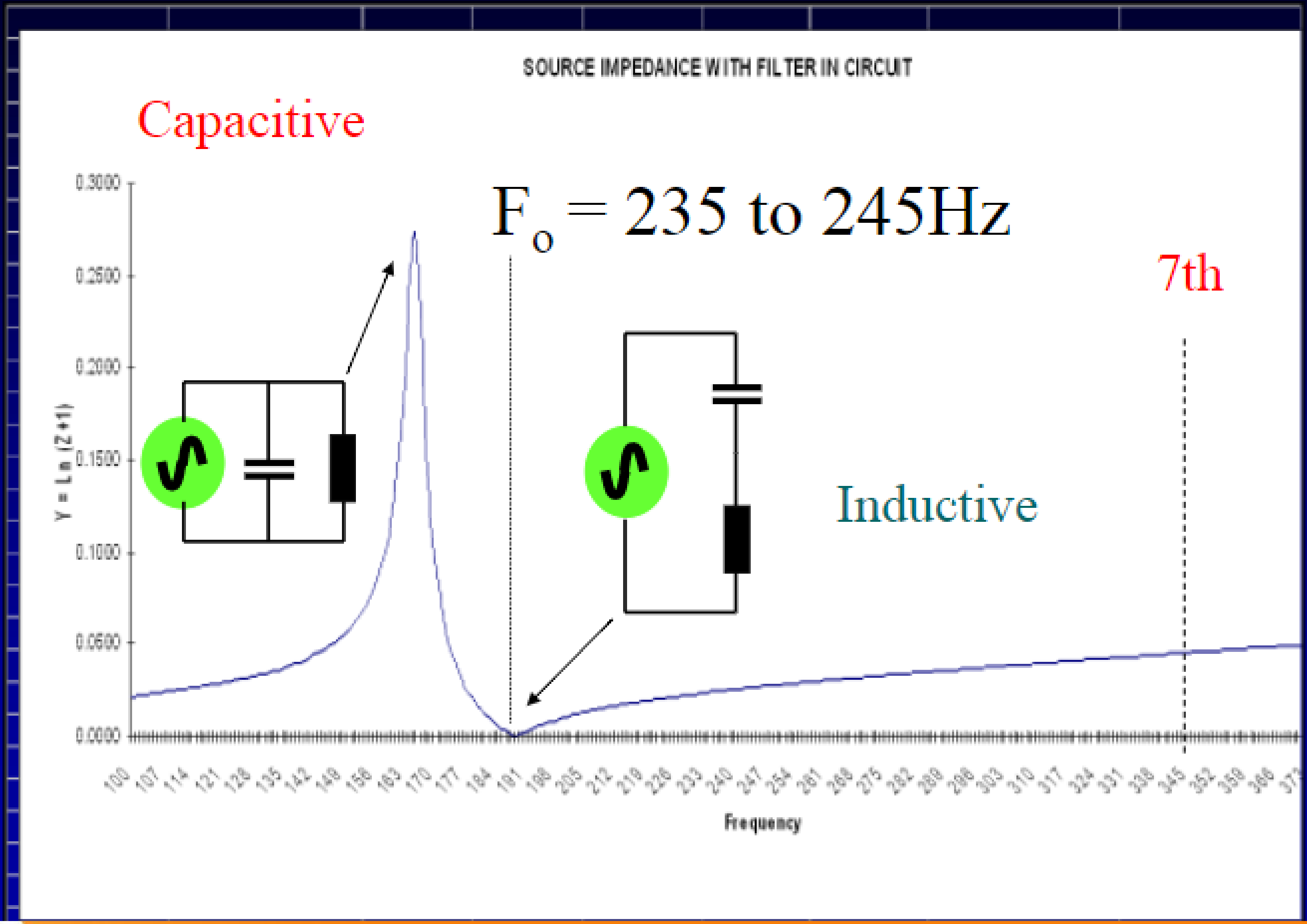
Harmonic Resonance



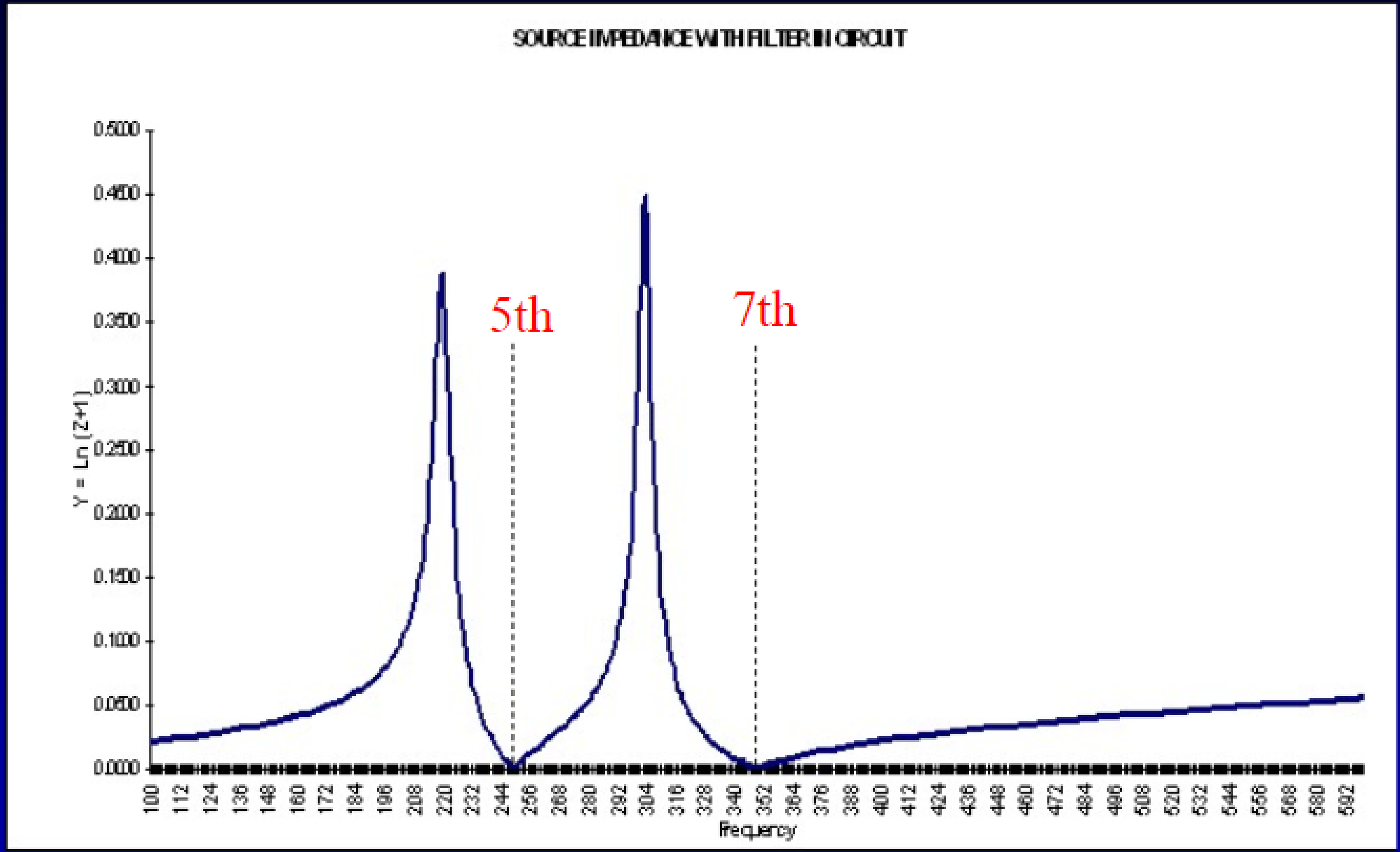
Detuned or Blocking Banks



Filter Banks - 5th Harmonic



Filter Banks 5th & 7th Harmonic



Thank you for listening !!!

METRO EAST
METRO MANILA REGION

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