Harmonic Issues in industry : Energy loss calculation:

PRACTICAL WAYS FOR SOLUTIONS

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POWER QUALITY

EXPECTATIONS AND PROBLEMS

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EXPECTED CONDITION OF POWER

- Good regulation and quality
- Sinusoidal waveform at 50 Hz
- Frequency variation within limits
- Minimum disturbance like
  - * Transient
  - * Sag and Swell
  - * Over and Under voltage
  - * Minimum interruptions
  - * Minimum waveform distortion – less EMI and RFI

VOLTAGE AND FREQUENCY VARIATION

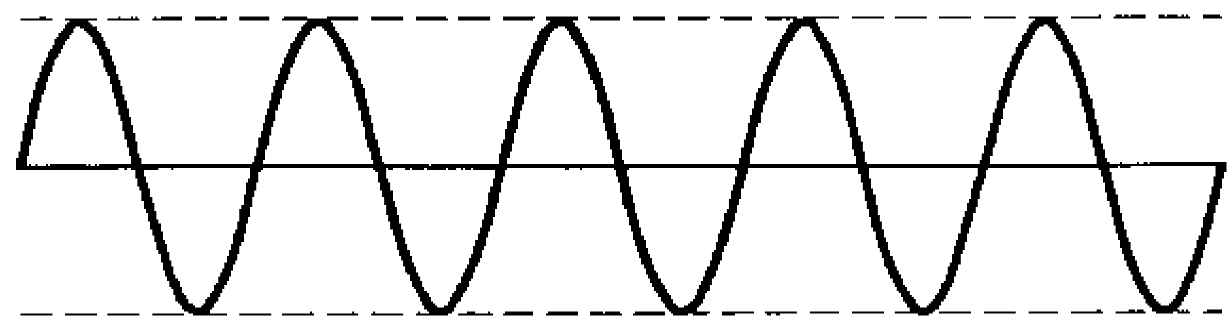
- Nominal voltages as per standards
  - Limitations as for as technically feasible
  - should be kept within limits I.e. +/- 10% of the adopted voltages
- Frequency: Adopted 50 Hz – variation within limits
- Harmonics – sinusoidal components of 50Hz - fundamental wave with frequencies, integral multiple of the fundamental –
  - should be within limits specified in IEE standards 519

Specified normal conditions for operation:

	Normal	Industrial
• Mean Voltage	415 Volts	
• Variation	± 6%	± 10%
• Frequency	50 HZ	
• Variation	± 3% ± 5%	
• Combined	± 6%	± 10%
• Ambient Temp	40°C	
• Altitude	1000M	

IDEAL VOLTAGE WAVE FORM AS EXPECTED

SINE WAVE FORM



A. Normal power supply.

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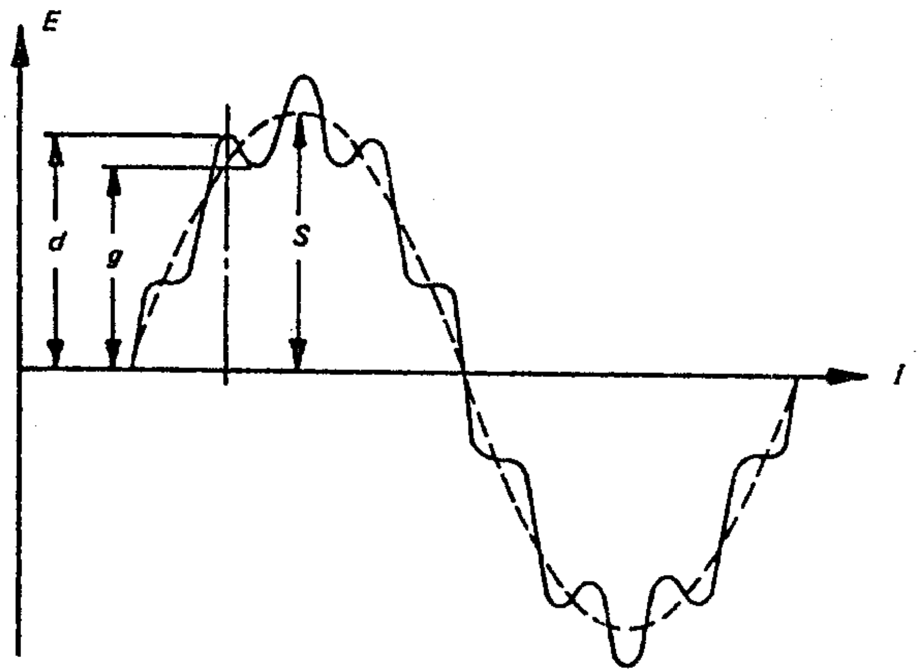
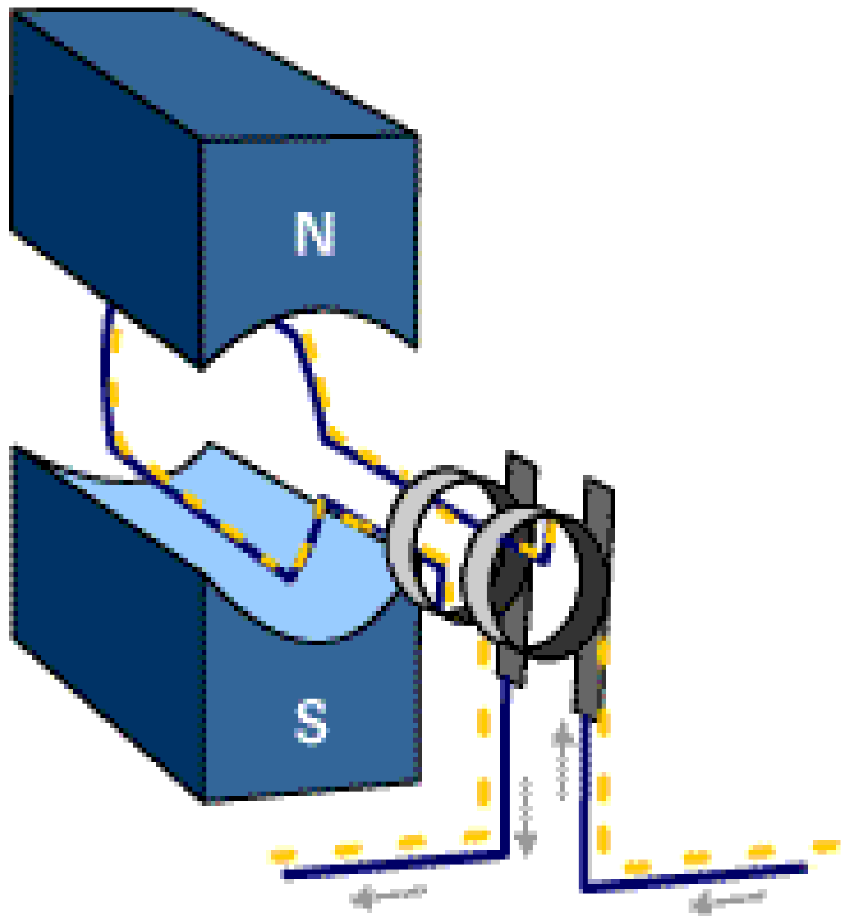
ACTUAL VOLTAGE WAVE FORM AS GENERATED

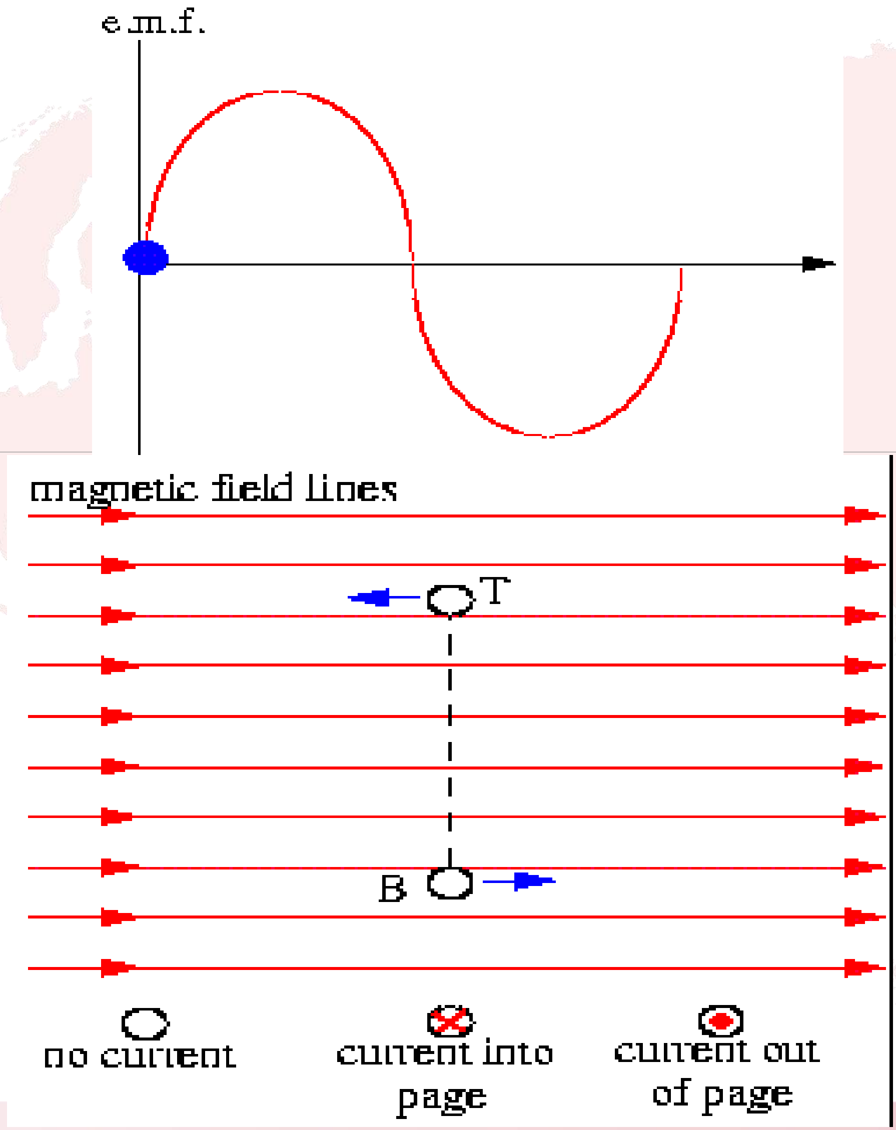


Generated voltage

- Voltage as generated by rotating machines is expected to be successive near sinusoidal waves
- A pure sinusoidal voltage is only conceptual quantity produced by an ideal AC generator
- Built with finely distributed stator and field windings that operates in uniform magnetic field

Production of Alternating Current




e.m.f.
magnetic field lines
T
B
no current
current into page
current out of page

Generated voltage

- In the practical AC generators neither of them are achieved
- Some deviations present causing harmonics
- For large generators, instantaneous deviation factor not to exceed 5% of the peak value, measured along the ordinates.
- Cycling up and down 50 times a second I.e. 50 Hz

DISTORTED WAVE FORMS

- Distorted voltage waveform can be caused
  - * by the consumer
  - * by utility

Findings by the Electric Power Research Institute:

* 80% originate from consumers industries / buildings
* 20% originated in the utility

TRANSIENTS

Surges or spikes caused by

- lightning
- Circuit breaker operations - switching OFF and ON of large loads

Transmission line faults like

- Earth faults and phase to phase faults

These upset computers, corrupt data, cause failures of electronic equipments

TRANSIENTS

Sags - Brief drop in voltage

- Caused by big motors starting etc
  - Cause starters, ASDs etc to drop out
  - Computers will lock up or lose memory

TRANSIENTS

Swell: A brief increase in normal voltage –

- caused by stopping of a large motor or dropping of heavy loads

    * May cause failure of electronic equipments like TV sets etc.

Over and Under voltage: Long term increases or decreases of normal voltage

- By overloaded transformers, feeders
- Inappropriate tap adjustment of transformers
- High source impedance

ELECTRICAL DISTURBANCES

Harmonics: regular distortion of the voltage waveform caused by,

* Non linear loads like power supplies of electronic equipments
* Discharge lamps control
* Thyristor drives
* Converts
* Induction furnaces and arc welders

May cause over heating of transformers, motors, cables etc.

ELECTRICAL DISTURBANCE

Interruption: Momentary power outage

* Caused by transmission equipment and line breakdowns, faults, cable punctures etc. causing feeder breaker to trip or fuse to blow
* May cause costly break downs of sensitive equipments, expensive interruptions of process especially chemicals, pharmaceuticals, fiber, glass and paper industries

ELECTRICAL DISTURBANCE

- **Noise - Electro Magnetic Interference (EMI)**

  * Caused by electric and magnetic fields emanated by transformers, ballast, and some electronic equipments.

  * Cause disturbance in TV screens, computer screens, etc.

ELECTRICAL DISTURBANCE

Noise: Radio Frequency Interference (RFI)

* High frequency electrical energy radiated by TV, radio transmitters, cell phones, electronic ballast, arcing sources, VSDs and power supplies
* Cause interference to control circuits

ELECTRICAL DISTURBANCE
By utilities

- Distortion from utility due to
  - * Switching surges
  - * Lightning surges
  - * Transmission line faults
  - * Cable faults
  - * Transmitted from neighboring consumers

ELECTRICAL DISTURBANCE
By Consumers

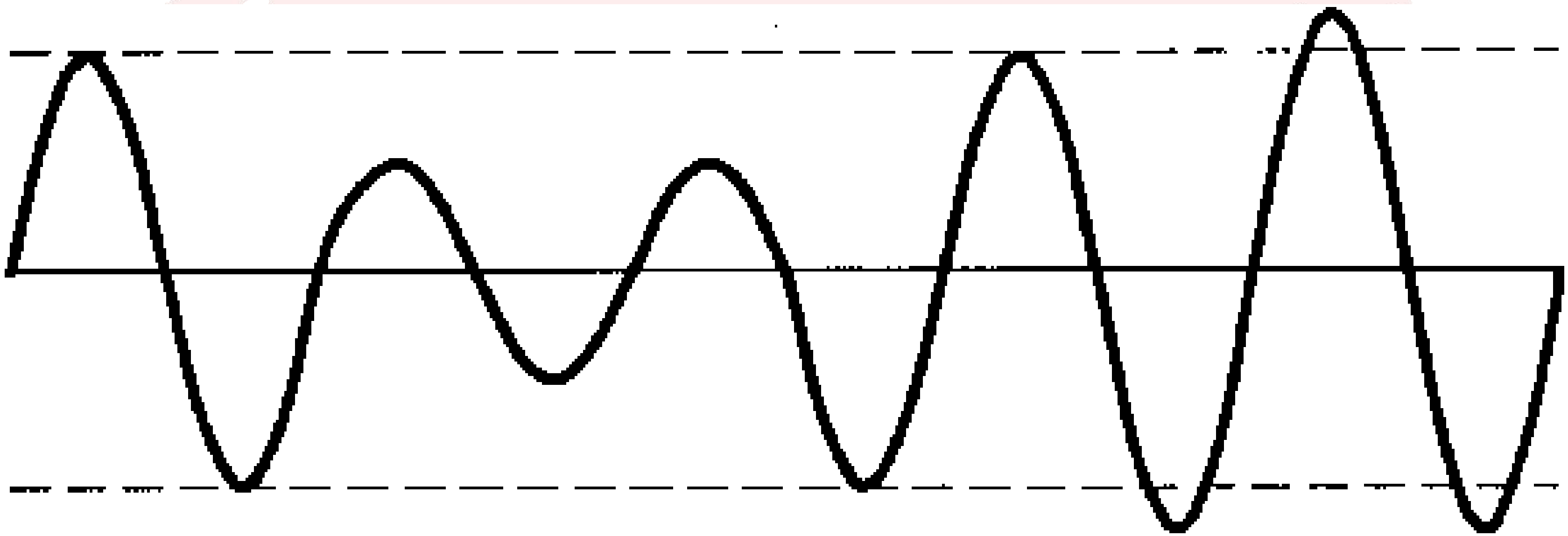
- Distortion caused by consumers:

  * Non linear loads like VSDs, Computers, Furnaces, Discharge lamps

  * Starting of heavy loads like large motors etc

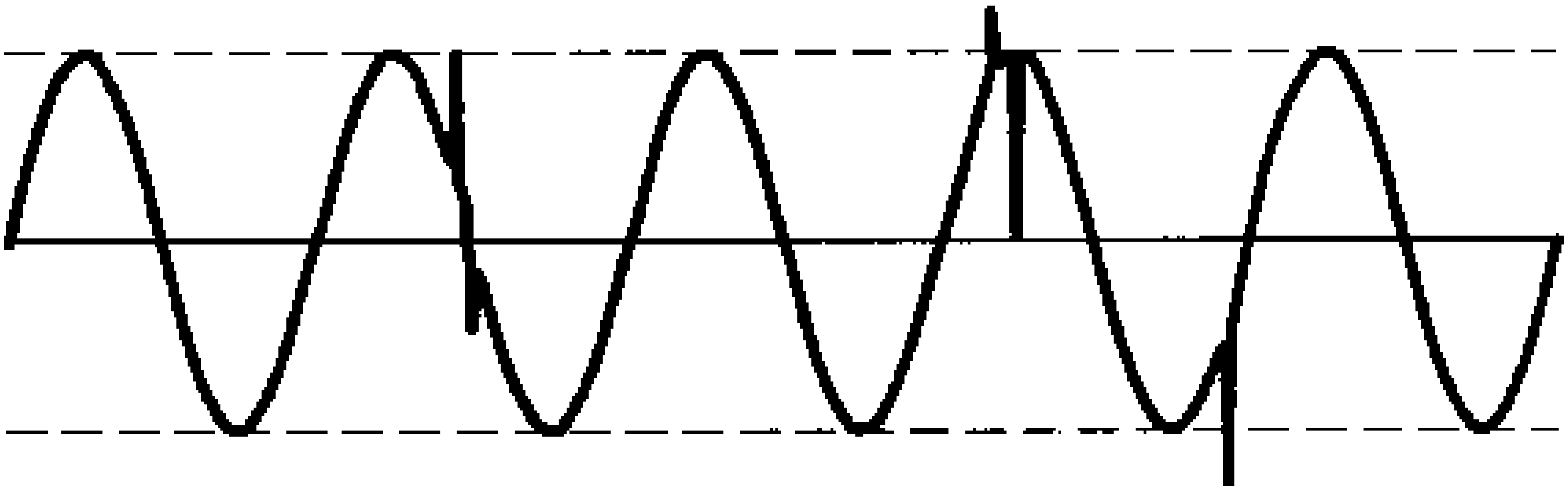
  * Tripping of heavy loads

VOLTAGE WAVEFORM WITH SAGS AND SWELLS



C. Sags and swells.

VOLTAGE WAVEFORMS WITH SPIKES AND IMPULSES



D. Surges, spikes and impulses.

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HARMONICS CREATED BY

NO LOAD CURRENT OF A STAR/STAR TRANSFORMER

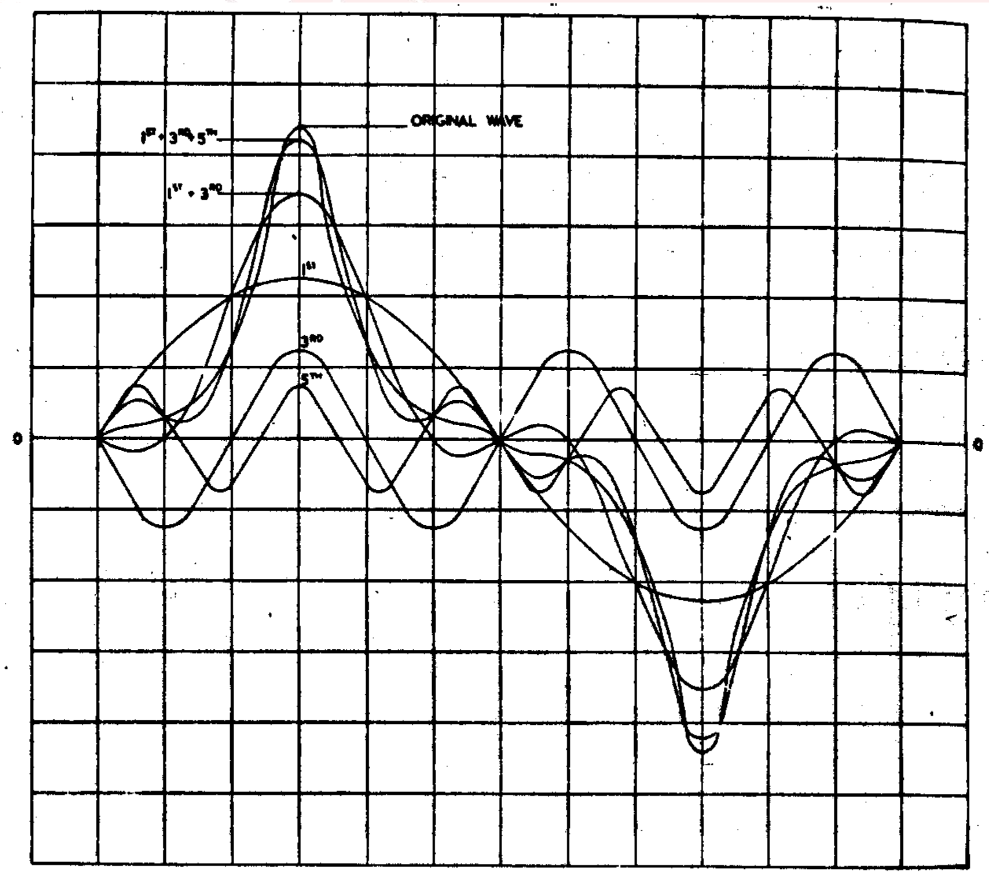

Figure 26.7 Harmonic analysis of peaked no-load current wave of Figure 26.3
$i_0 = 100 \sin\theta + 31{\cdot}5 \sin 5\theta + \ldots$

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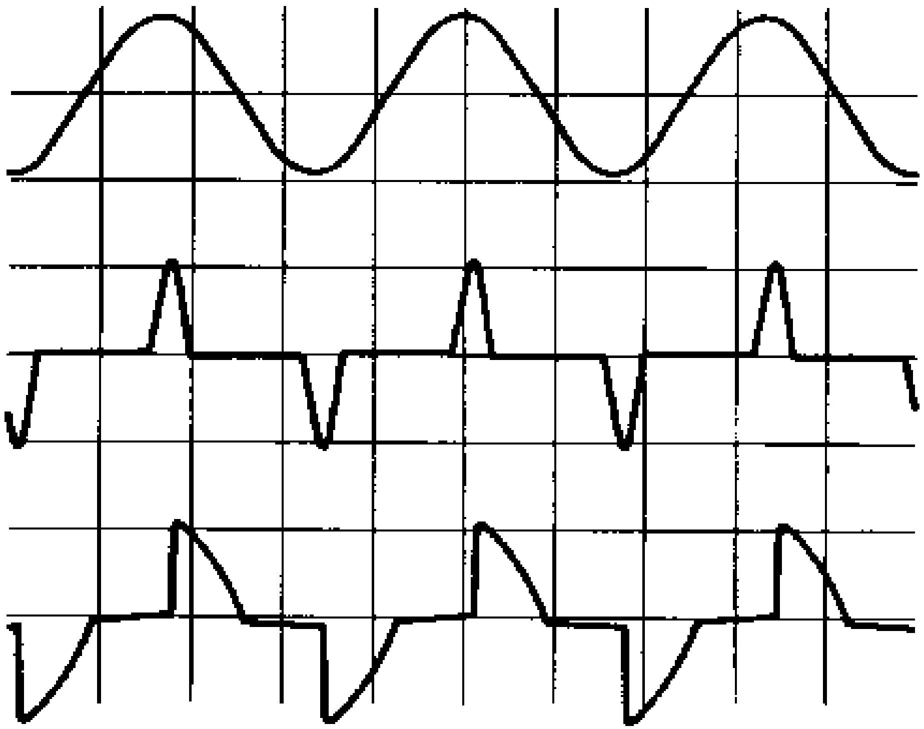
DISTURBANCE CAUSED BY CONSUMERS



Load current waveforms

Waveform distortion created by typical equipments by
1)Motors, inc lamps
2) computers and electronic equipments,
3)Dimmers and VSDs

Joseph Fourier
Mathematician

DISTORTED WAVEFORM AND HARMONICS

In 1822, the great French mathematician Joseph Fourier showed in a paper on heat conduction that:

- Any periodic function or any repetitive waveform can be resolved into:
- A fundamental component at the repetition frequency and
- A serious of integral components of that frequency
- Each with a particular amplitude and phase relationship relative to the fundamental
- So these distorted waveforms can be resolved into a number of waves of integral frequency,

DISTORTED WAVEFORM AND HARMONICS

These multiple waveforms are called "*Harmonics*"

- The current variation is not proportional to the voltage wave in each half cycle
- Such loads are called non linear loads
- Distorted waveform currents drawn by these loads create distorted voltage drops across the impedances in the circuit
- Even the power wave form is distorted

DISTORTED WAVEFORM AND HARMONICS

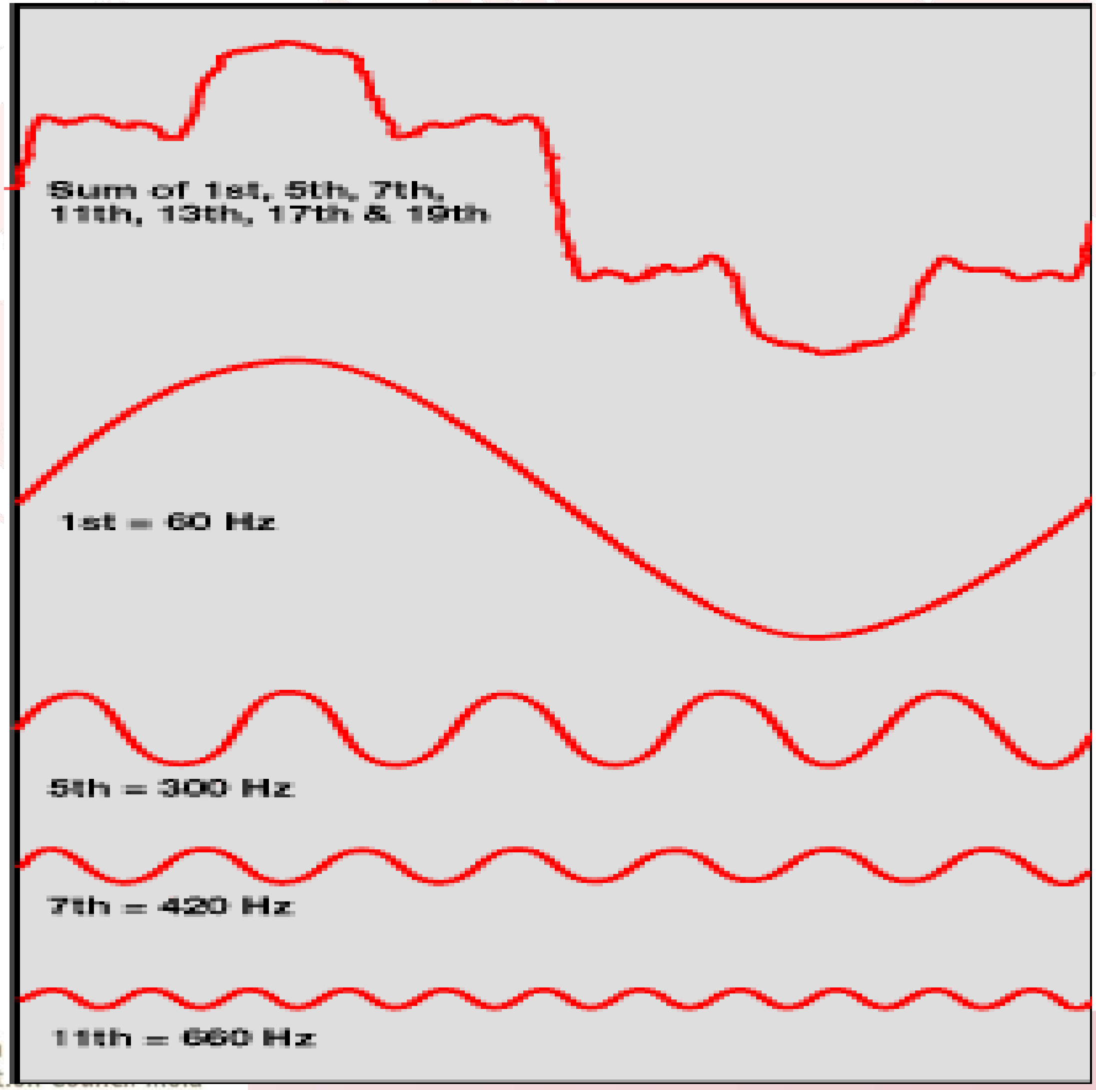
Definition per IEEE 519-1992

- *"A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency."*

WAVEFORM DISTORTION AND HARMONICS

- Sinusoidal waves - integral multiples of the fundamental 50 Hz waveform
- All complex waveforms - resolved into series of sinusoidal waves of various frequencies.
- complex waveform is the sum of a number of odd or even harmonics of lesser or greater value.
- They are referred to by their order, e.g.:
  - 1st harmonic = 50 Hz;
  - 5th harmonic = 250 Hz

WAVE FORM DISTORTION AND RESOLUTION IN TO HARMONICS (60Hz)

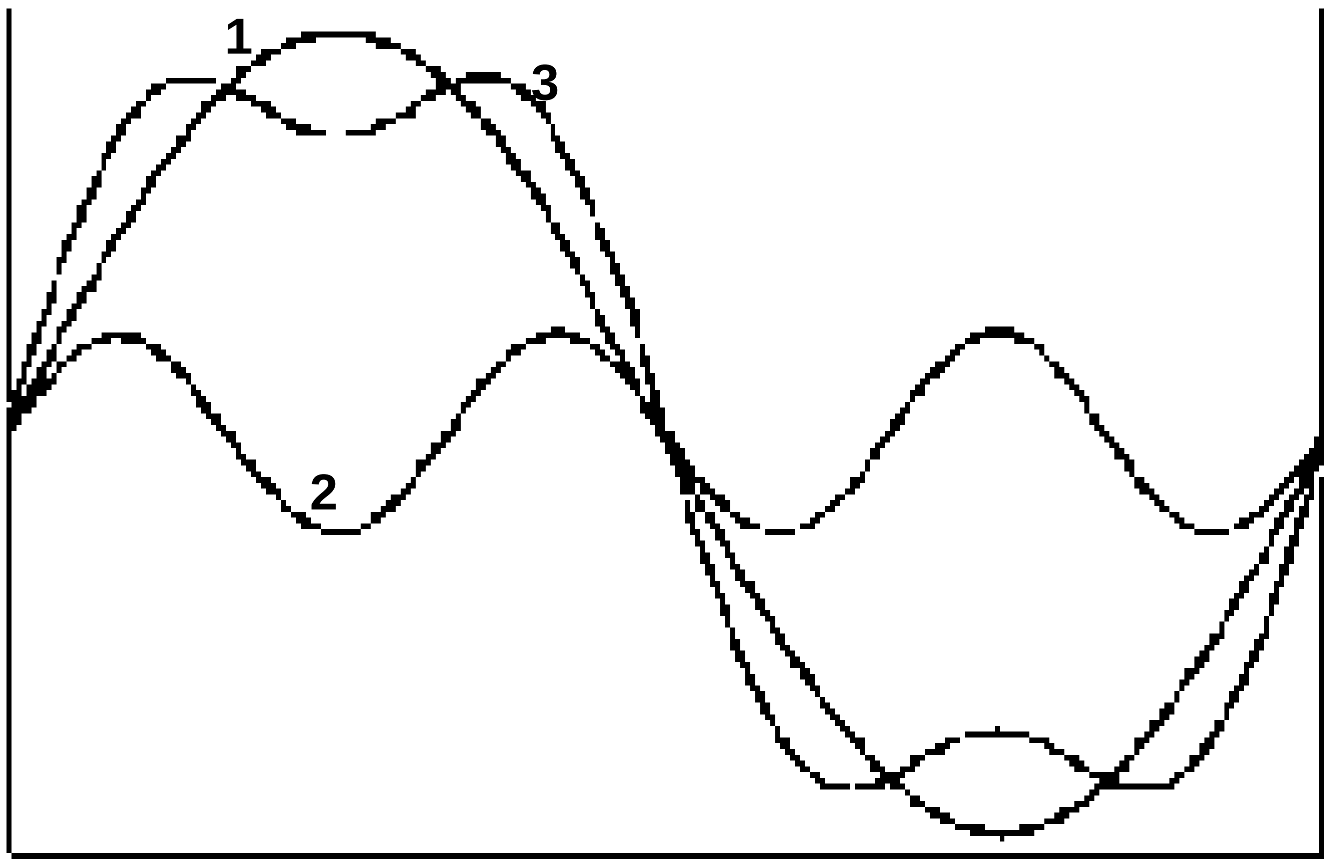


Distorted waveform

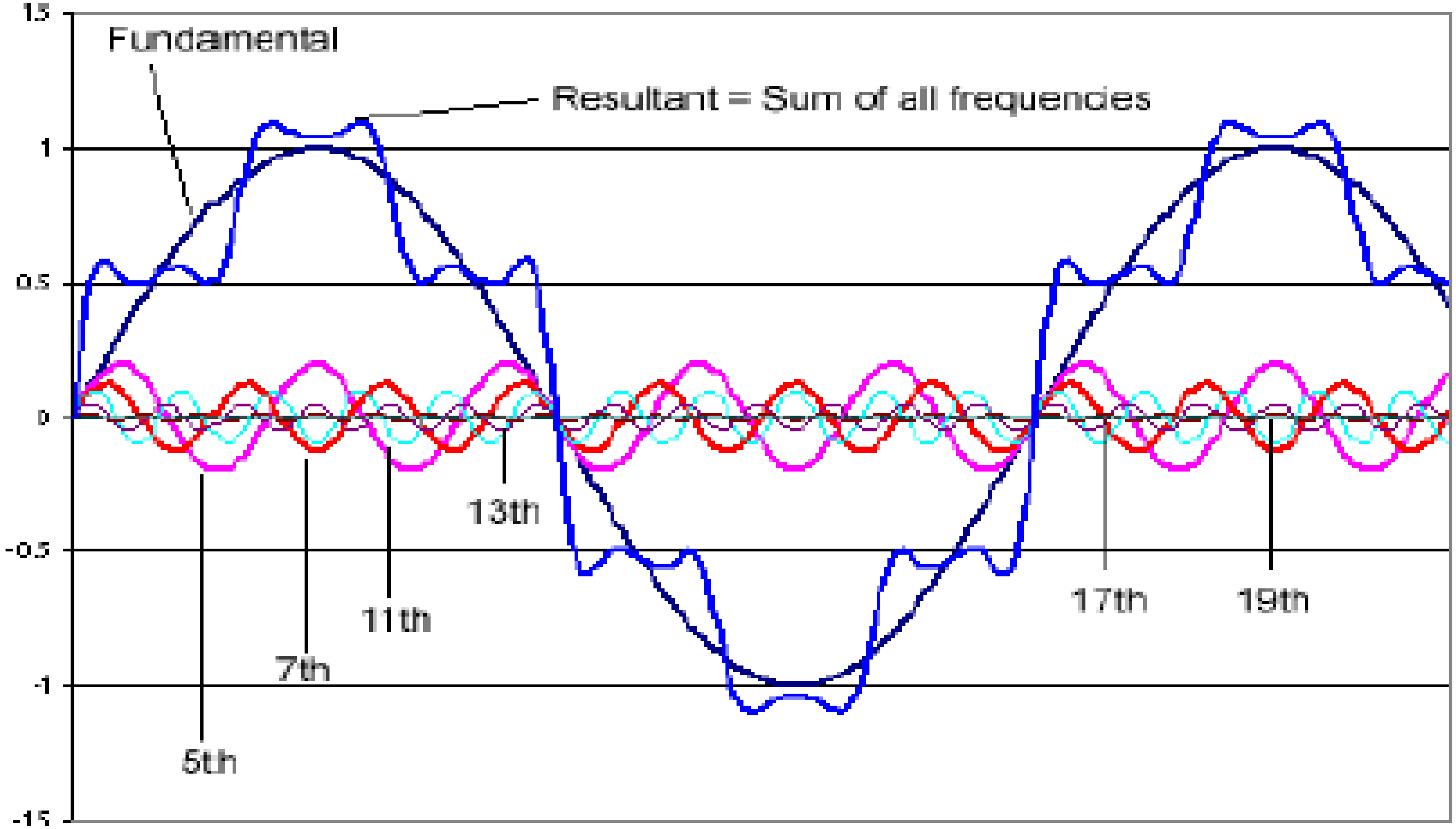
1.Fundamental frequency waveform

2. Third harmonic waveform

3. Distorted waveform



Harmonics currents injected by a typical VFD
5th,7th, 11th, 13th and so on.



HARMONIC CONTENT of a rectifier circuit

ORDER OF HARMONIC	TYPICAL PERCENTAGE OF HARMONIC CURRENT	
	6 PULSE	12 PULSE
1	100	100
5	20	-
7	14	-
11	9	9
12	8	8
17	6	-
19	5	-
23	4	4
23	4	

Reducing Harmonics

- By increased 'pulse count' by adding additional diode rectifier sections and
- By phase shifting three-phase transformers.

6 and 12 pulse systems will not meet harmonic limits of IEEE 519.
6-pulse VFD's generate harmonics distortion about 80% -
Typical THID is in the range of 16%.
18 pulse systems meet the IEEE 519 guidelines
Do not have any negative effects on system
Typical THID are less than 5%.

RECTIFICATION
THREE PHASE SIX PULSE

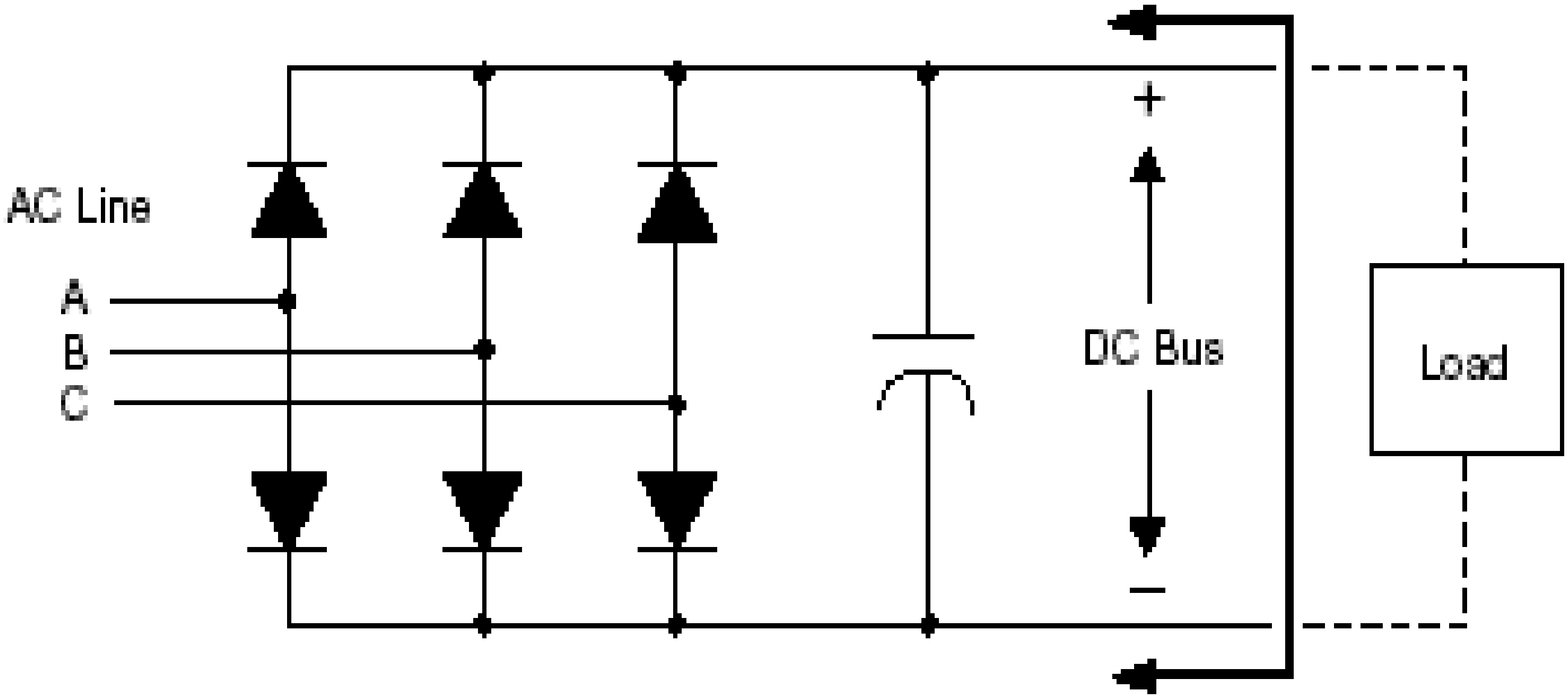


Figure 3 Typical Six-Pulse Front End Converter for AC Drive

RECTIFICATION

SIX PHASE TWELVE PULSE

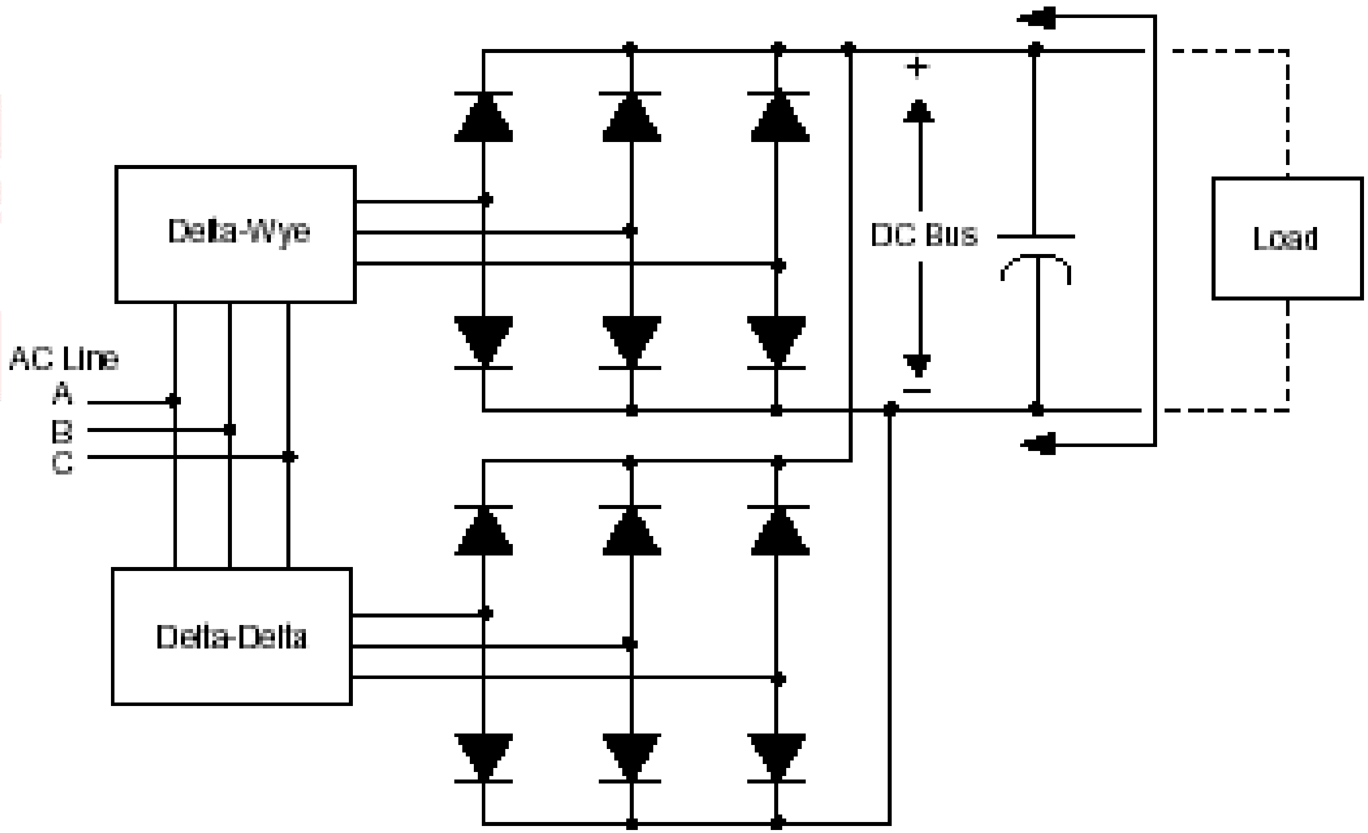


Figure 6 Typical Twelve-Pulse Front End Converter for AC Drive

MULTI PULSE RECTIFICATION SYSTEM

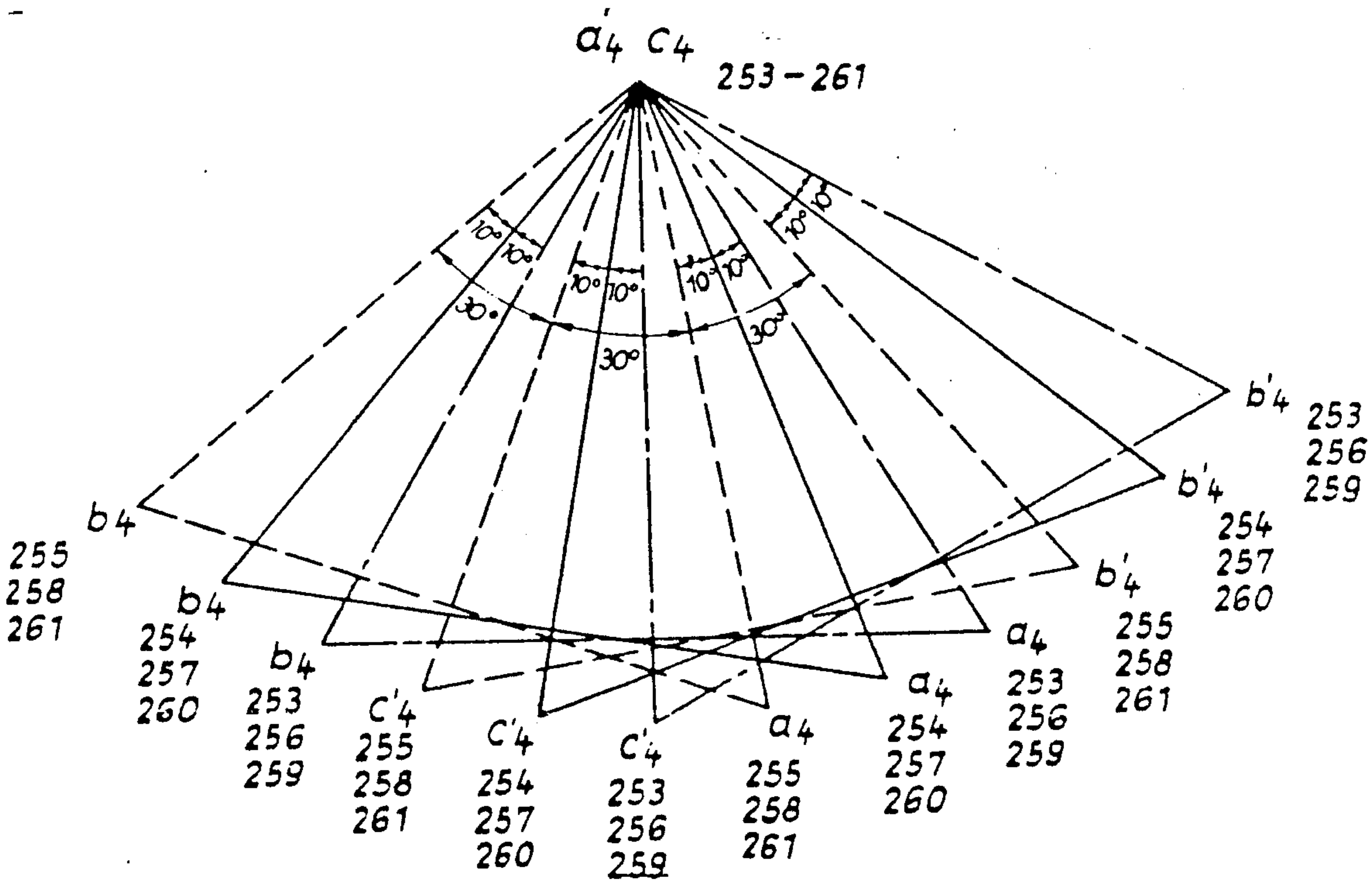
- For very huge capacity rectifiers, multi pulse transformers are employed
- The rectifier transformers have different secondary configurations
- For normal DC drive VFDs six phases are derived from a three phase system by a transformer having two secondaries, each connected in a delta and a star to get six phases or 12 pulses

MULTI PULSE RECTIFICATION SYSTEM

- In Tamil Nadu in a very large Pyro Electrolysis plant for manufacturing aluminum from alumina, a 36 phase transformer is used
- Each phase is split into nine secondary phases
- The secondaries have separate windings connected in forward zigzag,star, reverse zigzag to get 10 degree displacement within the 30 degrees displacement of main two secondary windings connected in delta/star

THIRTY SIX PHASE

RECTIFIER TRAN`SFORMER



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THIRTY SIX PHASE

RECTIFIER TRANSFORMER

$$b4_{255}-b4_{254} = \sqrt{300^2 + 300^2 - 2 \times 300 \times 300 \times \cos 10^\circ} \quad (0{,}9848) \quad = 52{,}3\ V$$

$$b4_{255}-b4_{253} = \sqrt{300^2 + 300^2 - 2 \times 300 \times 300 \times \cos 20^\circ} \quad (0{,}9397) \quad = 104\ V$$

$$b4_{255}-c4_{255} = \sqrt{300^2 + 303^2 - 2 \times 300 \times 303 \times \cos 30^\circ} \quad (0{,}866) \quad = 156\ V$$

$$b4_{255}-c4_{254} = \sqrt{300^2 + 303^2 - 2 \times 300 \times 303 \times \cos 40^\circ} \quad (0{,}766) \quad = 206\ V$$

$$b4_{255}-c4_{253} = \sqrt{300^2 + 303^2 - 2 \times 300 \times 303 \times \cos 50^\circ} \quad (0{,}6428) \quad = 255\ V$$

$$b4_{255}-a4_{254} = \sqrt{300^2 + 300^2 - 2 \times 300 \times 300 \times \cos 70^\circ} \quad (0{,}342) \quad = 344\ V$$

$$b4_{255}-a4_{253} = \sqrt{300^2 + 300^2 - 2 \times 300 \times 300 \times \cos 80^\circ} \quad (0{,}1736) \quad = 385\ V$$

$$b4_{255}-c4_{255} = \sqrt{300^2 + 303^2} \quad = 426\ V$$

$$b4_{255}-c4_{254} = \sqrt{300^2 + 303^2 - 2 \times 300 \times 303 \times \cos 100^\circ} \quad (-0{,}1736) \quad = 462\ V$$

$$b4_{255}-c4_{253} = \sqrt{300^2 + 303^2 - 2 \times 300 \times 303 \times \cos 110^\circ} \quad (-0{,}342) \quad = 494\ V$$

Problems Created by Harmonics

- Failure of capacitors, blowing of capacitor fuses, blowing of expensive thyristor fuses.
- Excessive heating - transformers, motors, fluorescent lighting ballasts, etc.
- Nuisance tripping of circuit breakers, blown fuses
- TRIPLENS: the 3rd harmonic currents add up in neutral; neutral conductors TO BE derated.
- Noise from harmonics: erroneous operation of control system components
- Damage to sensitive electronic equipment
- Electronic communications interference

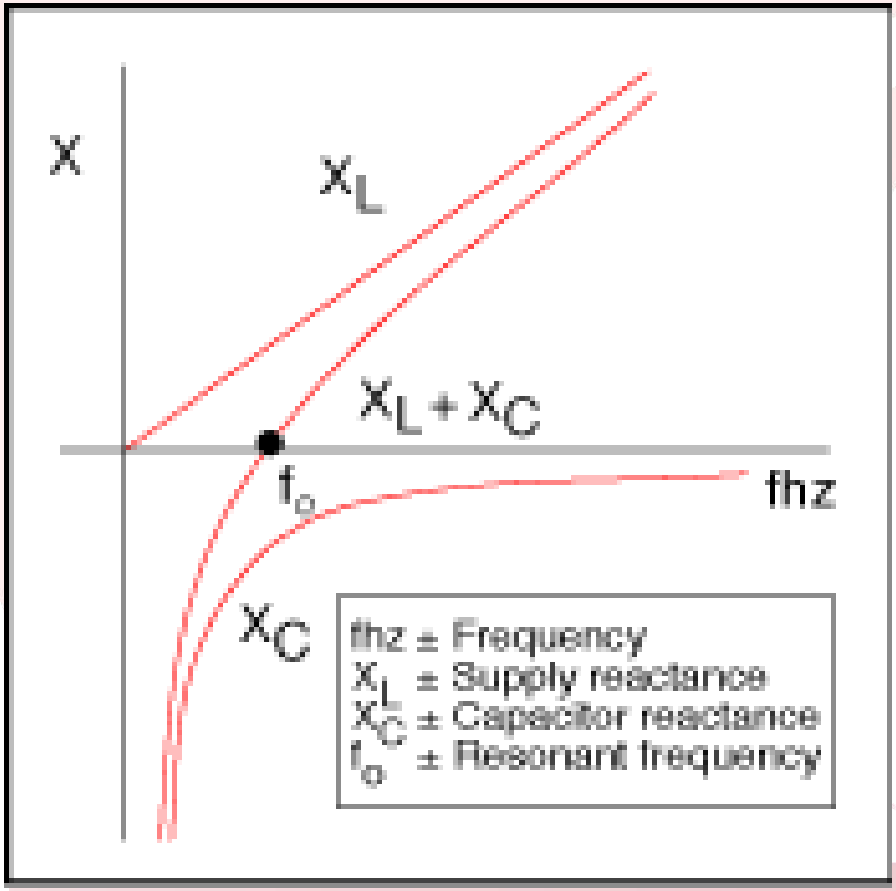
OTHER EFFECTS OF HARMONICS

- Incorrect meter readings,
- Nuisance tripping of zero sensing circuits,
- Motor bearing failure,
- Power factor correction system’s fuse blowing,

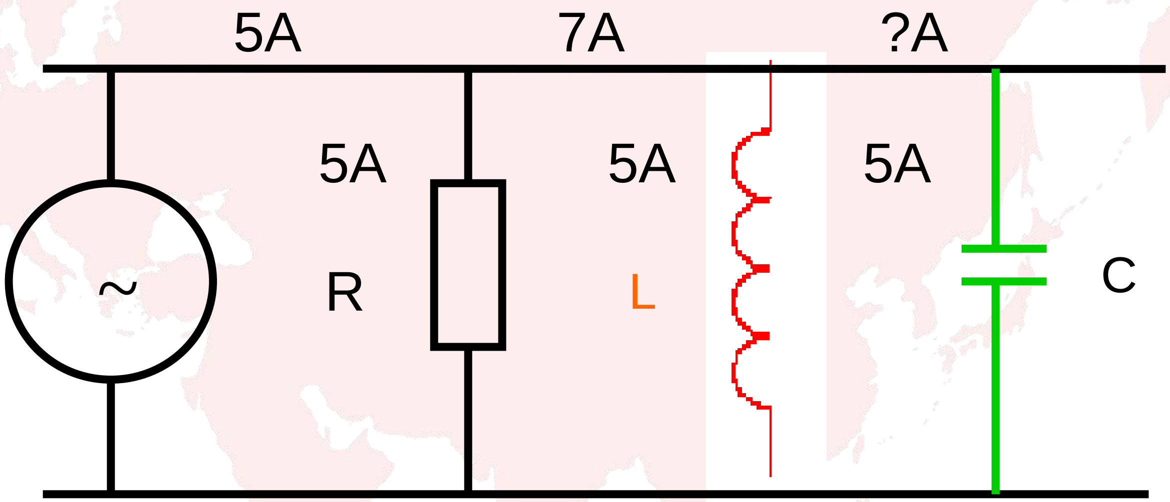
Cause many problems; most goes undetected until the equipment fails.

HARMONIC RESONANCE

At resonant frequency capacitor reactance and supply reactance are equal.



HARMONIC RESONANCE



Power factor correction capacitors may cause parallel resonance with the supply.

In such condition,

- one of the harmonics generated by a non linear load
- will circulate large harmonic currents between supply network and the capacitor equipment..
- will add to the harmonic voltage in the network
- cause increased voltage distortion.
- higher voltage across the capacitor and excessive current through all capacitor components.
- resonance concerned are 5th, 7th, 11th and 13th harmonics for 6 pulse systems.

ESTIMATING HARMONIC LEVELS

Details of electrical system required:

- Source transformer KVA and %Z or source fault current.
- Isolation transformer KVA and %Z (if present).
- Total installed kW or Amps of Linear Loads.
- Total installed kW or Amps of VFD driven loads.
- Details of installed mitigating devices.(Reactors, Filters etc)
- Information about the harmonics generated by other loads connected to the same PCC.

Harmonic resonance

- Nonlinear loads in a power distribution system creates harmonic currents that flow throughout the power system.
- Power system inductive reactance increases, capacitive reactance decreases as the harmonic order increases or the frequency increases
- At a given harmonic frequency, the inductive and capacitive reactances are equal.
- This is called the parallel resonant point.
- Every system with a capacitor has a parallel resonant point.

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Harmonic resonance

h_R is the parallel resonant frequency harmonic order,

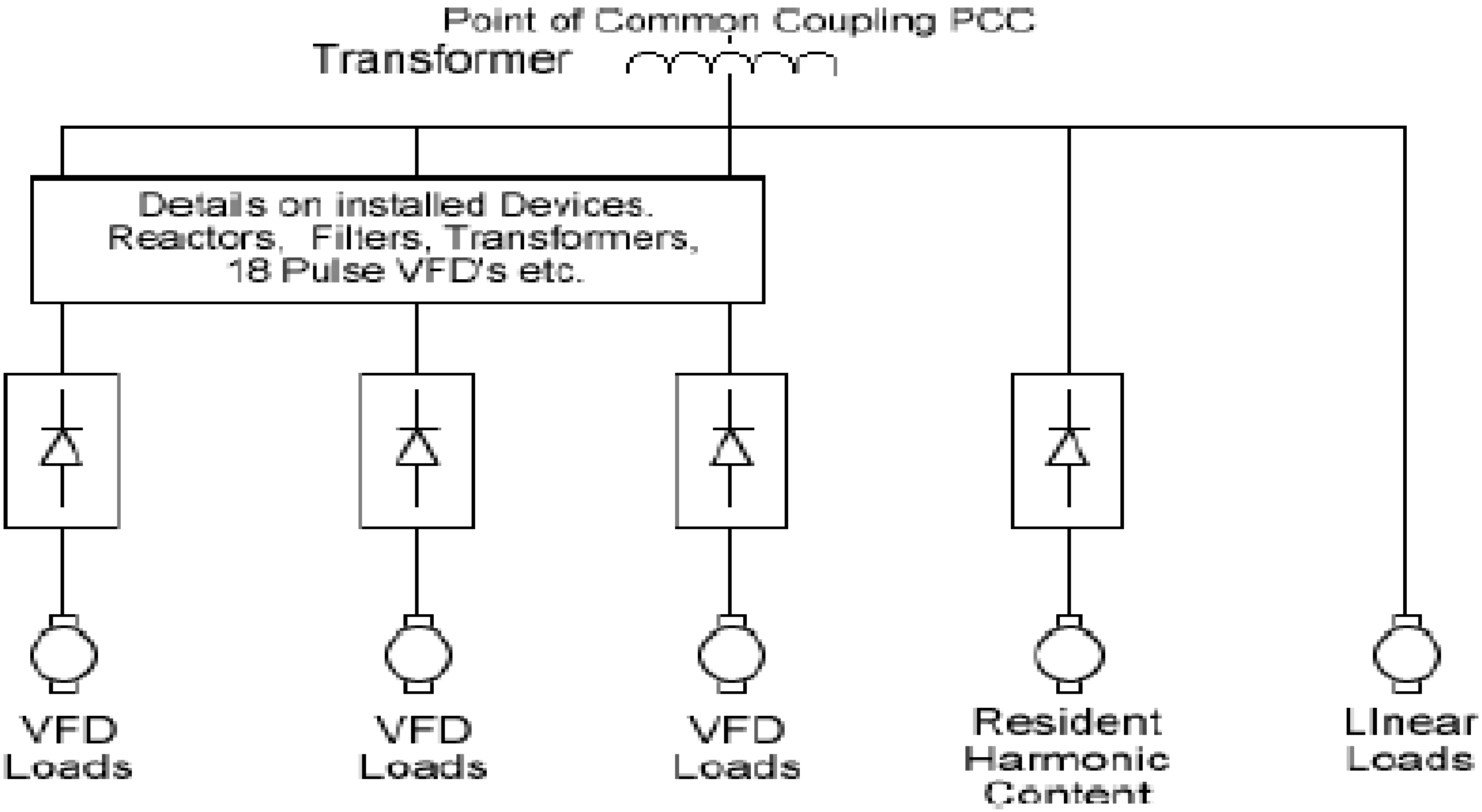
MVA_{SC} is the source impedance in MVA at the bus of interest,

and

$MVAR_{CAP}$ is the 3-phase rating in MVA of the capacitor bank.

$$h_R = \sqrt{\frac{MVA_{SC}}{MVAR_{CAP}}}$$

Single line diagram of the electrical system

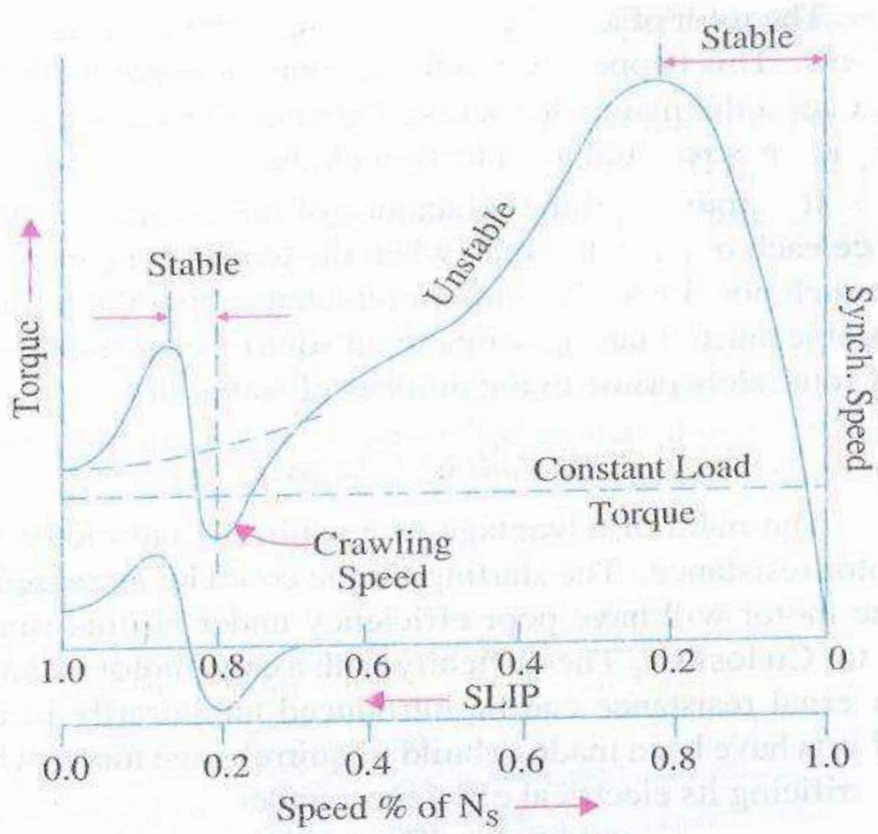


ELECTRICAL METERING

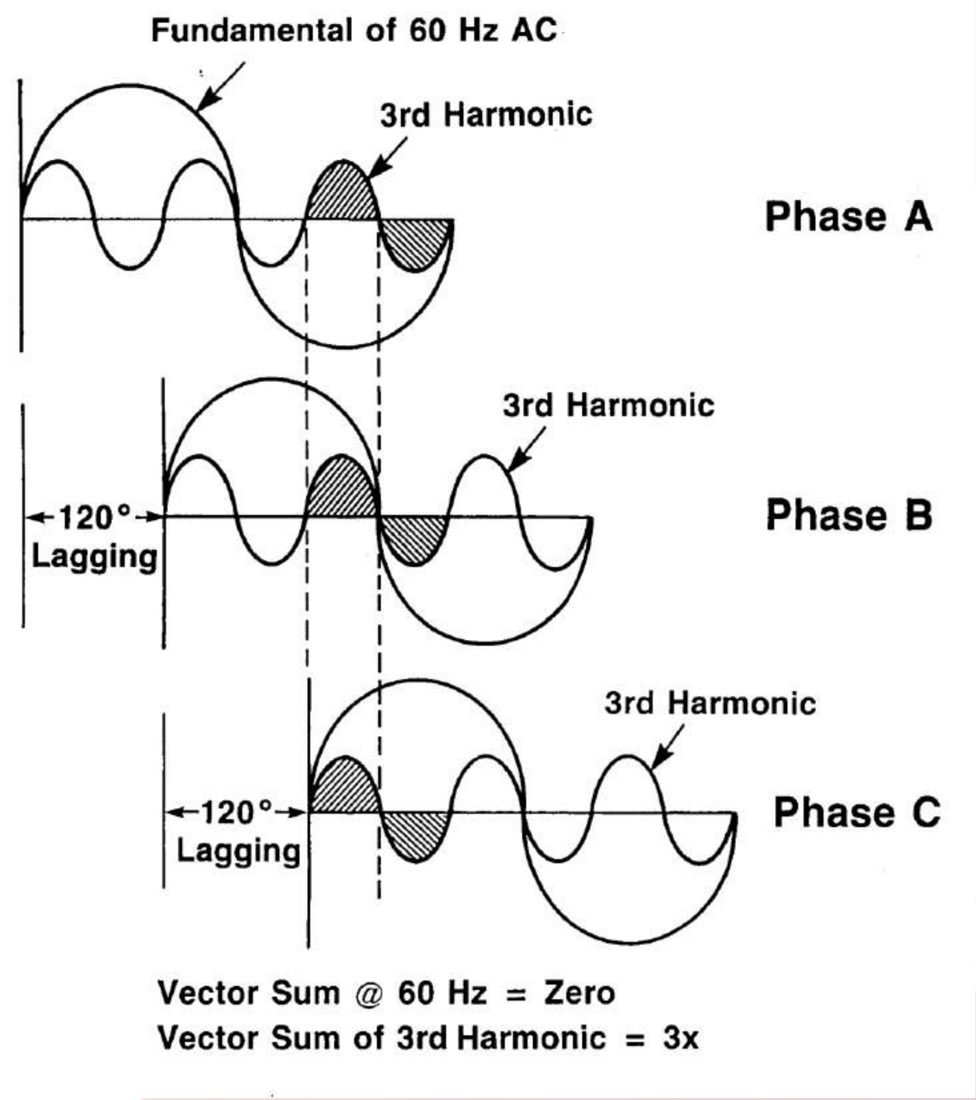
Induction disc type-integrating energy meters:

- Not capable of recording the harmonic power drawn:
- Some of the harmonics create negative torque.
- May not include the harmonic power drawn;
- Also affect the actual fundamental frequency energy drawn

Crawling of an induction motor due to harmonics



Third harmonics – neutral current

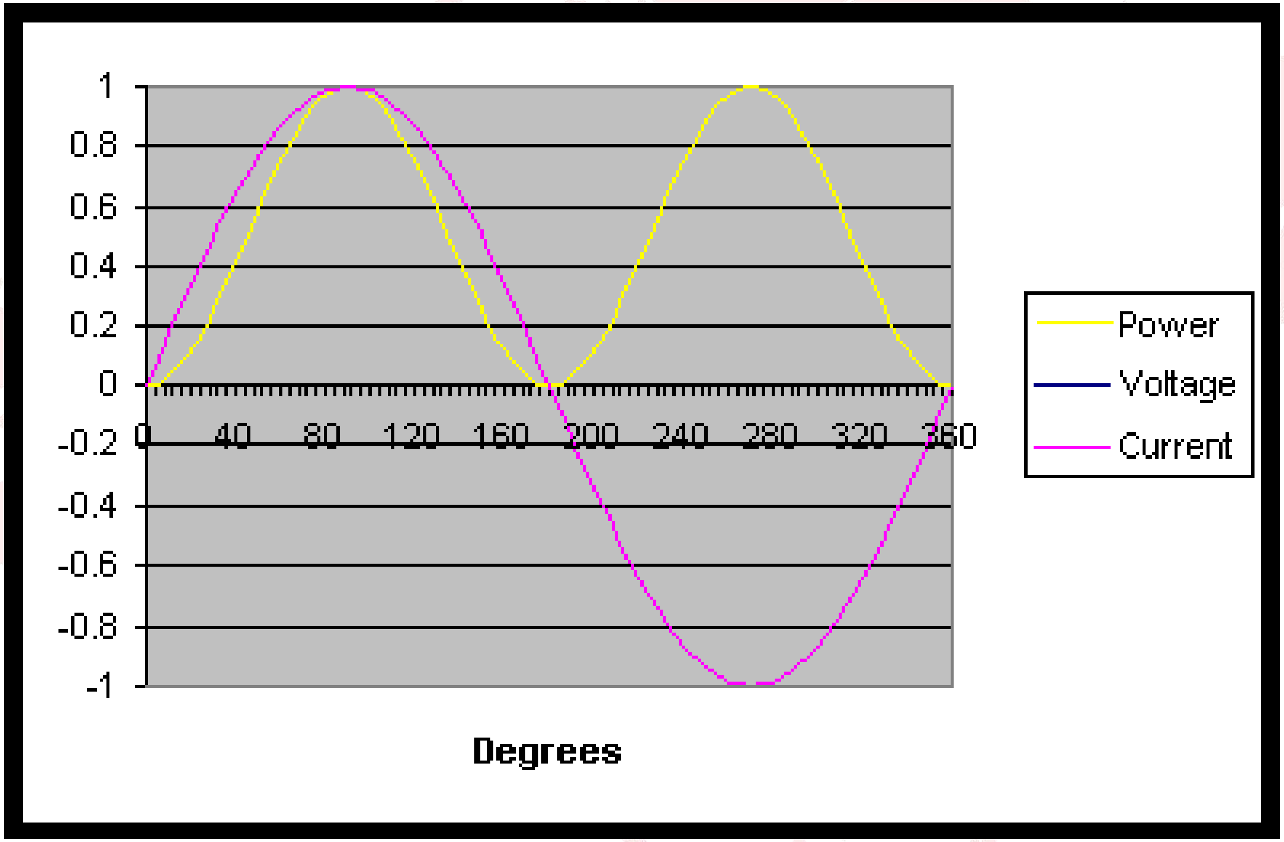


Harmonics are expected to exist; so are to be managed.

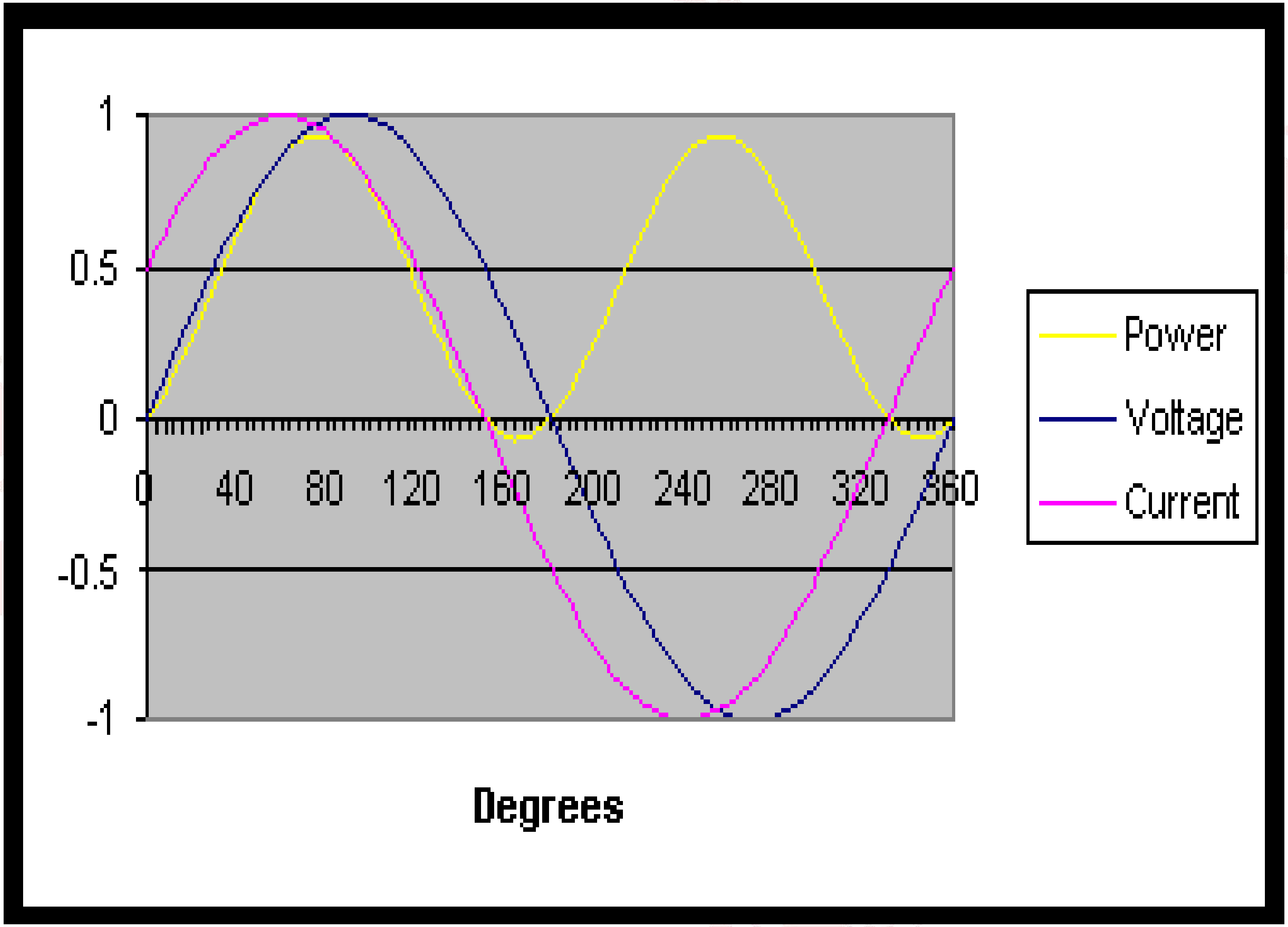
- Can be mitigated, to a certain level, but may be quite expensive.
- To a great extent, can be managed by selecting equipments to satisfactorily function in harmonic environments.

CONCLUSION

- It is not possible always to expect power quality to be as expected
- The problems are to be understood and managed.
- As far as possible the consumer should strive hard to limit harmonics developed in his installation, limit them at the point of common coupling
- This will greatly avoid polluting the power distribution system



1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
40
80
120
160
200
240
280
320
360
Degrees
Power
Voltage
Current


1
0.5
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Degrees
Power
Voltage
Current