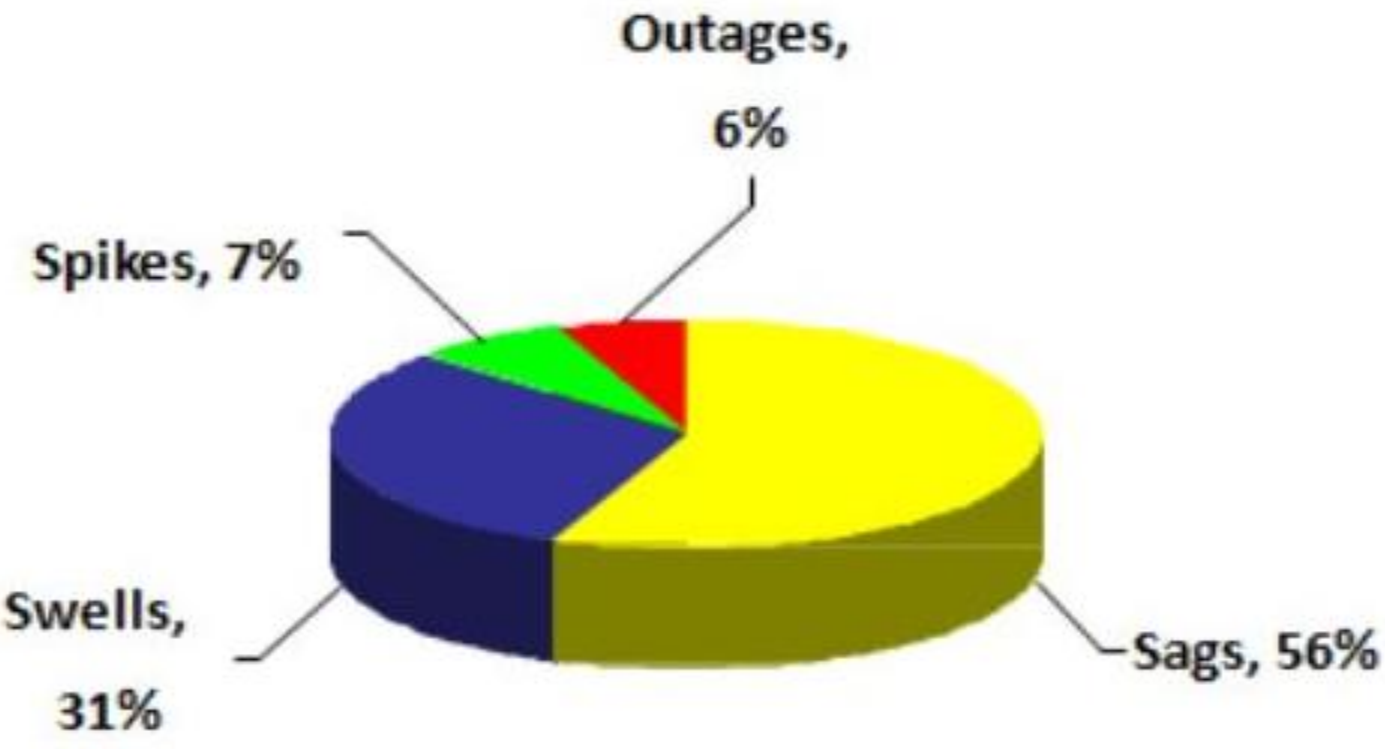
POWER QUALITY,HARMONICS &HARMONIC INDICES

- Introduction
- Types of Power Quality Disturbances
- Voltage Sag
- Transients
- Short & Long Duration Voltage Variation
- Voltage Imbalance
- Wave form Distortion
- Voltage flicker

- IEEE Defines Power quality as the ability of a system or equipment to function satisfactorily in its Electro magnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.
- Power Quality is defined as the Electrical Networks or Grids ability to supply a clean & stable power supply.
- The term Power Quality Disturbance is defined as any deviation from the ideal voltage or current waveform magnitude or frequency

Major PQ Problems



Swells

System fault conditions

Switching on a large capacitor bank

Switching off a large load

Sags (Dips)

Associated with system faults

Switching of heavy loads

Starting of large motors

Why is Power Quality Important?

- Low power quality contributes to **high energy cost** and rising energy and production disturbances.
- Voltage sag and swell can cause sensitive **equipment to fail,shutdown and create a large current unbalance**.
- **Reliability:** Uninterrupted power supply to the service sectors
- The **performance o**f electronic devices (semiconductor devices) is directly linked to the power quality level

TYPES OF POWER QUALITY DISTURBANCES

1. Voltage sag (or Dip)

Description:

A decrease of the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0.5 cycle to 1 minute

Causes:

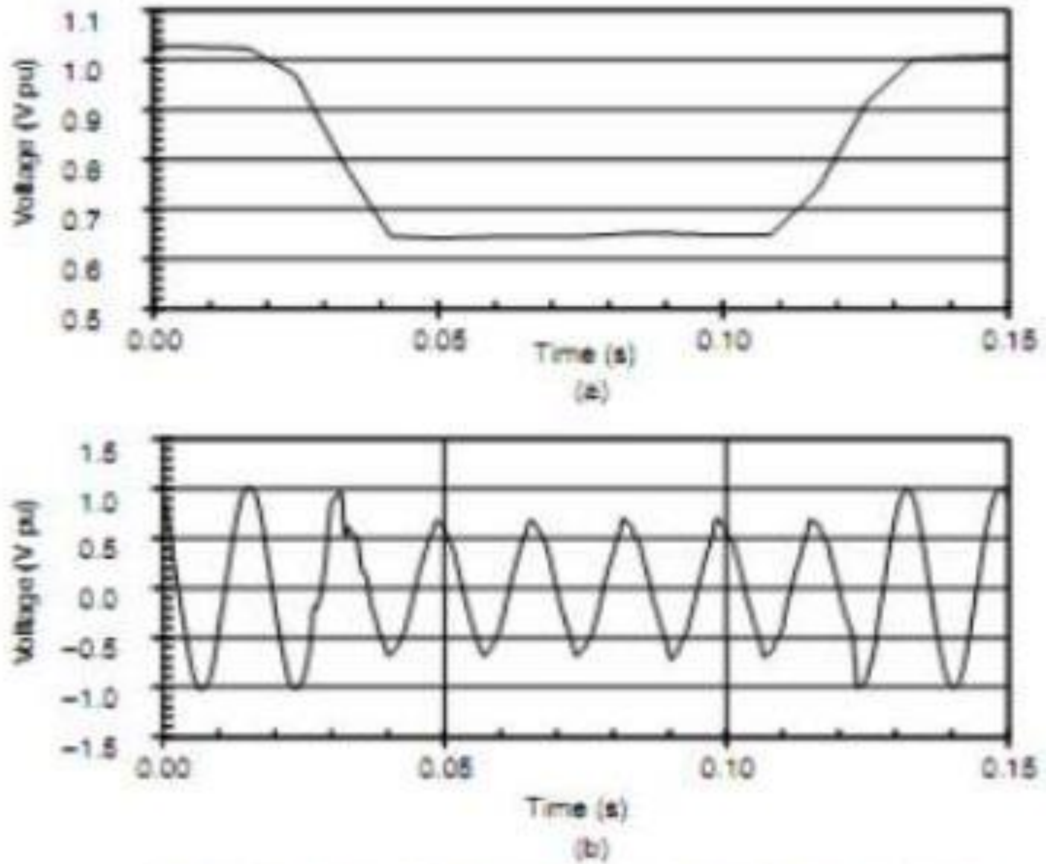
Faults on the transmission or distribution. Faults in consumer's installation. Connection of heavy loads and start-up of large motors

Consequences:

Malfunction of microprocessor-based control systems. Tripping of contactors and electromechanical relays. Disconnection of electric rotating machines

1. Voltage sag (or Dip)

Voltage sag associated with a single-line-to-ground (SLG) fault on another feeder from the same substation



RMS Waveform and Voltage sag waveform

Power Quality Disturbances

2. Transients

- An undesirable and momentary variation in voltage and current or both is termed transient.
- Transient disturbances are caused by the injection of energy by switching or by lightning.

Types:

1. Impulsive Transient
2. Oscillatory Transient

3. Long duration Voltage Variations

Long-duration variations encompass rms deviations at power frequencies for longer than 1 min

a) **Overvoltage:** An increase in the rms ac voltage greater than 110 percent at the power frequency for a duration longer than 1 min. Overvoltages are usually the result of load switching

b) **Undervoltage:** A decrease in the rms ac voltage to less than 90 percent at the power frequency for a duration longer than 1 min. A load switching on or a capacitor bank switching off can cause undervoltage

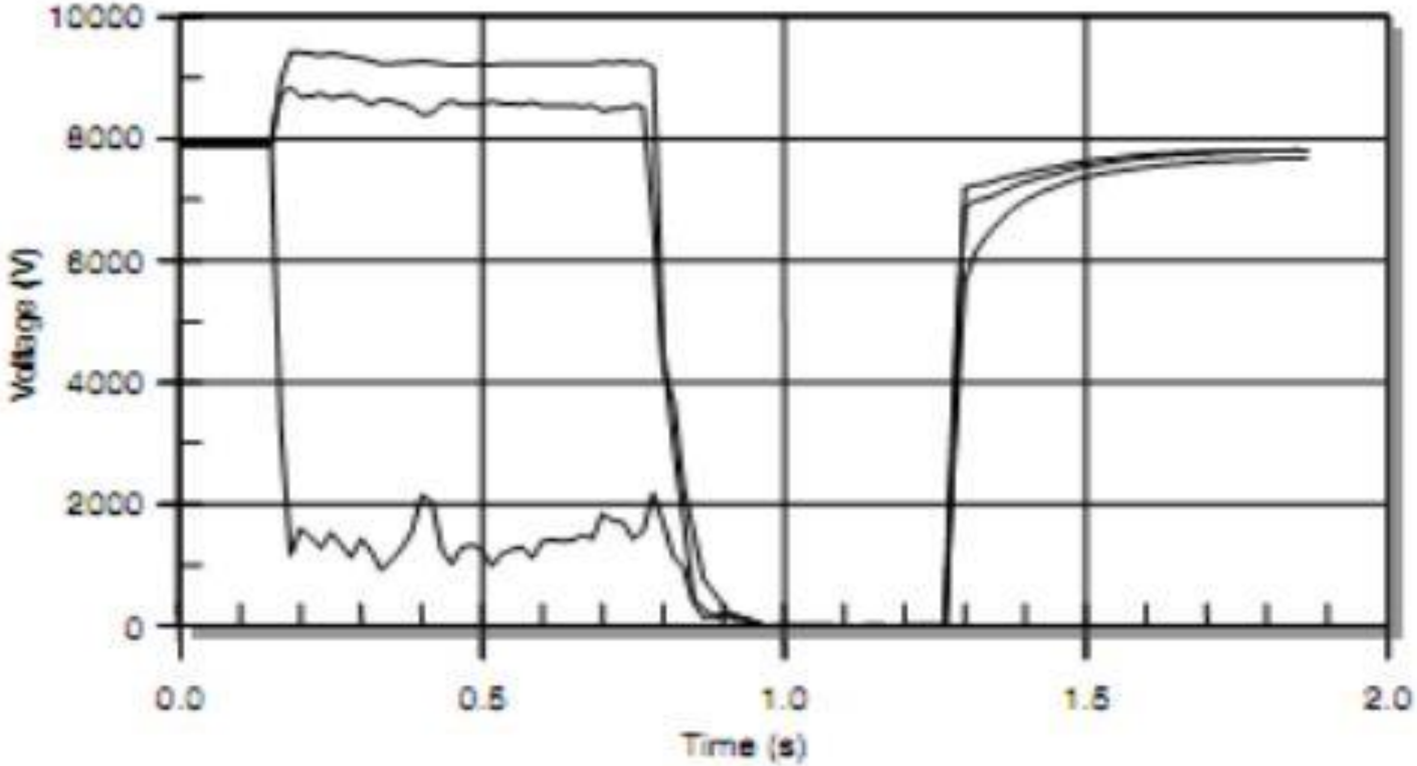
c) **Sustained interruptions:** Voltage interruptions longer than 1 min

4. Short duration Voltage Variations

- Deviations at power frequencies for less than 1 min.
- Caused by fault conditions, the energization of large loads which require high starting currents, or intermittent loose connections in power wiring
- Can cause
  - Interruptions: A complete loss of voltage
  - Swells: Voltage rises or
  - Sags :Temporary voltage drops

Interruptions:

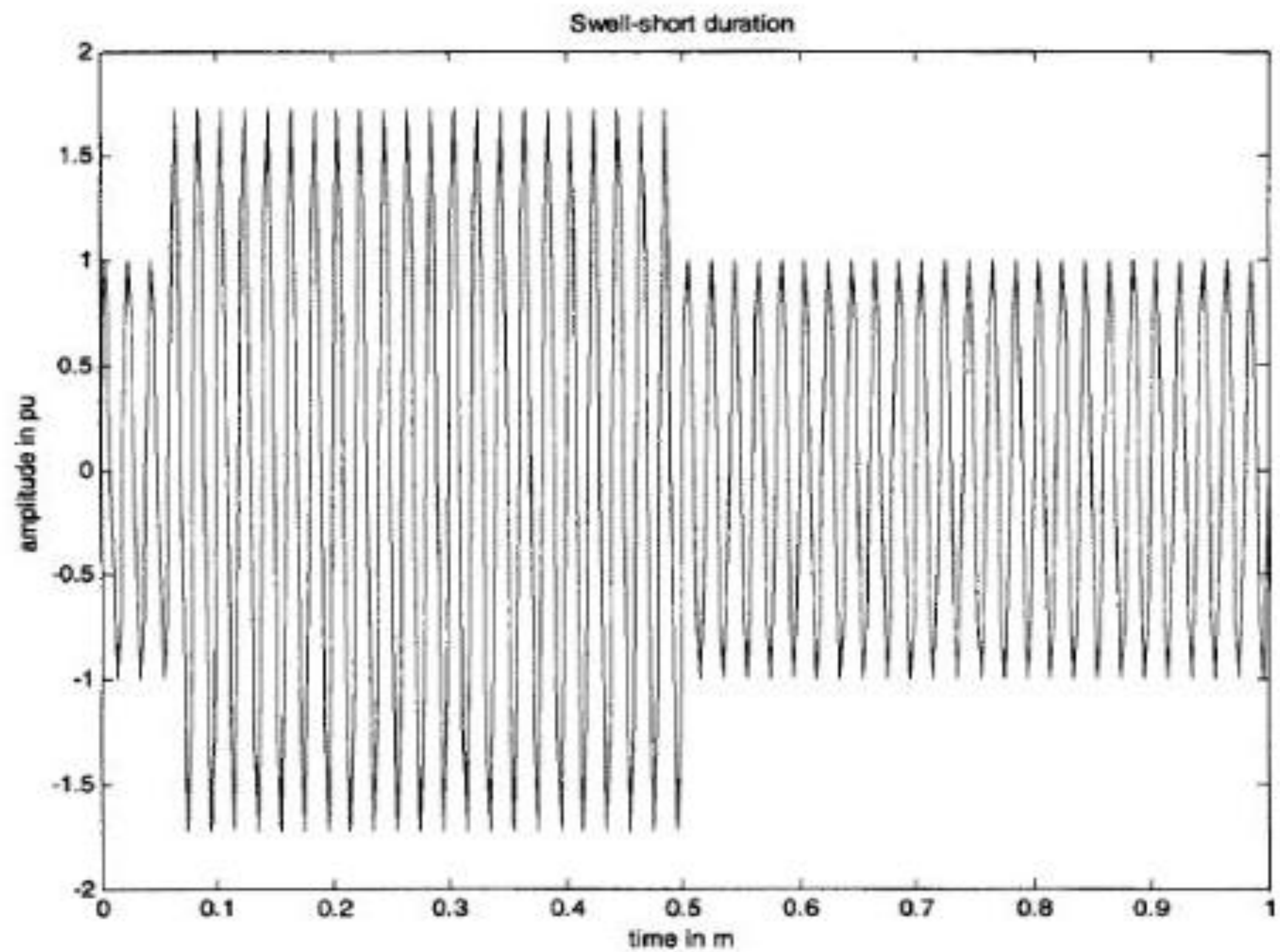
An interruption occurs when the supply voltage or load current decreases to less than 0.1 pu for a period of time not exceeding 1 min



Three Phase rms voltage fora momentary interruption due toa fault and subsequent reclosure operation

Voltage Swells:

Momentary increase of the voltage, at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few seconds



5. Voltage Imbalance

Voltage imbalance is defined as the maximum deviation from the average of the 3 phase voltages or currents, divided by the average of the 3 phase voltages or currents

Line Voltage unbalance rate , Phase Voltage unbalance rate

Voltage Unbalance Factor are defined as

$$\% LVUR = \frac{Max\,Voltage\ deviation\ from\ the\ average\ line\ voltage}{Average\ Line\ voltage}\ x\,100$$

$$\% PVUR = \frac{Max\,Voltage\ deviation\ from\ the\ average\ phase\ voltage}{Average\ phase\ voltage}\ x\,100$$

$$\% VUF = \frac{Negative\ sequence\ Voltage\ components}{Positive\ Sequence\ voltage\ components}\ x\,100$$

What causes Voltage Imbalance?

- Single phase loads on a three phase circuit
- Blown fuses in one phase of a three phase capacitor bank
- Single phasing conditions

6. Waveform Distortion

Waveform Distortion is defined as a **steady state deviation from an ideal sine wave** of power frequency principally characterized by the spectral content of the deviation.

The primary types of waveform distortion are

- DC offset
- Harmonics
- Interharmonics
- Notching
- Noise

DC offset

The presence of a dc voltage or current in an ac power system is termed dc offset. This can occur as the result of a geomagnetic disturbance or due to the effect of half wave rectification

Harmonics

- Harmonics are sinusoidal voltages or currents having frequencies that are integral multiples of the frequency at which the supply system is designed to operate

Notching

Notching is a periodic voltage disturbance caused by the normal operation of power electronics devices when current is commutated from one phase to another

Interharmonics

- Interharmonics are voltages or currents having frequencies that are not integral multiples of the frequency at which the supply system is designed to operate
- **Caused By**

  static frequency converters, cycloconverters, induction motors, arcing devices and Power line carrier signals

Noise

An unwanted electrical signals with broadband spectral content lower than 200 KHz superimposed upon the power system voltage or current in phase conductors or found on neutral conductors or signal lines.

Caused By

Power electronic devices, control circuits, arcing equipments, loads with solid state rectifiers, switching power supplies.

Power Quality Disturbances

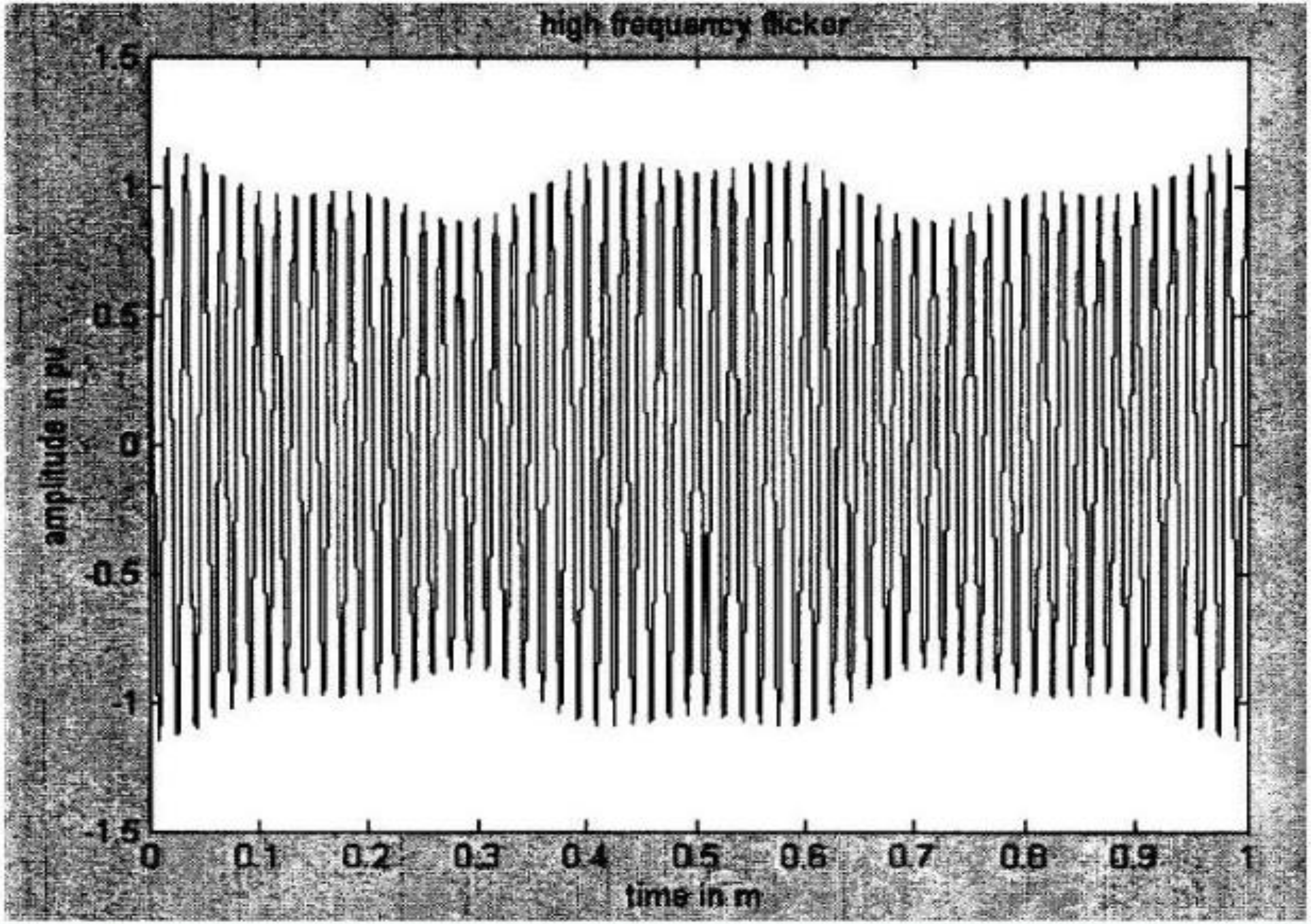
7. Voltage Flicker (Voltage Fluctuation)

Voltage Fluctuations are systematic variations of the voltage envelope or a series of random voltage changes, the magnitude of which does not normally exceed the voltage ranges of 0.9 - 1.1 pu.

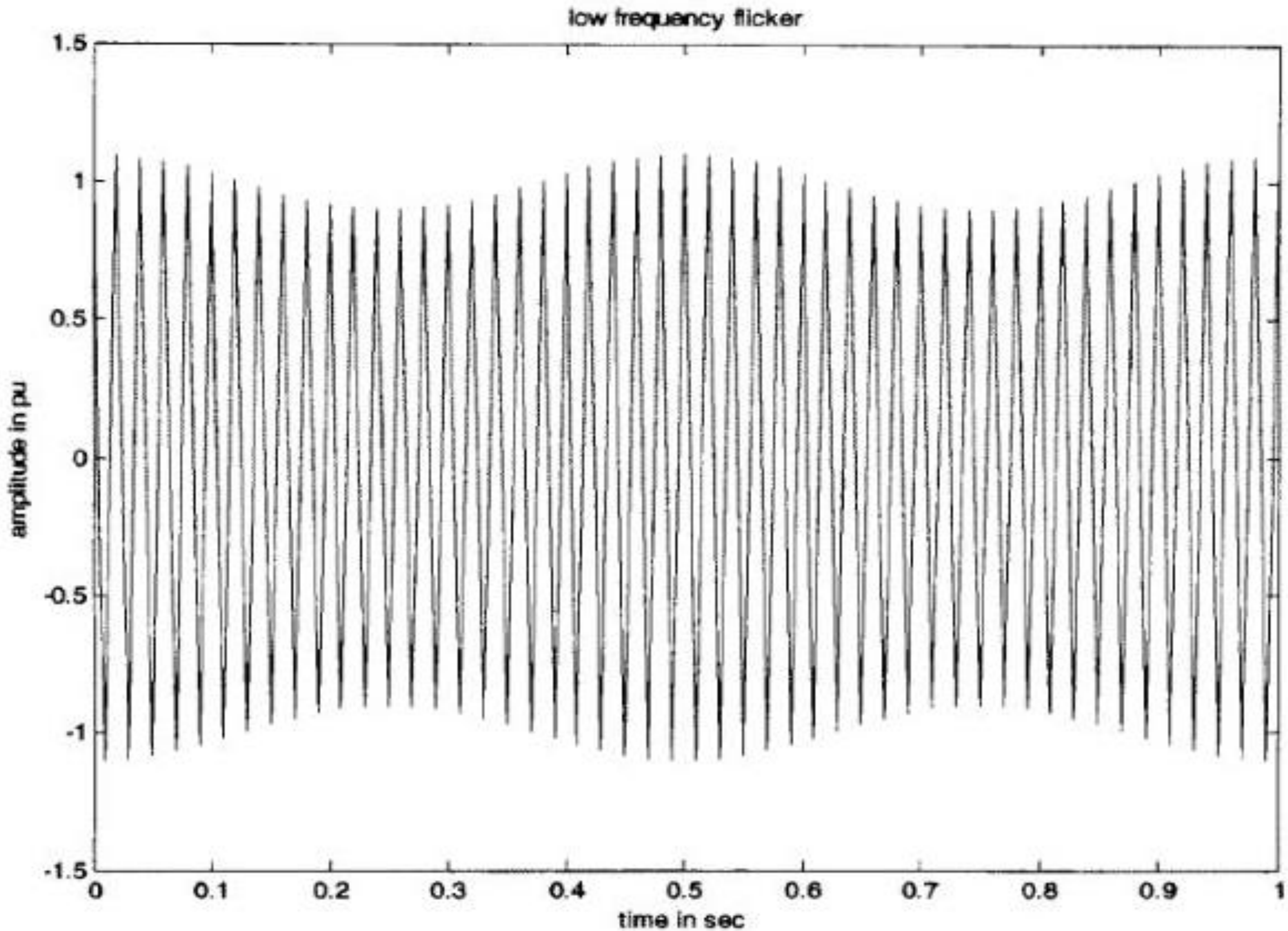
Caused By

Loads that can exhibit rapid and continuous variations in the load current

High Frequency Flicker Waveform



Low Frequency Flicker Waveform



Harmonics Basics

- Harmonics is the integer multiple of fundamental component
- Any periodic sinusoids can be expressed as sum of sinusoids
- When a waveform is identical from one cycle to the next, it can be represented as a sum of pure sine waves in which the frequency of each sinusoid is an integer multiple of the fundamental frequency of the distorted wave

Harmonics Basics

- Why only Odd Harmonics?
- When both the positive and negative half cycles of a waveform have identical shapes, the Fourier series contains only odd harmonics
- The presence of even harmonis is often a clue that there is something wrong- either with the load equipment or with the transducer used to make the measurement (Half wave rectifiers and arc furnaces with random arcs are exceptions)

Harmonics

One Period

Fundamental Frequency at 60 Hz

Third Harmonic 180 Hz

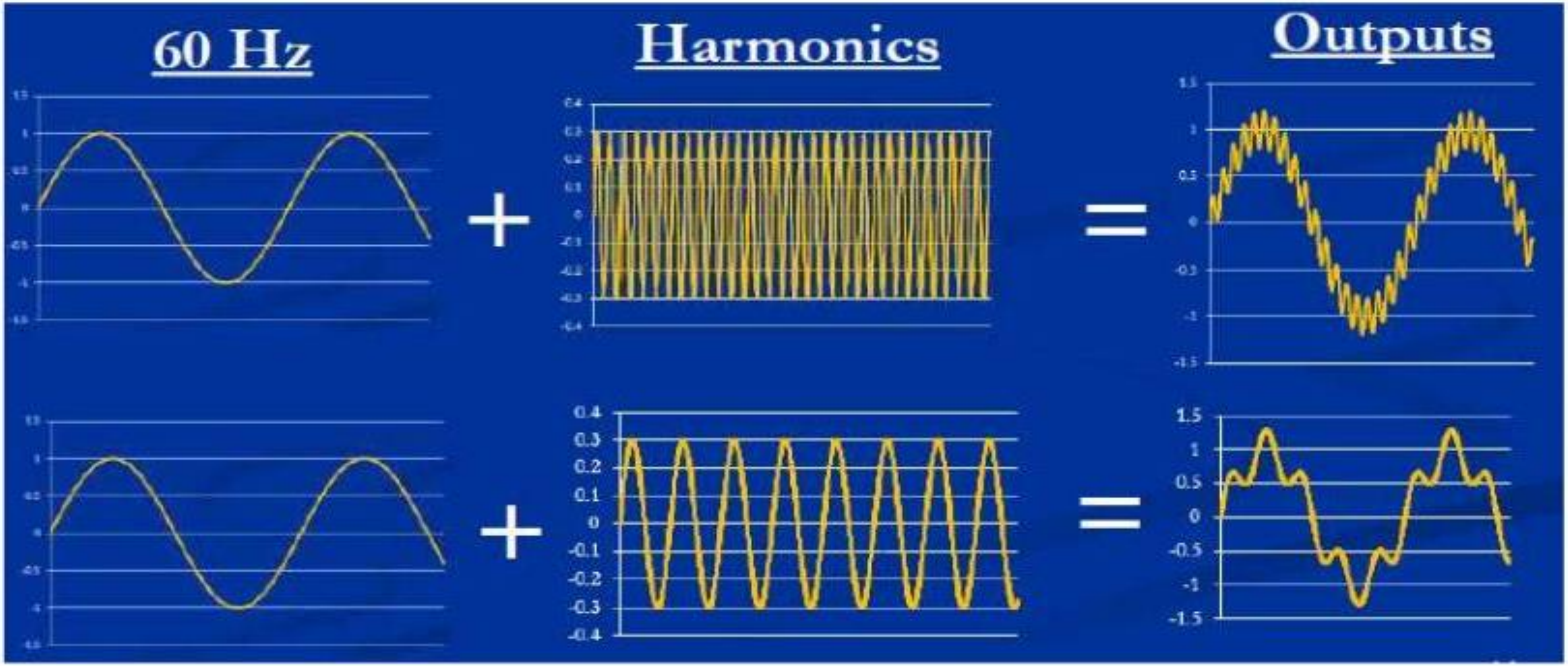
Harmonics Overview

Increasing Harmonics ↓

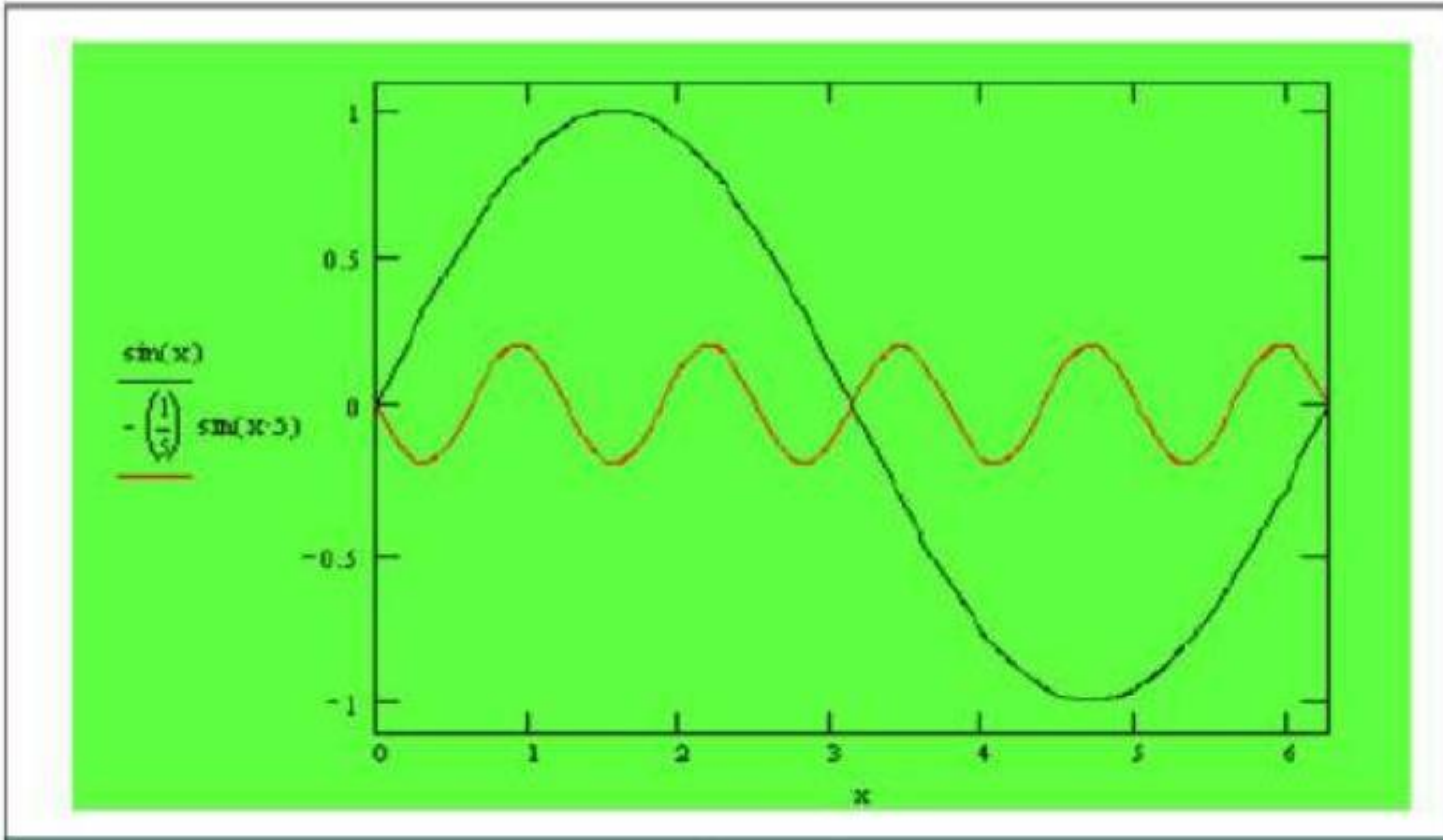
Generation
↓
Transmission
↓
Distribution
↓
Customer (Load)

Harmonics Distortion

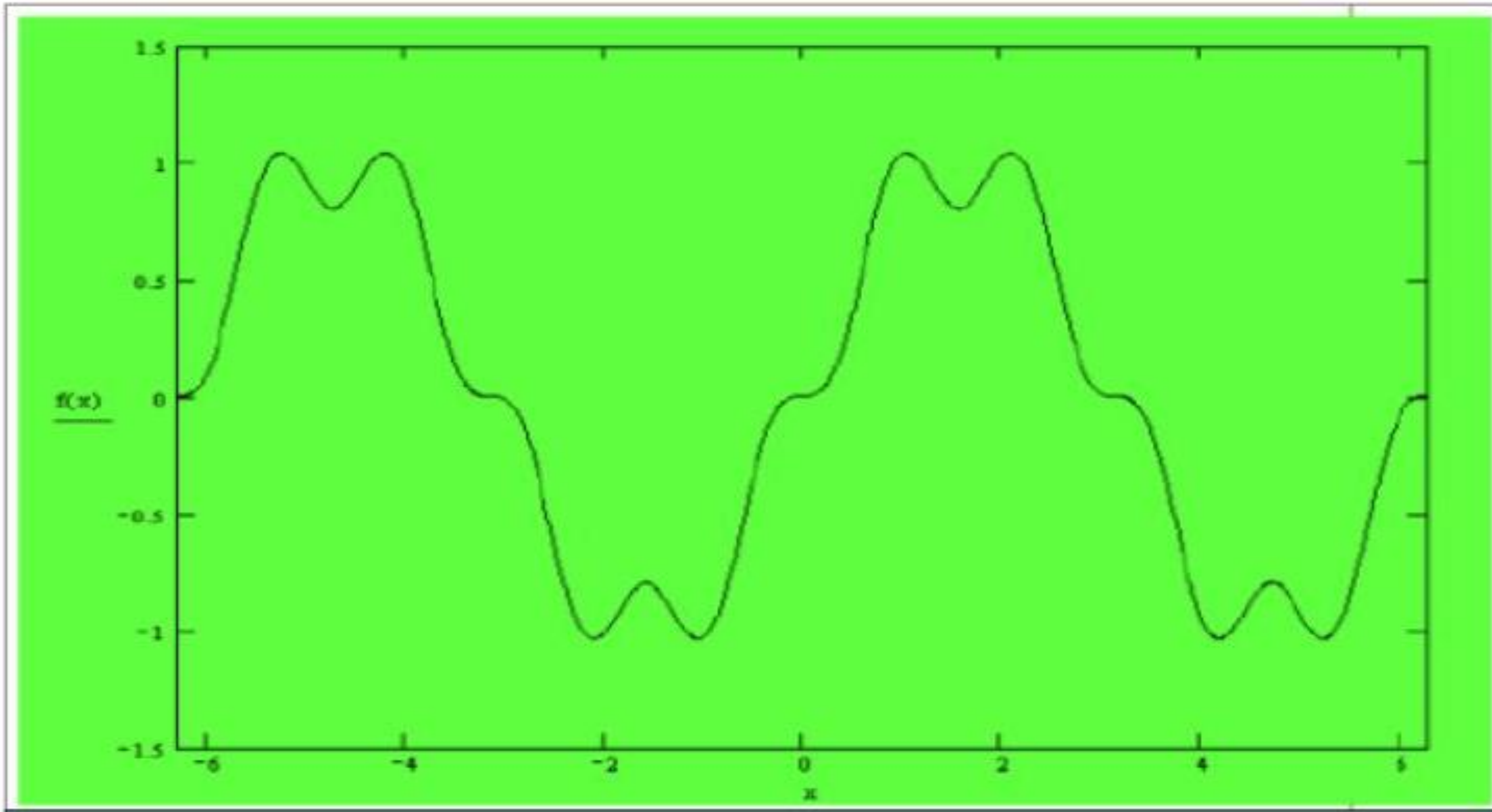
Any variation in the shape of a sinusoidal waveform is referred to as harmonic distortion



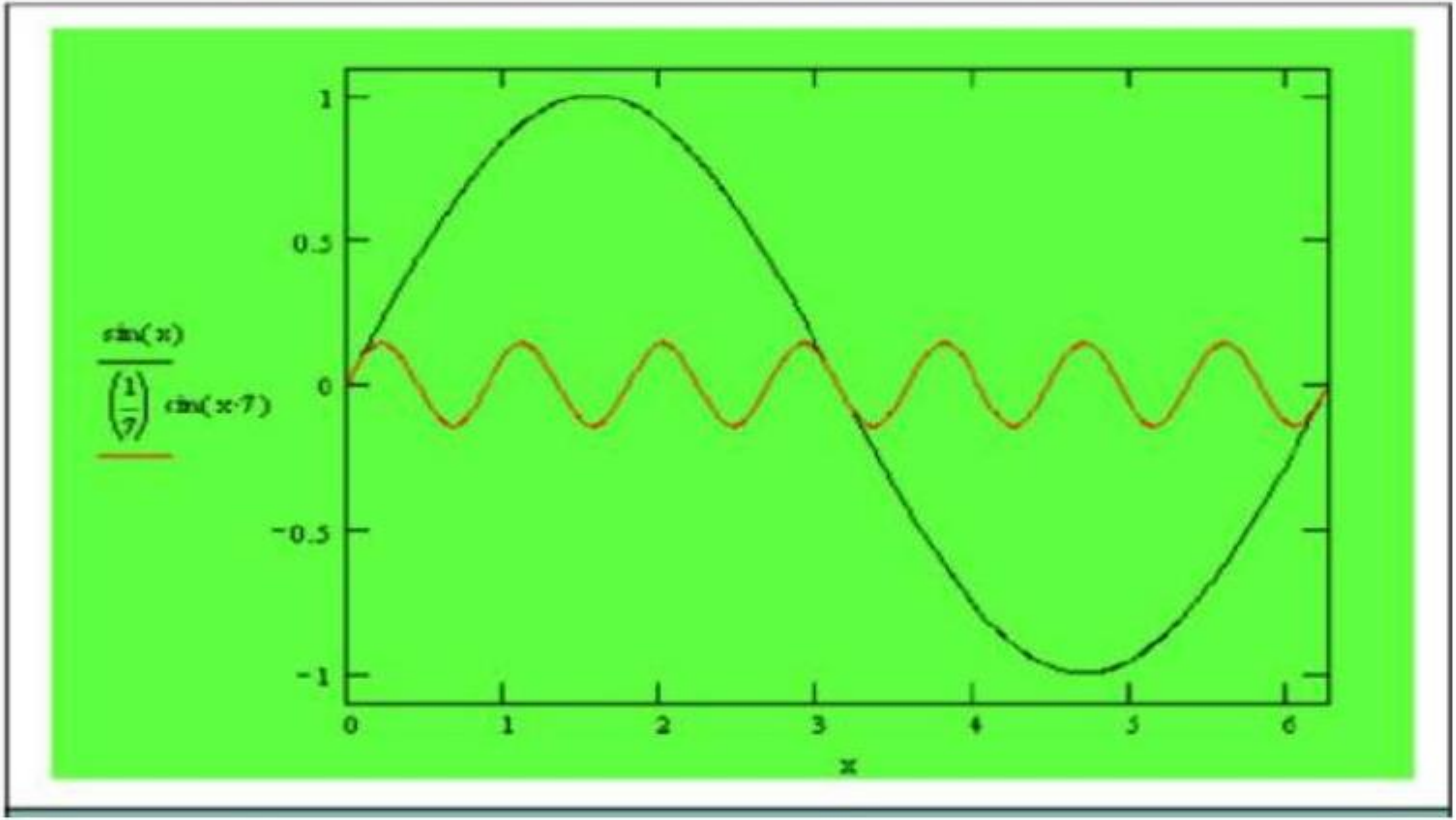
Fundamental with 5th Harmonic



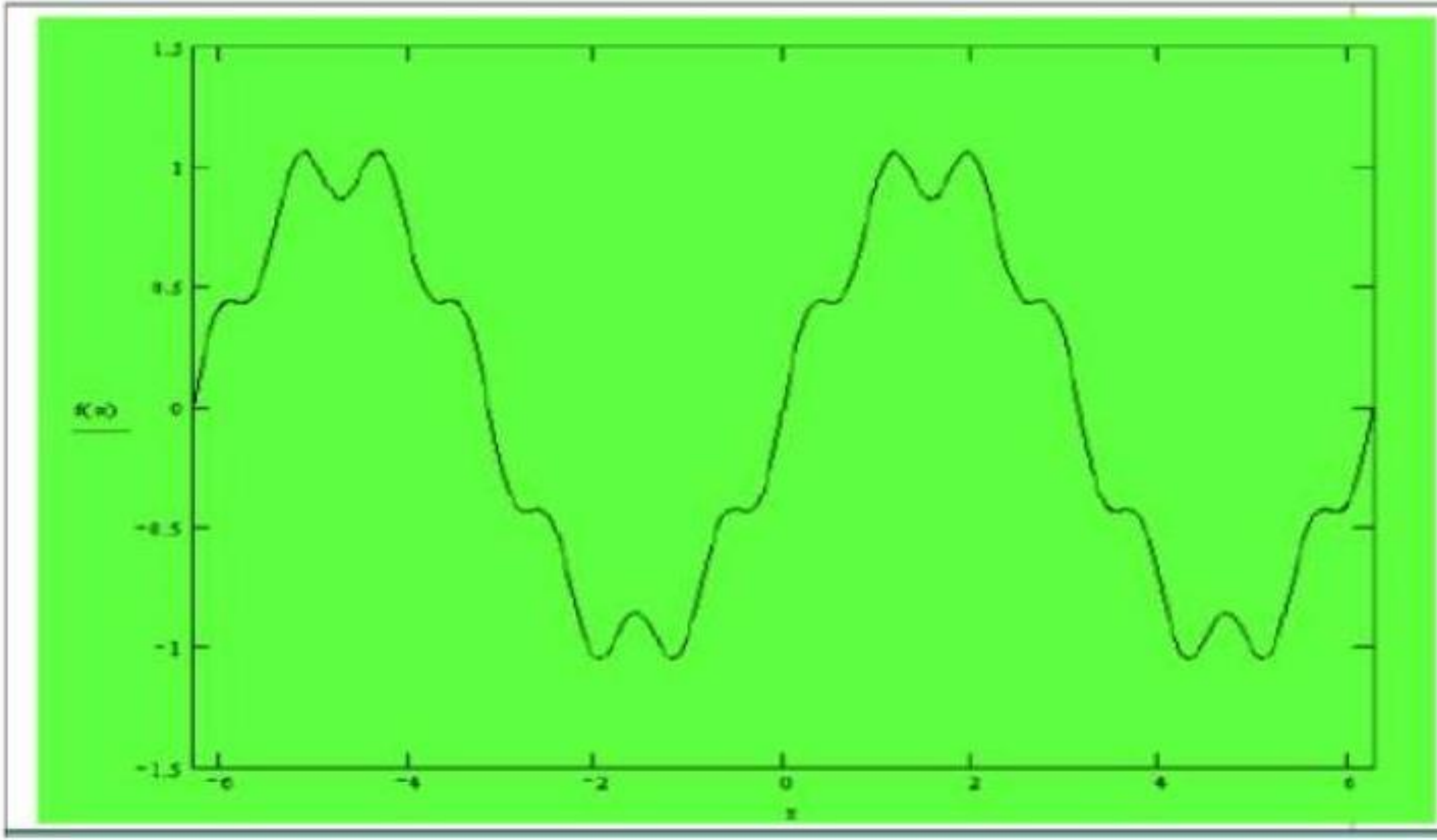
Distortion by 5th Harmonic



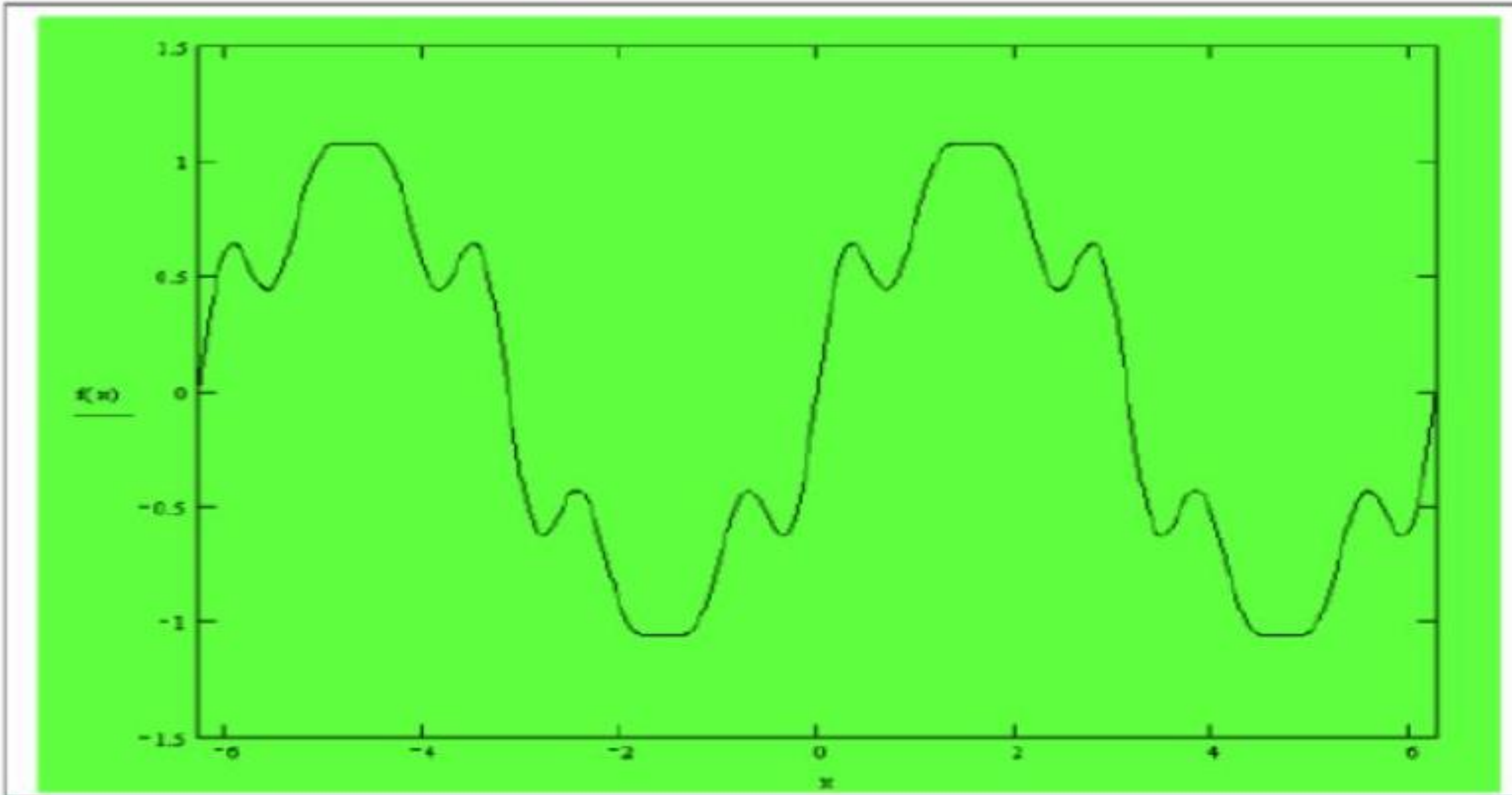
Fundamental with 7th Harmonic



Distortion by 7th Harmonic



Distortion by 5th and 7th Harmonic



Harmonic Sources

Classification

- Harmonic Sources from Commercial Loads
- Harmonic Sources from Industrial Loads

Harmonic Sources from Commercial Loads

Offices, Shopping malls, hospitals etc are dominated with high-efficiency fluorescent lighting with electronic ballasts, adjustable-speed drives (ASD) for the heating, ventilation and air conditioning (HVAC) loads, elevator drives and sensitive electronic equipment supplied by single-phase switch-mode power supplies (SMPS)

Major source of harmonics in commercial loads are

- **Single-Phase Power Supplies**
- **Fluorescent Lighting**

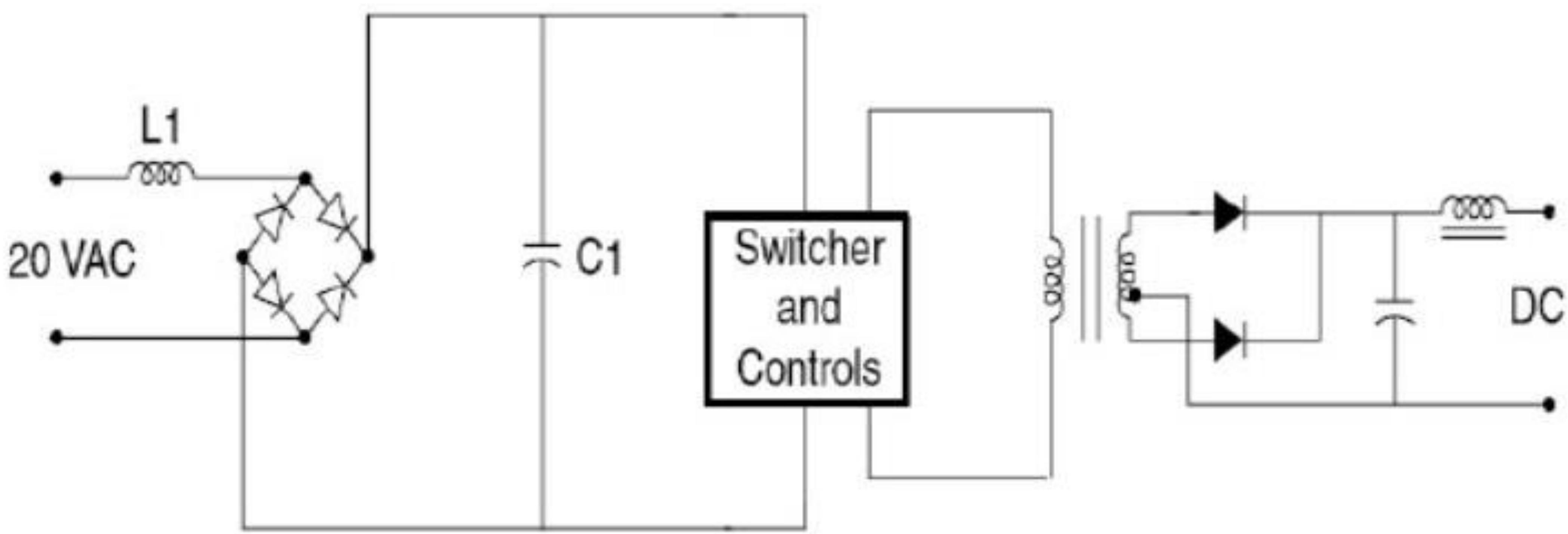
Harmonic Sources from Commercial Loads

Single-Phase Power Supplies

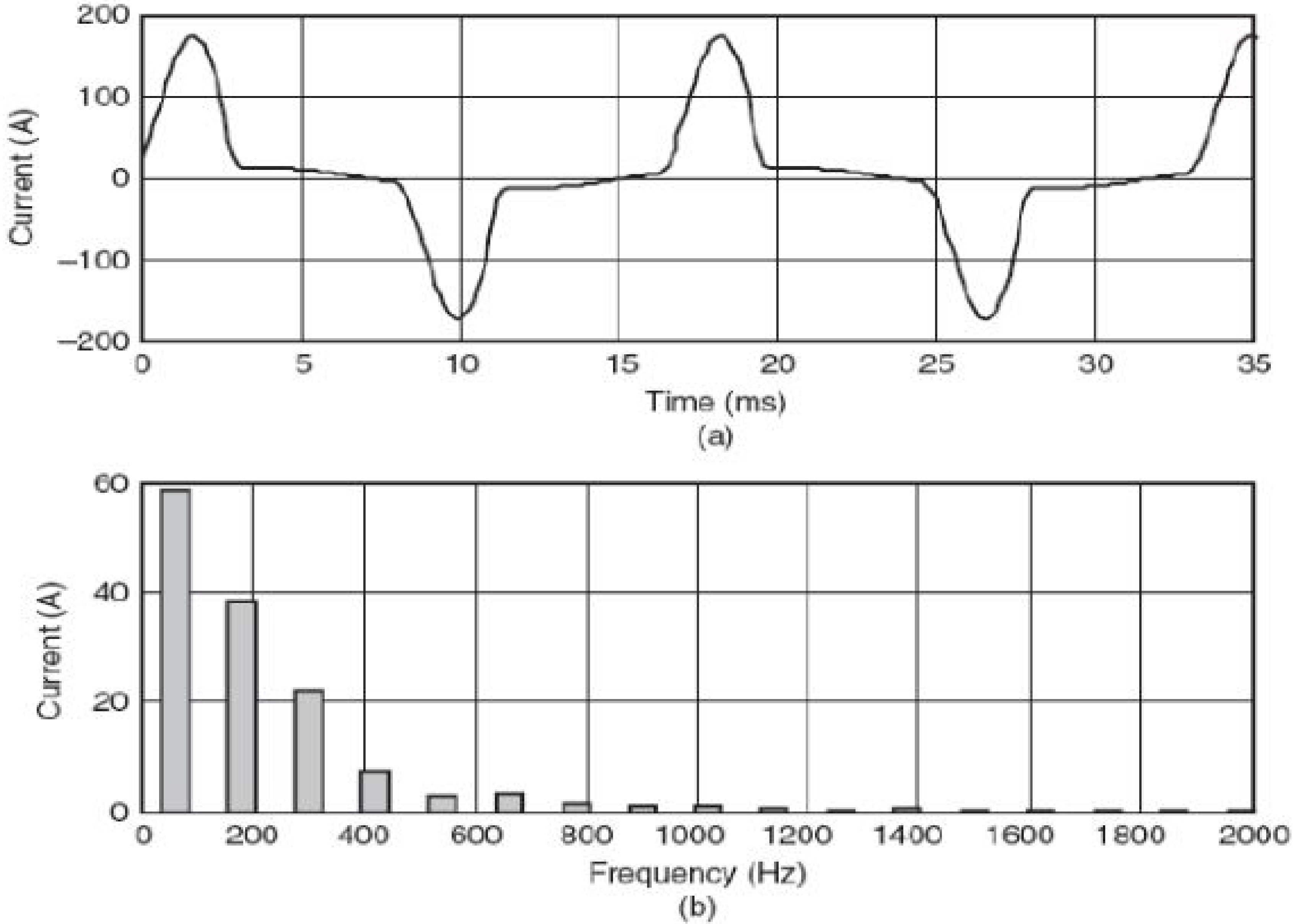
- Electronic power converter loads constitute the most important class of nonlinear loads in the power system which produce harmonic currents
- Power supplies for single-phase electronic equipment will produce too much harmonic current
- SMPS use dc-to-dc conversion techniques to achieve a smooth dc output with small, lightweight components

Single-Phase Power Supplies (SMPS)

- Key advantages of a SMPS are lightweight, compact size, efficient operation and no need for a transformer



Single-Phase Power Supplies (SMPS)



SMPS current and harmonic spectrum

Fluorescent Lighting

- Fluorescent lights are discharge lamps
- They require a ballast to provide a high initial voltage to initiate the discharge
- An electronic ballast employs a switch-mode–type power supply to convert the incoming fundamental frequency voltage to a much higher frequency –a source of harmonics

Harmonic Sources from Industrial Loads

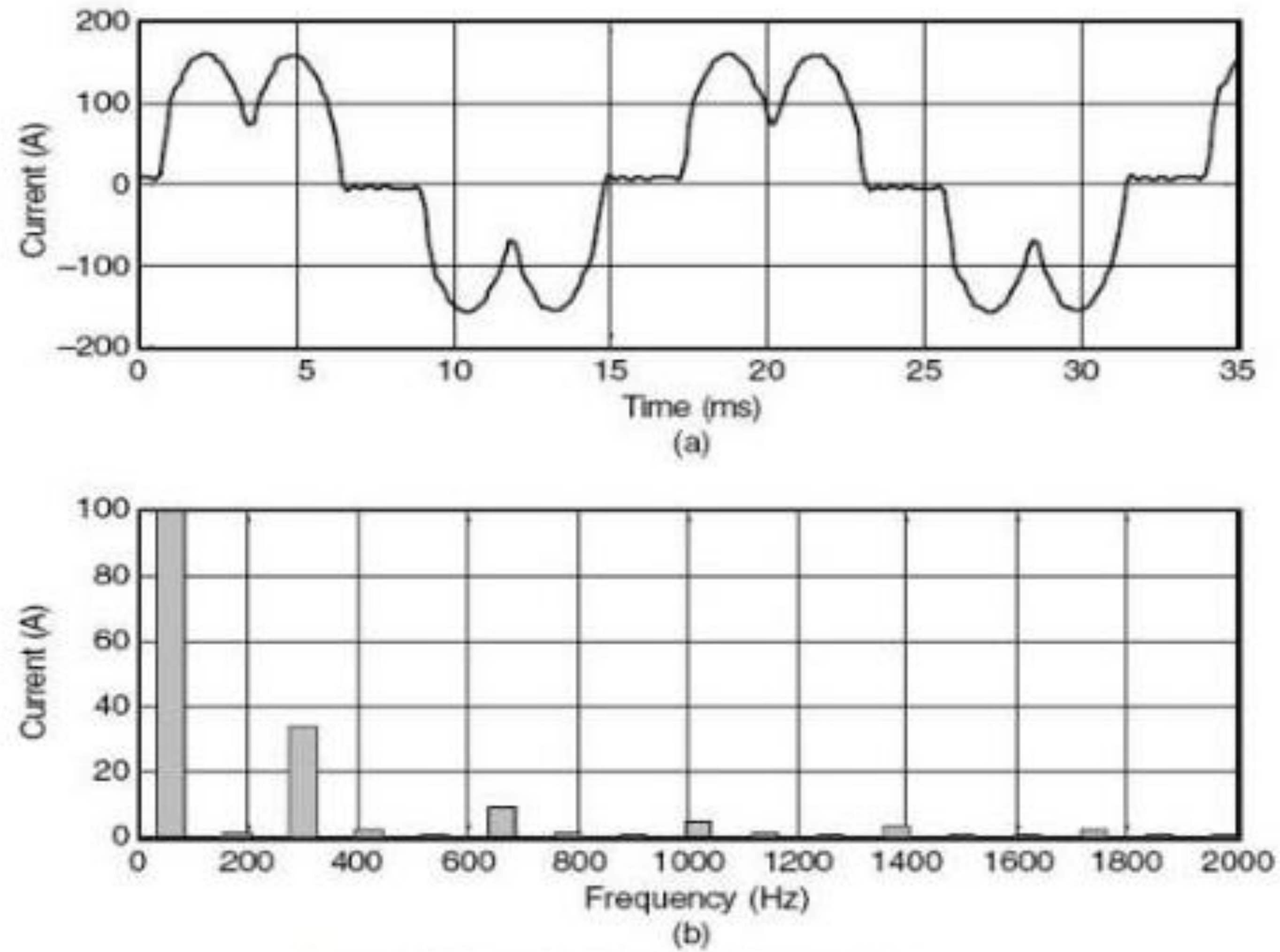
Classification

- Three Phase Power Converters
  - DC Drives
  - AC Drives
- Arcing Devices
- Saturable Devices

Three Phase Power Converters

- 3-phase electronic power converters do not generate third-harmonic currents

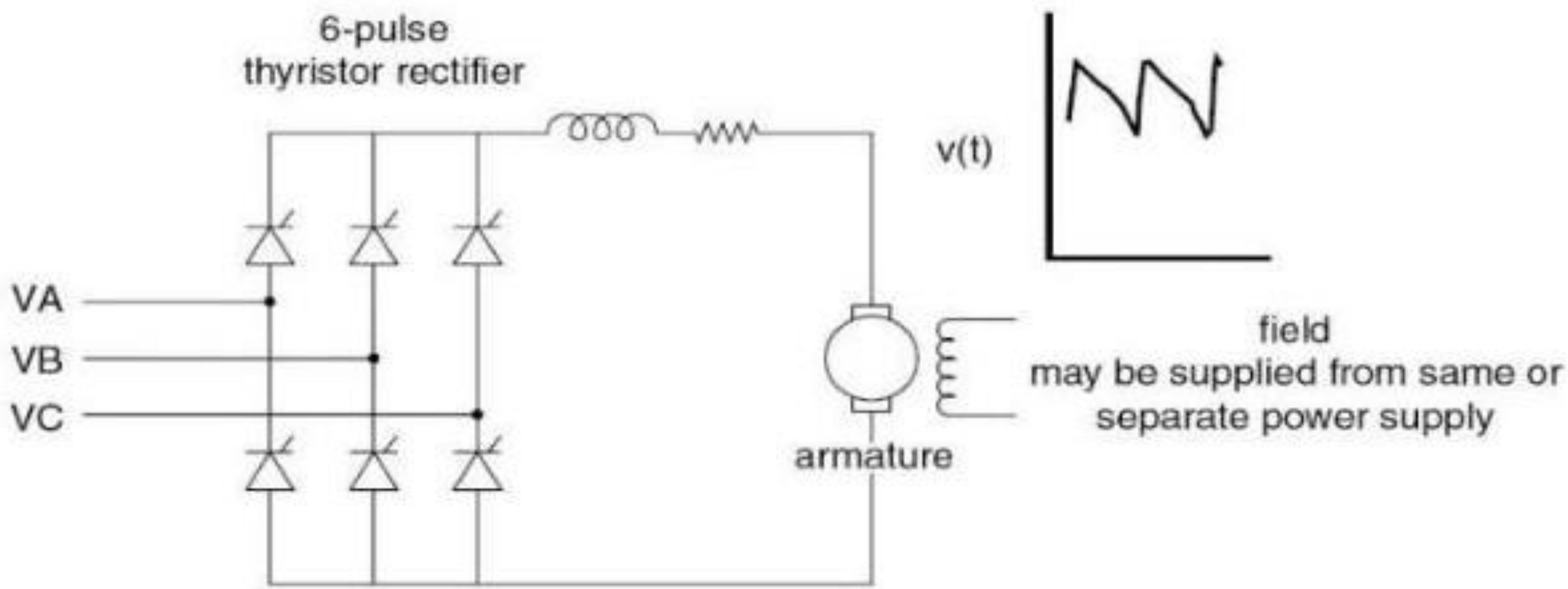
- Still they are significant sources of harmonics at their characteristic frequencies



Current and harmonic spectrum for CSI-type ASD.

Three Phase Power Converters- DC Drives

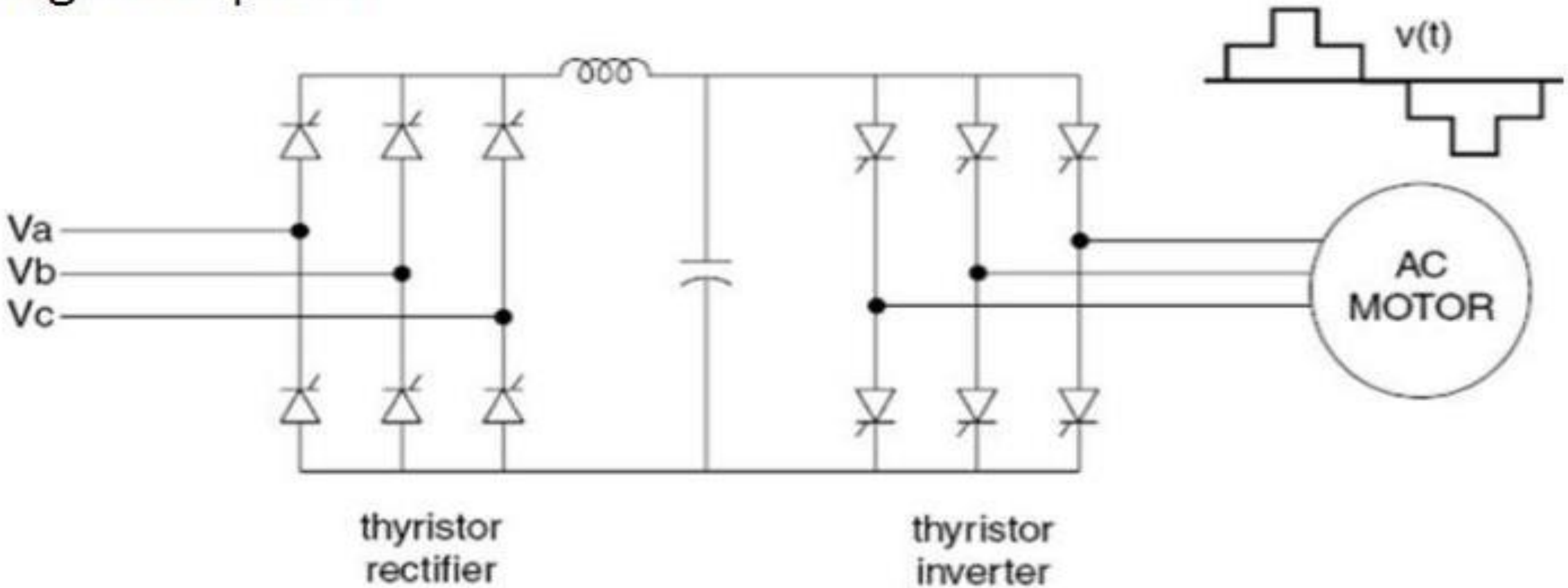
- Rectification is the only step required for dc drives
- Therefore relatively simple control systems
- Most dc drives use the six-pulse rectifier
- Two largest harmonic currents for this are the fifth and seventh



Six Pulse DC ASD

Three Phase Power Converters- AC Drives

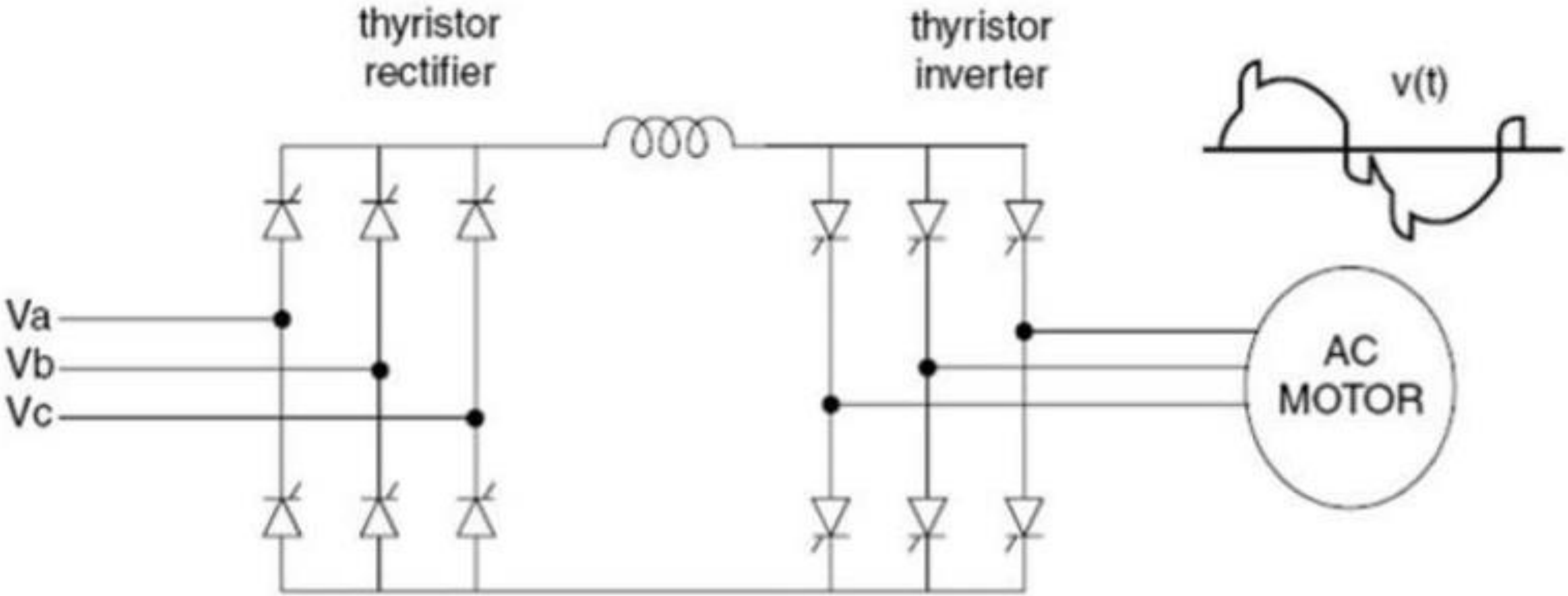
- A VSI requires a constant dc (i.e., low-ripple) voltage input to the inverter stage. This is achieved with a capacitor or LC filter in the dc link.
- VSI drives are limited to applications that do not require rapid changes in speed



VSI AC Drive

Three Phase Power Converters- AC Drives

- The CSI requires a constant current input; hence, a series inductor is placed in the dc link
- CSI drives have good acceleration/deceleration characteristics but require a motor with a leading power factor

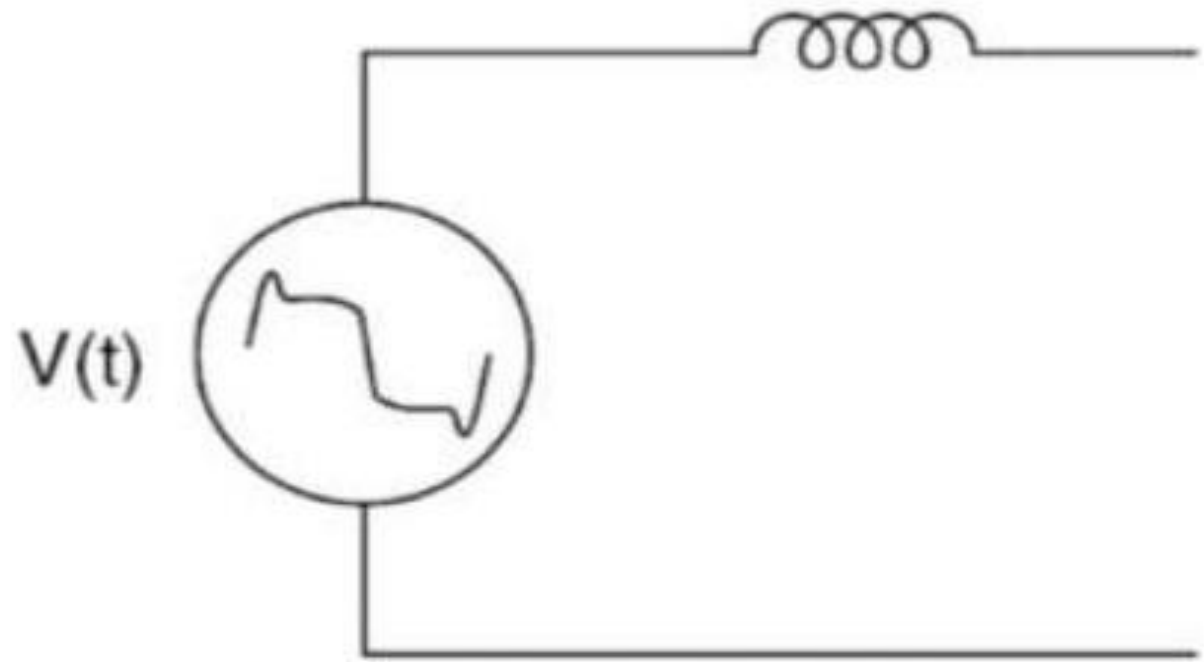


CSI AC Drive

Harmonic Sources

Arcing Devices

- This category includes arc furnaces, arc welders, and discharge-type lighting (fluorescent, sodium vapor, mercury vapor) with magnetic ballasts
- The voltage-current characteristics of electric arcs are nonlinear



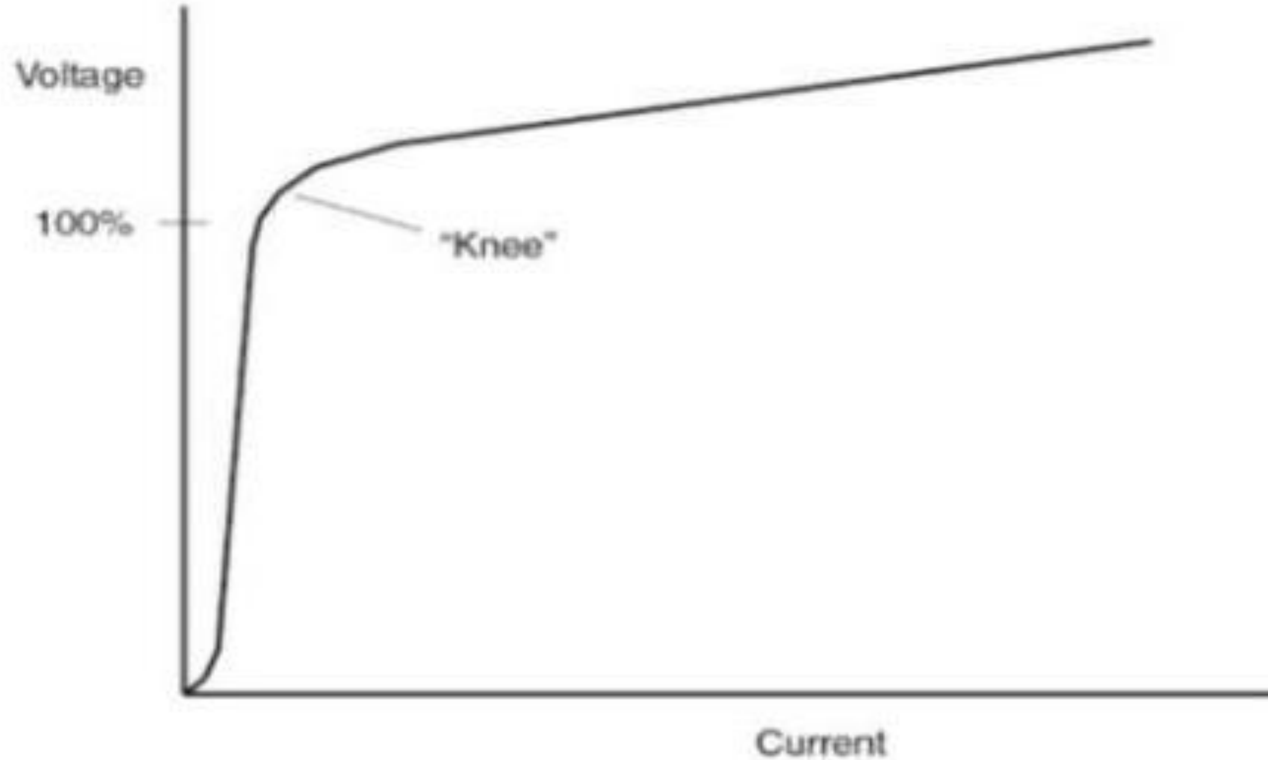
Equivalent circuit for an arcing device

Harmonic Sources

Saturable Devices

- Equipment in this category includes transformers and other electromagnetic devices with a steel core, including motors.

- Harmonics are generated due to the nonlinear magnetizing characteristics of the steel



Transformer magnetizing characteristic

Harmonic Indices

- Total Harmonic Distortion **THD**
- Total Demand Distortion **TDD**
- Telephone Interference Factor **TIF**
- Distortion Index **DIN**
- C-Message Weighted Index **CMWI**

Total Harmonic Distortion THD

- THD is the ratio between the RMS values of the harmonics and the RMS value of fundamental

- THD for voltage:

$$THD = \frac{\sqrt{\sum_{k=2}^{N}(v_k^2)}}{\sqrt{\sum_{k=1}^{N}(v_k^2)}}$$

Total Demand Distortion TDD

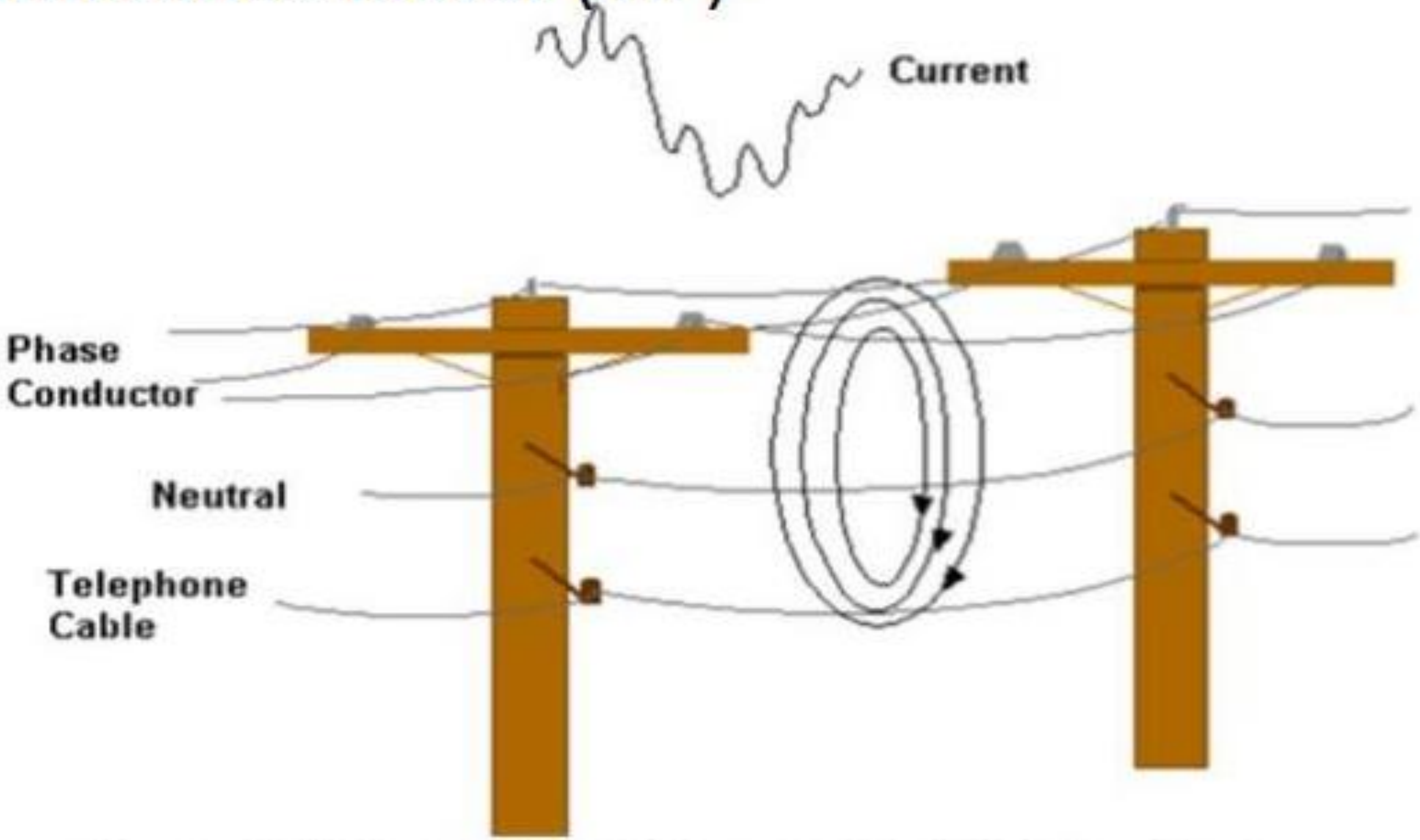
- TDD is the ratio between the RMS values of the harmonics current and the RMS value of fundamental current

- TDD for Current:

$$TDD = \frac{\sqrt{\sum_{k=2}^{N}(I_k^2)}}{\sqrt{\sum_{k=1}^{N}(I_k^2)}}$$

Telephone Interference Factor TIF

Telephone noise originating from harmonic currents and voltages in power systems is generally quantified as a telephone influence factor (TIF)



Magnetic Fields Causing Induced Voltages into Nearby Telephone Circuits

Telephone Interference Factor TIF

$$TIF = \frac{\sqrt{\sum_{k=1}^{k=N} (\mathrm{TIF}^2(k) \cdot v_k^2)}}{\sqrt{\sum_{k=1}^{k=N} (v_k)^2}}$$

Distortion Index DIN

The distortion index is defined in terms of the harmonic power divided by the total power in the waveform itself

$$DIN_v = \frac{\sqrt{\sum_{k=2}^{k=\infty} |v_k|^2}}{\sqrt{\sum_{k=1}^{k=\infty} |v_k|^2}}$$

C-Message Weighted Index CMWI

- A noise spectral weighting used in a noise power measuring set to measure noise power on a line that is terminated by a 500-type (Musical) set or similar instrument

$$CMWI = \frac{\sqrt{\sum_{k=1}^{N}(C^2(k)v_k^2)}}{\sqrt{\sum_{k=1}^{N}(v_k^2)}}$$

Flicker Factor F

- Flicker is a frequency domain effect and can cause discomfort in humans and animals

$$Flicker = \frac{(Max - Min)}{Average}\, x\, 100$$

Power Quality Issues with Smart Grid

- **Sustained Interruptions:** DGs are designed to provide backup power to the load in case of power interruption but increase the number of interruptions in some cases.
- **Voltage Regulation:** Limiting factor for how much Distributed Generation can be accommodated on a distribution feeder
- **Harmonics:** Harmonics from rotating machines are not negligible in grid parallel operation
- **Voltage Sags:** Most common PQ problem . The ability of Distributed Generation to reduce sags is dependent on the type of generation technology and the interconnection location.

- **Operating Conflicts that can result in power quality problems**
  1. Utility Fault Clearing requirements
  2. Reclosing
  3. Interference with Relaying
  4. Voltage regulation issues
  5. Harmonics
  6. Islanding
  7. Ferroresonance
  8. Shunt Capacitor Interaction

Thank You!