UNIT II HARMONICS
Harmonic sources from commercial and industrial loads, locating harmonic sources.Power system response characteristics - Harmonics Vs transients. Effect of harmonics - harmonic distortion - voltage and current distortion - harmonic indices - inter harmonics – resonance. Harmonic distortion evaluation - devices for controlling harmonic distortion - passive and active filters. IEEE and IEC standards

➢ Harmonic sources from commercial and industrial loads

Harmonics of different orders generated when connected power system network bydifferent sources as below:

i. The nonlinear loads such as inverter fed adjustable speed drive.
ii. The use of power factor correction capacitor creates parallel or series resonance problemsincreasing the harmonic distortion.
iii. Process control and solid state power conversion equipments.
iv. Energy efficient compact flourescent lamps.
v. Use of AC and DC adjustable speed drives
vi. Static VAR compensators.
vii. Transformers produce very high levels of harmonics when they are initially energized, theso called in rush current will generate harmonics of several orders.
viii. Cycloconverters, Lift control system, Traction, AC voltage regulators, UPS, Batterychargers.

➢ **Harmonic Sources Commercial Loads:**

Commercial Places:

- Office complexes
- Department stores
- Hospitals and
- Internet data centers

Loads:

- High-efficiency fluorescent lighting with electronic ballasts
- Adjustable-speed drives for the heating, ventilation, and air conditioning (HVAC) loads
- Elevator drives and
- Sensitive electronic equipment supplied by single-phase switch-mode power supplies.

❖ Commercial loads are characterized by a large number of small harmonic-producing loads.

❖ Depending on the diversity of the different load types, these small harmonic currents may add in phase or cancel each other.

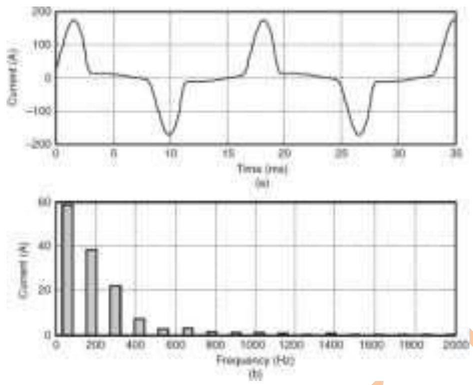
❖ Voltage distortion levels depend on both the circuit impedances and the overall harmonic current distortion.

Single-phase power supplies:

❖ Electronic power supplies are very important in commercial premises because of increased utilization of personal computers, adjustable speed drives, dc motor drives, battery charges etc.,

❖ The SMPS is now replacing the old transformer power supplies. The input diode bridge is directly connected to the AC main, eliminating transformer. The direct current is then converted back to AC at very high frequency by the switches and subsequently rectified again. All computer peripherals are now employ SMPS because of its light weight, compact size, efficient operation and lack of need for a transformer.

- SMPS causes very high 3rd Harmonics. These 3rd Harmonics causes overloading of neutral conductors, especially where undersized old neutral wires may have been installed.



Current and Frequency spectrum of SMPS

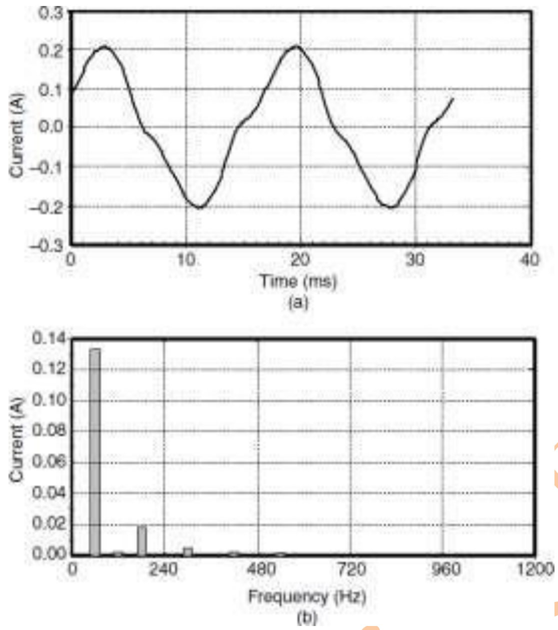
Fluorescent Lighting:

- Commercial building loads consumes 40% - 60% of generated energy for lighting
- Lighting (1995) – 77% Fluorescent lighting, 14% Incandescent lighting.
- In discharge lamps, ballasts are used for generating high initial voltage. After establishing the electron flow from one electrode to another, arc current increases and the voltage decreses.
- Discharge is a short circuit. Ballast has to reduce the current within the limit to maintain the specified lumen output. i.e, Ballast is also a current limiting device.
- Types: 1. Magnetic Ballast and 2. Electronic Ballast.
  Magnetic Ballast: It is made with iron core and used with a capacitor. It produces heat loss.
  Electronic Ballast: Switch mode power supply is used to convert the fundamental frequency voltage in to a much higher frequency (25-40 kHz) voltage.

  <u>Advantages of High frequency:</u>

  - Small inductor is enough to limit the arc current.
  - High Frequency eliminates 100 or 120 Hz flicker associated with iron core magnetic ballast.
- Magnetic Ballast can be used for 2 lamps. But electronic Ballast can be used for 4 lamps.
- Comparison: Electronic Ballast produces double or triple the standard magnetic ballast harmonic output.
- Other electronic ballasts have been specifically designed to minimize harmonics and may actually produce less harmonic distortion than the normal magnetic ballast-lamp combination.
- Typical THD allowed in electronic ballast is betwee10-32%.
- THD greater than 32% is excessive according to ANSI C82.11-1993, *Highfrequency Fluorescent Lamp Ballasts.*
- In many cases, passive filtering used to reduce input current harmonic distortion to less than 20%.

- ❖ Harmonics in commercial buildings are usually distributed along the phases in a nearly balanced manner.



Current and Frequency spectrum of fluorescent lighting

Adjustable Speed Drives:

- ❖ Applications of ASDs:
  - Elevator Motors
  - Pumps and Fans of HVAC Systems
- ❖ ASD consists of electronic power converter that converts constant ac voltage and frequency into variable voltage and frequency.
- ❖ Variable voltage and frequency allows the ASD to control motor speed to match the application requirement such as slowing a pump or fan.
- ❖ ASDs also find many applications in industrial loads

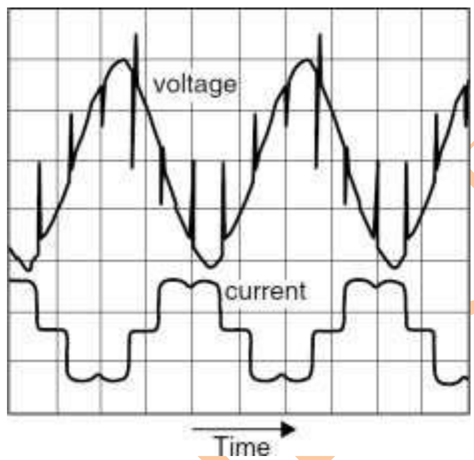
➢ **<u>Harmonic Sources – Industrial Loads:</u>**

- ❖ In modern Industries, non linear loads are unavoidable today. They are injecting harmonics in to the system.
- ❖ Non linear Loads are operating at low power factor. Therefore, power factor correction strategies are applied to the system. Widely using power factor correction capacitors magnify the harmonics.
- ❖ High Voltage distortions are experienced at LV side (Capacitor side).
- ❖ At resonance condition, motor and transformer overheating, and misoperation of sensitive electronic equipment are occurred.
- ❖ Three categories of nonlinear industrial loads :
  - Three-phase power converters
  - Arcing devices and
  - Saturable devices.

Three-phase power converters:

All equipment containing static converters, as variable speed controllers, UPS units and a.c./d.c. converters in general, are based on a three-phase bridge, also known as a six- pulse bridge because there are six voltage pulses per cycle (one per half cycle per phase) on the d.c. output.

- This bridge produces in supply networks current harmonics of order 6n±1, which means one more and one less than each multiple of six.
- In theory, the magnitude of each harmonic should be equal to the reciprocal of the harmonic number, so there would be 20% of the 5th harmonic and 9% of the 11th harmonic, etc.
- Figure shows a waveform of a thyristor bridge current against the phase voltage.
- Commutation notches are clearly visible in the voltage waveform (the source of high-frequency distorting components).
- The magnitude of the harmonics is significantly reduced by the use of a 12-pulse converter.



Example waveforms of the supply voltage and current of a six-pulse thyristor bridge with d.c. side reactor

Arcing Devices:

- The following are the arcing devices:
  - 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. Following arc ignition, the voltage decreases as the arc current increases, limited only by the impedance of the power system.
- In electric arc furnace applications, the limiting impedance is primarily the furnace cable and leads with some contribution from the power system and furnace transformer. Currents in excess of 60,000 A are common.
- The electric arc itself is actually best represented as a source of voltage harmonics. Its magnitude is largely a function of the length of the arc.
- The arcing load thus appears to be a relatively stable harmonic current source, which is adequate for most analyses.
- The exception occurs when the system is near resonance and a Thevenin equivalent model using the arc voltage waveform gives more realistic answers.
- Three phase arcing devices can be arranged to cancel the triplen harmonics through the transformer connection.
- However, this cancellation may not work in three-phase arc furnaces because of the frequent unbalanced operation during the melting phase.
- During the refining stage when the arc is more constant, the cancellation is better.

Saturable Devices:

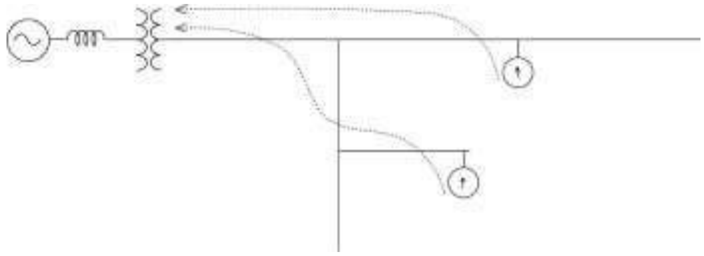
- ❖ Equipment in this category includes transformers and other electromagnetic devices with a steel core, including motors.
- ❖ Harmonics are generated due to the nonlinear magnetizing characteristics of the steel.
- ❖ Power transformers are designed to operate below the 'knee point' of the magnetic saturation characteristics.
- ❖ Selection of the operating point depends on,
    - o Steel cost
    - o No-load losses
    - o Noise and
    - o Other factors
- ❖ Some transformers are purposefully operated in the saturated region. One example is a triplen transformer used to generate 180 Hz for induction furnaces.
- ❖ Motors also exhibit some distortion in the current when overexcited, although it is generally of little consequence.
- ❖ There are, however, some fractional horsepower, single-phase motors that have a nearly triangular waveform with significant third-harmonic currents.

Transformer magnetizing current and harmonic spectrum.

- ❖ The waveform shown in Fig.is for single-phase or wye-grounded three-phase transformers.
- ❖ The current obviously contains a large amount of third harmonic.
- ❖ Delta connections and ungrounded-wye connections prevent the flow of zero-sequence harmonic, which triplens tend to be.
- ❖ Thus, the line current will be void of these harmonics unless there is an imbalance in the system

➢ Locating harmonic sources

- ❖ On radial utility distribution feeders and industrial plant power systems, the main tendency is for the harmonic currents to flow from the harmonic-producing load to the power system source.
- ❖ The impedance of the power system is normally the lowest impedance seen by the harmonic currents. Thus, the bulk of the current flows into the source



General flow of harmonic current in radial system

- This general tendency of harmonic current flows can be used to locate sources of harmonics.
- Using a power quality monitor capable of reporting the harmonic content of the current, simply measure the harmonic currents in each branch starting at the beginning of the circuit and trace the harmonics to the source.
- Power factor correction capacitors can alter this flow pattern for at least one of the harmonics.
- Adding a capacitor to the circuit may draw a large amount of harmonic current into that portion of the circuit. In such a situation, following the path of the harmonic current will lead to a capacitor bank instead of the actual harmonic source.
- Thus, it is generally necessary to temporarily disconnect all capacitors to reliably locate the sources of harmonics.
- It is usually straightforward to differentiate harmonic currents due to actual sources from harmonic currents that are strictly due to resonance involving a capacitor bank.
- A resonance current typically has only one dominant harmonic riding on top of the fundamental sine wave.
- None of the harmonic sources presented earlier in this chapter produce a single harmonic frequency in addition to the fundamental.
- They all produce more than one single harmonic frequency.
- Waveforms of these harmonic sources have somewhat arbitrary waveshapes depending on the distorting phenomena, but they contain several harmonics in significant quantities. A single, large, significant harmonic nearly always signifies resonance.
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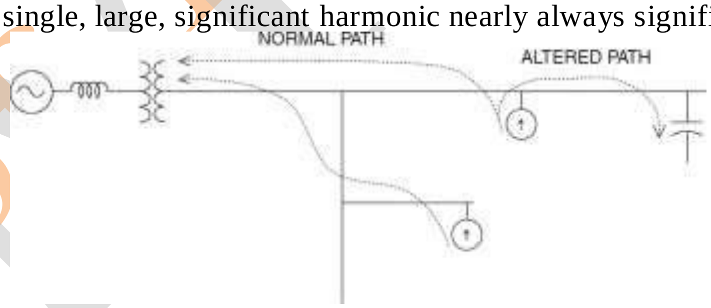


Power factor capacitors can alter the direction of flow of one of the harmonic components of the current.

- This fact can be exploited to determine if harmonic resonance problem are likely to exist in a system with capacitors. Simply measure the current in the capacitors.
- If it contains a very large amount of one harmonic other than the fundamental, it is likely that the capacitor is participating in a resonant circuit within the power system.
- Always check the capacitor currents first in any installations where harmonic problems are suspected.

➢ Power system response characteristics

- In power systems, the response of the system is equally as important as the sources of harmonics.
- Power systems are quite tolerant of the currents injected by harmonic-producing loads unless there is some adverse interaction with the impedance of the system.
- Identifying the sources is only half the job of harmonic analysis. The response of the power system at each harmonic frequency determines the true impact of the nonlinear load on harmonic voltage distortion.
- There are three primary variables affecting the system response characteristics, i.e.,
  - the system impedance,
  - the presence of a capacitor bank, and
  - the amount of resistive loads in the system

System impedance

- At the fundamental frequency, power systems are primarily inductive, and the equivalent impedance is sometimes called simply the short-circuit reactance.
- Capacitive effects are frequently neglected on utility distribution systems and industrial power systems.
- One of the most frequently used quantities in the analysis of harmonics on power systems is the short-circuit impedance to the point on a network at which a capacitor islocated.
- If not directly available, it can be computed from short-circuit study results that give either the short-circuit mega- voltampere (MVA) or the short-circuit current

Capacitor impedance

- Shunt capacitors, either at the customer location for power factor correction or on the distribution system for voltage control, dramatically alter the system impedance variation with frequency.
- Capacitors do not create harmonics, but severe harmonic distortion can sometimes be attributed to their presence.
- While the reactance of inductive components increases proportionately to frequency, capacitive reactance X_C decreases proportionately
- For three-phase banks, use phase-to-phase voltage and the three- phase reactive power rating.
- For single-phase units, use the capacitor voltage rating and the reactive power rating.

Parallel resonance

- All circuits containing both capacitances and inductances have one or more natural frequencies.
- When one of those frequencies lines up with a frequency that is being produced on the power system, a resonance may develop in which the voltage and current at that frequency continue to persist at very high values.
- From the perspective of harmonic sources the shunt capacitor appears in parallel with the equivalent system inductance (source and transformer inductances) at harmonic frequencies
- Furthermore, since the power system is assumed to have an equivalent voltagesource of fundamental frequency only,
- Parallel resonance occurs when the reactance of XC and the distribution system cancel each other out.
- The frequency at which this phenomenon occurs is called the parallel resonant frequency

Series resonance

- There are certain instances when a shunt capacitor and the inductance of a transformer or distribution line may appear as a series LC circuit to a source of harmonic currents.
- If the resonant frequency corresponds to a characteristic harmonic frequency of the nonlinear load, the LC circuit will attract a large portion of the harmonic current that is generated in the distribution system.
- A customer having no nonlinear load, but utilizing power factor correction capacitors, may in this way experience high harmonic voltage distortion due to neighboring harmonic sources
- During resonance, the power factor correction capacitor forms a series circuit with the transformer and harmonic sources.
- The inductance in series with the capacitor is that of the service entrance transformer.
- The series combination of the transformer inductance and the capacitor bank is very small (theoretically zero) and only limited by its resistance.
- The harmonic current corresponding to the resonant frequency will flow freely in this circuit.
- The voltage at the power factor correction capacitor is magnified and highly distorted

Effects of resistance and resistive load

- Loads and line resistances are the reasons why catastrophic harmonic problems from capacitors on utility distribution feeders are seldom seen.
- That is not to say that there will not be any harmonic problems due to resonance, but the problems will generally not cause physical damage to the electrical system components.
- The most troublesome resonant conditions occur when capacitors are installed on sub-station buses, either utility substations or in industrial facilities.
- In these cases, where the transformer dominates the system impedance and has a high X/R ratio, the relative resistance is low and the corresponding parallel resonant impedance peak is very sharp and high.
- This is a common cause of capacitor, transformer, or load equipment failure.

Effect of harmonics

The duration presence of long duration harmonic cause more serious effects on the various equipments connected to the power system.

- ***Amplitude of harmonics:*** Large amplitude harmonics of short duration under resonance condition cause dielectric breakdown due to over voltages.
- Now a day various devices and equipment being measured applications are more sensitive compared to the past.
- The capacitor used for power factor correction and in different filters decreases resulting in increasing in current drawn by capacitor beyond permissible limits.
- The capacitor acts as sink for harmonic currents resultant effect of harmonics is overloading , hence over heating increases dielectric stress and increase the power lost.
- The thermal failure of capacitor may take place because of higher temperature.
- Non sinusoidal power supplies results in reduction of torque of induction motor.
- It will increase interference with telephone, communication and logic circuits.
- Error in reading of induction type energy meters which are calibrated for pure sinusoidal A.C power.

- Higher order harmonics causes voltage stress and corona.
- Presence of harmonics in power system network can cause additional losses in power system network, overheating of transmission lines, transformers and generators etc.
- Malfunction or even failure of electronic or computer controls.
- Hence it is clear that day by day the increase in harmonic contents will impose new problems on operations of electronic equipment.
- The energy efficient electronic equipment that will be produced in future trends result in poor performance due to the voltage distortion.
- Hence it is essential to have the proper coordination between the supply authorities and consumers regarding the power quality problem, their causes and results and solutions available to eliminate them.

Harmonic indices

The two most commonly used indices for measuring the harmonic content of a waveform are the total harmonic distortion and the total demand distortion. Both are measures of the effective value of a waveform and may be applied to either voltage or current.

Total harmonic distortion(THD)

The THD is a measure of the effective value of the harmonic components of a distorted waveform. That is, it is the potential heating value of the harmonics relative to the fundamental. This index can be calculated for either voltage or current:

The ratio of the root mean square of the harmonic content to the rms value of the fundamental quantity, expressed as a per- cent of the fundamental

$$\mathrm{THD} = \frac{\sqrt{\sum_{h>1}^{h_{max}} M_h^2}}{M_1}$$

where Mh is the rms value of harmonic component h of the quantity M.

The rms value of a distorted waveform is the square root of the sum of the squares

Total demand distortion(TDD)

The ratio of the root mean square of the harmonic current to the rms value of the rated or maximum demand fundamental current, expressed as a percent.

$$\mathrm{TDD} = \frac{\sqrt{\sum_{h=2}^{h_{max}} I_h^2}}{I_L}$$

Harmonic Distortion

- Harmonic distortion is caused by nonlinear devices in the power system. A nonlinear device is one in which the current is not proportional to the applied voltage.
- While the applied voltage is perfectly sinusoidal, the resulting current is distorted. Increasing the voltage by a few percent may cause the current to double and take on a different wave shape.

- 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. This multiple is called a harmonic of the fundamental.
- The sum of sinusoids is referred to as a Fourier series, 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 harmonics is often a clue that there is something wrong—either with the load equipment or with the transducer used to make the measurement.

Harmonics Vs transients

- Harmonics represent distortion of sinusoidal voltage or current signals. They are caused by nonlinear elements in the system like saturating cores or switching elements like thyristors.
- The Fourier series analysis of a distorted waveform shows presence of harmonics. They are present in every cycle of the signal.
- On the contrary, transients, which are also distortions, are present only for a limited period of time. They are caused by abrupt switching on or switching off of a load or occurrence of a fault.
- We normally use time domain methods to analyse transients and frequency domain methods to analyse harmonics.

Voltage versus Current Distortion

1. The harmonic voltages are too great (the voltage too distorted) for the control to properly determine firing angles.
2. The harmonic currents are too great for the capacity of some device in the power supply system such as a transformer, and the machine must be operated at a lower than rated power.
3. The harmonic voltages are too great because the harmonic currents produced by the device are too great for the given system condition.

- Nonlinear loads appear to be sources of harmonic current in shunt with and injecting harmonic currents into the power system.
- For nearly all analyses, it is sufficient to treat these harmonic-producing loads simply as current sources. voltage distortion is the result of distorted currents passing through the linear, series impedance of the power delivery system, although, assuming that the source bus is ultimately a pure sinusoid, there is a nonlinear load that draws a distorted current.
- The harmonic currents passing through the impedance of the system cause a voltage drop for each harmonic.
- This results in voltage harmonics appearing at the load bus. While the load current harmonics ultimately cause the voltage distortion, it should be noted that load has no control over the voltage distortion.
- The same load put in two different locations on the power system will result in two different voltage distortion values.
- IEEE Standard 519-1992, Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems:
    1. The control over the amount of harmonic current injected into the system takes place at the end-use application.
    2. Assuming the harmonic current injection is within reasonable limits, the control over the voltage distortion is exercised by the entity having control over the

system impedance, which is often the utility.

➢ Interharmonics

- Voltages or currents having frequency components that are not integer multiples of the frequency at which the supply system is designed to operate (e.g., 50 or 60 Hz) are called interharmonics. They can appear as discrete frequencies or as a wideband spectrum. Interharmonics can be found in networks of all voltage classes.
- Causes: Static frequency converters, cycloconverters, induction furnaces, and arcingdevices. Power line carrier signals can also be considered as interharmonics.
- Interharmonic currents can excite quite severe resonances on the power system as the varying interharmonic frequency becomes coincident with natural frequencies of the system. They have been shown to affect power-line-carrier signaling and induce visual flicker in fluorescent and other arc lighting as well as in computer display devices.
- Since interharmonics can assume any values between harmonic frequencies, the interharmonic spectrum must have sufficient frequency resolution.
- Thus, a single-cycle waveform sample is no longer adequate to compute the interharmonic spectrum since it only provides a frequency resolution of 50 or 60 Hz.
- Any frequency in between harmonic frequencies is lost. The one-cycle waveform though is commonly used to compute the harmonic spectrum since there is no frequency between harmonic frequencies.

➢ Resonance

- A condition in which the natural frequencies of the inductances and capacitances in the power system are excited and sustained by disturbing phenomena. This can result in excessive voltages and currents.
- Waveform distortion, whether harmonic or nonharmonic, is probably the most frequent excitation source.
- Also, various short-circuit and open-circuit faults can result in resonant conditions.

Parallel resonance

- All circuits containing both capacitances and inductances have one or more natural frequencies.
- When one of those frequencies lines up with a frequency that is being produced on the power system, a resonance may develop in which the voltage and current at that frequency continue to persist at very high values.
- This is the root of most problems with harmonic distortion on power systems.
- From the perspective of harmonic sources the shunt capacitor appears in parallel with the equivalent system inductance (source and transformer inductances) at harmonic frequencies
- Furthermore, since the power system is assumed to have an equivalent voltage source of fundamental frequency only,
- Parallel resonance occurs when the reactance of XC and the distribution system cancel each other out.
- The frequency at which this phenomenon occurs is called the parallel resonant frequency

Series resonance

- There are certain instances when a shunt capacitor and the inductance of a transformer or distribution line may appear as a series LC circuit to a source of harmonic currents.
- If the resonant frequency corresponds to a characteristic harmonic frequency of the nonlinear load, the LC circuit will attract a large portion of the harmonic current that isgenerated in the distribution system. A customer having no nonlinear load, but utilizing power factor correction capacitors,may in this way experience high harmonic voltage distortion due to neighboring harmonic sources
- During resonance, the power factor correction capacitor forms a series circuit with the transformer and harmonic sources.
- The inductance in series with the capacitor is that of the service entrance transformer.
- The series combination of the transformer inductance and the capacitor bank is very small (theoretically zero) and only limited by its resistance.
- The harmonic current corresponding to the resonant frequency will flow freely in this circuit.
- The voltage at the power factor correction capacitor is magnified and highly distorted

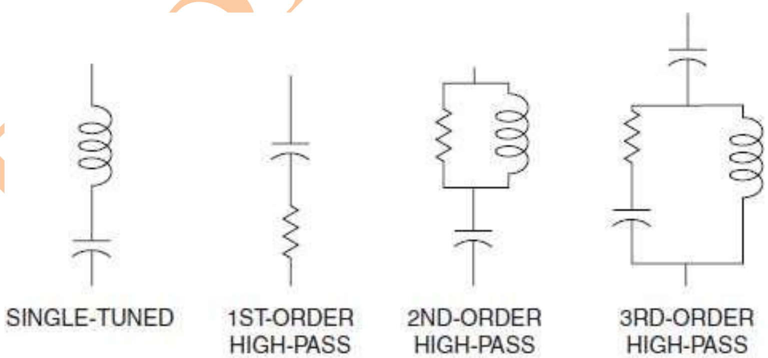
Devices for controlling harmonic distortion

- Three different solutions can be adopted in the reduction of the harmonic distortion:
  i. Reduction of harmonic emission from non-linear loads, by modifications to their structure;
  ii. High harmonic filters (passive and active); and
  iii. Isolation and harmonic reduction transformers.
- The devices used to control harmonic distortion are,
  i. Reinforce distribution system
  ii. Passive Filters
  iii. Active Filters
  iv. Isolation transformers
  v. Harmonic mitigation transformer
  vi. Multi-pulse converters

Passive and active filters

Passive Filters:

- They include devices that provide low impedance paths to divert harmonics to ground and devices that create a high impedance path to discourage the flow of harmonics.



Common passive filter configurations.

- Both of these devices, by necessity, change the impedance characteristics of the circuits into which they are inserted.
- Another weakness of the passive harmonic technologies is that they cannot adapt to changes in electrical systems in which they operate.
- Notch filters can

provide power factor correction in addition to harmonic suppression. In fact, power factor correction capacitors may be used to make notch filters.

Advantages of Passive filters:

1. Simple in construction, less costly and efficient
2. Serves dual purpose: harmonic filtration and power factor correction of load.

Disadvantages of Passive filters:

1. Cannot function under saturated condition. Number of passive filters installed must be equal to the number of harmonic levelsto be compensated.
2. Connection of passive filters necessities a specific analysis of each installation.
3. Non adaptability to system variations.
4. Bulky in size.
5. Tendency to resonate with the other load.

Active filters:

- ❖ When the number of harmonics to be filtered, large no of branches of passive filters will be required .
- ❖ The large no of branches of passive filters will be required.
- ❖ The actual number of branches will depend upon no of harmonic level of branches will depend upon no of harmonic level to be compensated.
- ❖ Hence, because of passive filter use for filtration of large no of harmonics results in large size &more cost.
- ❖ Introduction of self commutated devices e.g. MOSFETS, IGBT etc, accelerated the research in design of active filter & resulted low cost, high performance active filter suitable to eliminate the harmonics of different orders to overcome the drawbacks of passive filters.
- ❖ Active filters compensate voltage of current harmonic signal measured.
- ❖ The injected voltage or current harmonic signal measured.
- ❖ The injected voltage or current harmonic signals in to the power system network is of same magnitude and opposite in phase of the measured harmonic signal.
- ❖ It comprises power converter and control loop which controls the harmonics injection of the filter as the function of harmonic signal measure.

Advantages of Active filters:

1. Superior filtering performance
2. Smaller physical size
3. Flexibility

➢ Harmonic Distortion Evaluations

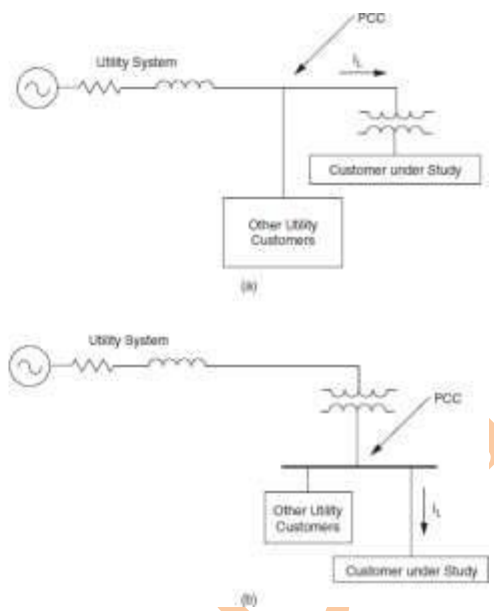
1. End users

- ❖ For individual end users, IEEE Standard 519-1992limits the level of harmonic current injection at the point of common coupling (PCC). This is the quantity end users have control over.
- ❖ Recommended limits are provided for both individual harmonic components and the total demand distortion.
- ❖ These limits are expressed in terms of a percentage of the end user’s maximum demand current level, rather than as a percentage of the fundamental. This is intended to provide a common basis for evaluation over time.

2. *The utility*.

- Since the harmonic voltage distortion on the utility system arises from the interaction between distorted load currents and the utility system impedance, the utility is mainly responsible for limiting the voltage distortion at the PCC.
- The limits are given for the maximum individual harmonic components and for the total harmonic distortion (THD).
- These values are expressed as the percentage of the fundamental voltage. For systems below 69 kV, the THD should be less than 5 percent. Sometimes the utilitysystem impedance at harmonic frequencies is determined by the resonance of power factor correction capacitor banks. This results in a very high impedance and high harmonic voltages.
- Therefore, compliance with IEEE Standard 519-1992 often means that the utility must ensure that system resonances do not coincide with harmonic frequencies present in the load currents

3. *Point of common coupling*



- Evaluations of harmonic distortion are usually performed at a point between the end user or customer and the utility system where another customer can be served. This point is known as the point of common coupling.
- The PCC can be located at either the primary side or the secondary side of the service transformer depending on whether or not multiple customers are supplied from the transformer.
- In other words, if multiple customers are served from the primary of the transformer, the PCC is then located at the primary.
- On the other hand, if multiple customers are served from the secondary of the transformer, the PCC is located at the secondary.

➢ IEEE and IEC standards

IEEE Standards:

IEEE power quality standards: Institute Of Electrical and Electronics Engineer.
IEEE power quality standards: International Electro Technical Commission.
IEEE power quality standards: Semiconductor Equipment and Material International.
IEEE power quality standards: The International Union for Electricity Applications
IEEE Std 519-1992: IEEE Recommended practices and requirements for Harmonic control in Electric power systems.
IEEE Std 1159-1995: IEEE Recommended practices for monitoring electrical power
IEEE std 141-1993, IEEE Recommended practice for electric power distribution for industrial plants.

IEEE std 1159-1995, IEEE recommended practice for Monitoring electrical power quality.

IEC Standards:

Part 1: General.

These standards deal with general considerations such as introduction, fundamental principles, rationale, definitions, and terminologies. They can also describe the application and interpretation of fundamental definitions and terms. Their designation number is **IEC 61000-1-x.**

Part 2: Environment.

These standards define characteristics of the environment where equipment will be applied, the classification of such environment, and its compatibility levels.

Their designation number is **IEC 61000-2-x.**

Part 3: Limits.

These standards define the permissible levels of emissions that can be generated by equipment connected to the environment. They set numerical emission limits and also immunity limits.

Their designation number is **IEC 61000-3-x.**

Part 4: Testing and measurement techniques.

These standards provide detailed guidelines for measurement equipment and test procedures to ensure compliance with the other parts of the standards.

Their designation number is **IEC 61000-4-x.**

Part 5: Installation and mitigation guidelines.

These standards provide guidelines in application of equipment such as earthing and cabling of electrical and electronic systems for ensuring electromagnetic compatibility among electrical and electronic apparatus or systems. They also describe protection concepts for civil facilities against the high-altitude electromagnetic pulse (HEMP) due to high altitude nuclear explosions.

They are designated with **IEC 61000-5-x.**

Part 6: Miscellaneous.

These standards are generic standards defining immunity and emission levels required for equipment in general categories or for specific types of equipment.

Their designation number is **IEC 61000-6-x.**

IEC standards relating to harmonics generally fall in parts 2 and 3. Unlike the IEEE standards on harmonics where there is only a single publication covering all issues related to harmonics, IEC standards on harmonics are separated into several publications. There are standards dealing with environments and limits which are further broken down based on the voltage and current levels.