What is Electric Power Quality?

- To maintain the power distribution bus voltages to near sinusoidal waveform at rated voltage magnitude & frequency.
- It is a measure of how well electric power can be utilized by customers.

Need for Power Quality:

- ➢ In the recent years, power quality (PQ) has become a significant issue for both power suppliers and customers.
- ➢ There have been three important changes in relation to power quality.
- First of all, the characteristics of load have become so complex that the voltage and current of the power line connected with these loads are easy to be distorted.
- Lately, non-linear loads with power electronic interface that generate large harmonic current have been greatly increased in power system.
- Next, the end-user equipments have become more sensitive to power quality than before.

Main Power Quality Problems/Issues:

1. Harmonic distortion
2. Momentary Interruptions
3. Temporary Interruptions
4. Long Term outage
5. Noise
6. Voltage Sag
7. Voltage Swell
8. Voltage Spikes
9. Undervoltages

Voltage based Power Quality Problems:

- Voltage sag
- Voltage swell
- Voltage Interruption

- Under/over Voltage
- Voltage Flicker
- Harmonic Distortion
- Voltage Notching
- Transient Disturbance
- Outage and frequency variation

Current based Power Quality Problems:

- Reactive Power Compensation
- Voltage Regulation
- Current Harmonic Compensation
- Load Unbalancing (for 3-phase systems)
- Neutral Current Compensation (for 3-phase 4-wire systems)

Sources of Power Quality Problems:

- Power electronic devices
- IT and office equipments
- Arching devices
- Load switching
- Large motor starting
- Embedded generation
- Sensitive Equipment
- Storm and environmental related damage

Harmonic Distortion:

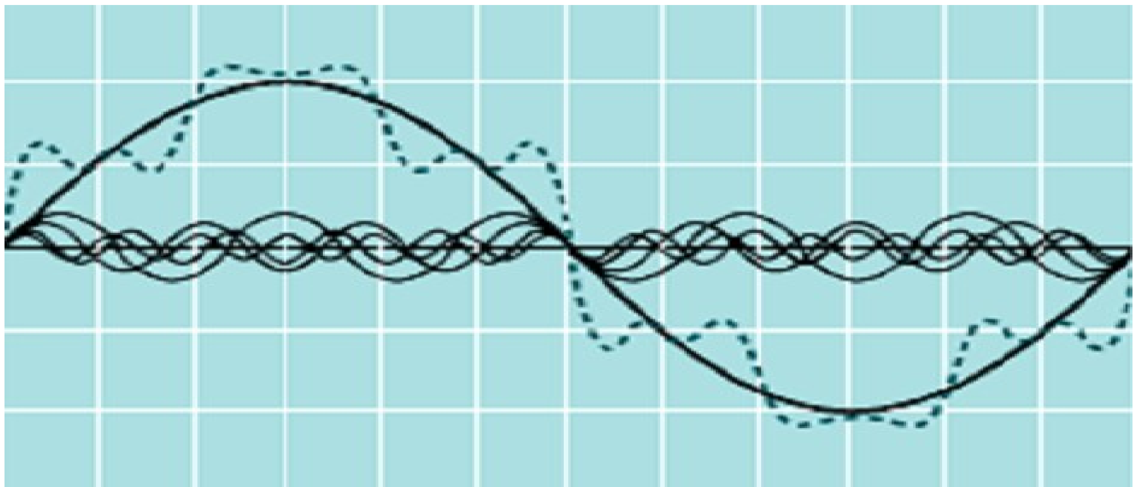

Fig. : Harmonic Distortion

Definition: Continuous or sporadic distortions of 50/60 Hz voltage sine waveform.

Causes: By micro-processor-based loads in the building such as computer power supplies, lighting ballasts, and electronic adjustable speed drives, telecommunications or computer interface; overheating in motors, transformers or neutral conductors; decreased motor performance; deterioration of power factor capacitors; or erratic operation of breakers, fuses, and relays.

Momentary Interruptions:

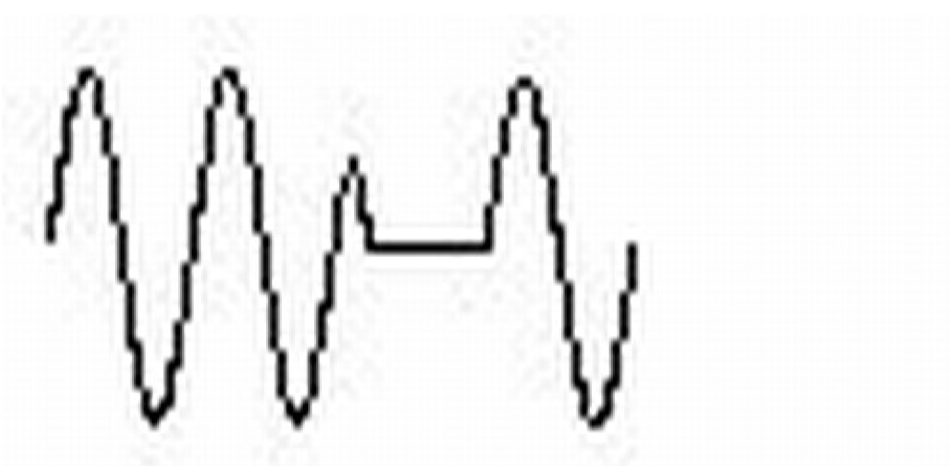

Fig. : Momentary Interruptions

Definitions: A very short loss of utility power that lasts up to 2 seconds.

Causes: Utility switching operations to isolate a nearby electrical problems.

Temporary Interruptions:

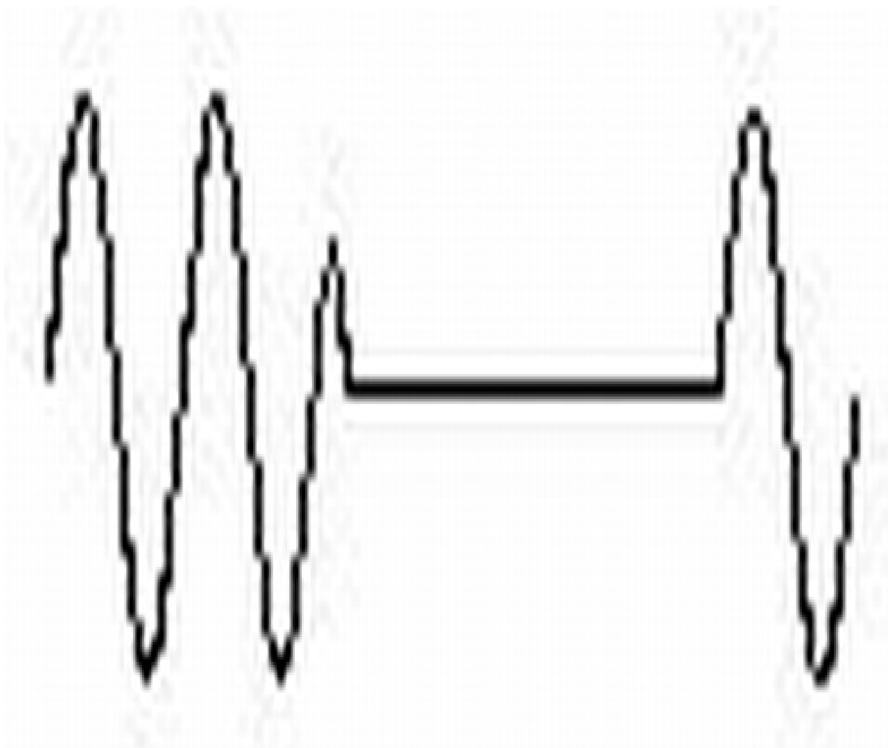

Fig. : Temporary Interruptions

Voltage sags or Voltage dips:

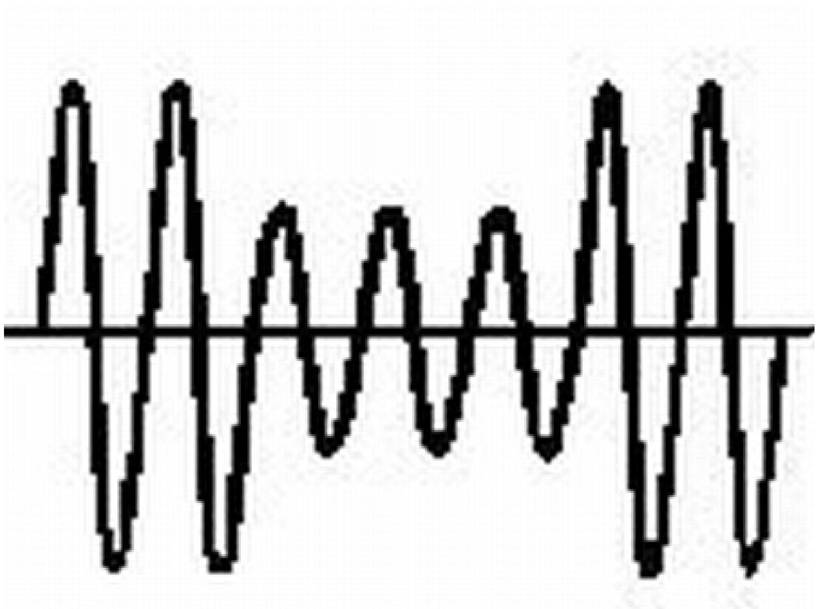

Fig. : Voltage Sag

Definitions: A short-term decrease in voltage lasting any where from milliseconds up to a few seconds.

- Sags starve a machine of the electricity it needs to function, causing computer crashes or equipment lock-ups.

Causes: Equipment start-up such as elevators, heating & air-conditioning equipment, compressors, and copy machines or nearby short ckts on the utility system.

Voltage swells:

Fig. : Voltage Swell

Voltage swell:

Definition: A short term increase in voltage lasting anywhere from milliseconds up to a few seconds.

- Voltage swells may lead to damage of sensitive equipment.

Causes: Due to start/stop of heavy loads and poorly regulated transformers.

Spikes:

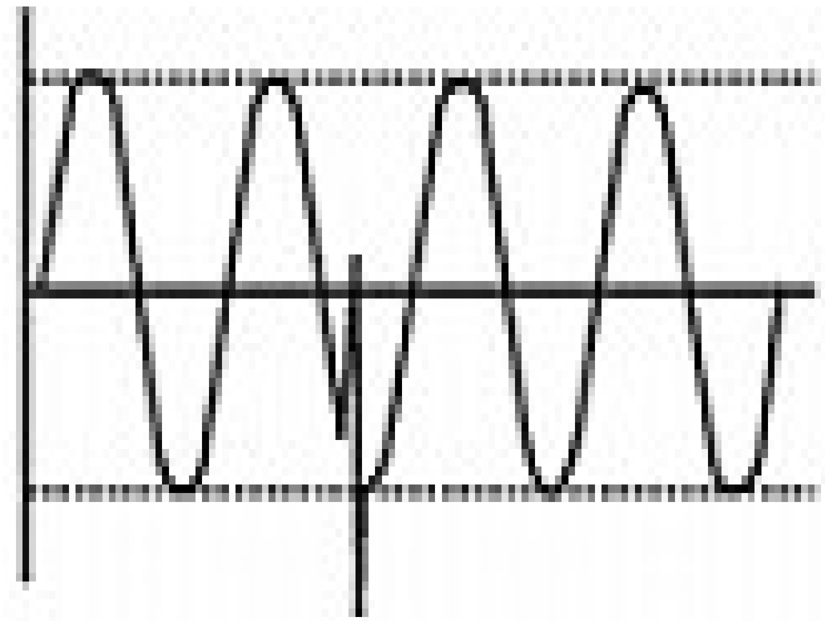

Fig. : Spikes

Definition: A very brief (nanoseconds to milliseconds) change in voltage ranging from tens to thousands of volts.

Causes: Produced by utility and conditioners or motors switching on or offs, or to utility activities, such as capacitor switching.

Undervoltage:

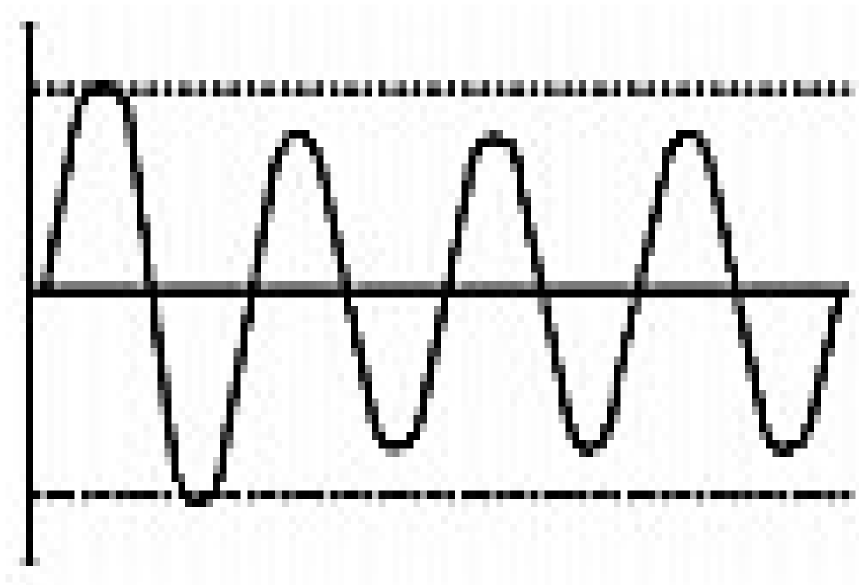

Fig. : Undervoltage

Definition: A decrease in voltage lasting longer than a few seconds.

Causes: Due to undersized wiring at the facility; by overloaded utility circuits which results in brownouts.

Effects of PQ Quantities:

Voltage sags/dips: Machine/process downtime, scrap cost, cleanup costs, product quality and their repair costs all contribute to make these types of problems costly to the end user.

Transients: Tripping, component failure, hardware reboot required, software 'glitches', poor product quality.

Harmonics: Transformer and neutral conductor heating leading to reduced equipment life span; audio hum, video 'flutter', software glitches, power supply failure.

Flicker: Visual Irritation

Power Quality Problems & their effects:

- Nonlinear devices inject harmonics in the AC system and increase overall reactive power demanded by the equipment load.
- Cause of power system harmonics is the supply voltage distortion at PCC.
- When a static power converter injects a distorted current into the supply network, a harmonic voltage is developed across the source impedance.
- The supply voltage at the PCC, being difference between the source voltage and voltage across the source impedance, is distorted.

Table: Categories of Power Quality Variation

Categories	Spectral Content	Typical Duration	Typical Magnitudes
1.0 Transients			
1.1 Impulsive			
1.1.1 Voltage	> 5 kHz	< 200 μs	
1.1.2 Current	> 5 kHz	< 200 μs	
1.2 Oscillatory			
1.2.1 Low Frequency	< 500 kHz	< 30 cycles	
1.2.2 Medium Frequency	300–2 kHz	< 3 cycles	
1.2.3 High Frequency	> 2 kHz	< 0.5 cycle	
2.0 Short-Duration Variations			
2.1 Sags			
2.1.1 Instantaneous		0.5–30 cycles	0.1–1.0 pu
2.1.2 Momentary		30–120 cycles	0.1–1.0 pu
2.1.3 Temporary		2 sec–2 min	0.1–1.0 pu
2.2 Swells			
2.1.1 Instantaneous		0.5–30 cycles	0.1–1.8 pu
2.1.2 Momentary		30–120 cycles	0.1–1.8 pu
2.1.3 Temporary		2 sec–2 min	0.1–1.8 pu
3.0 Long-Duration Variations			
3.1 Overvoltages		> 2 min	0.1–1.2 pu
3.2 Undervoltages		> 2 min	0.8–1.0 pu
4.0 Interruptions			
4.1 Momentary		< 2 sec	0
4.2 Temporary		2 sec–2 min	0
4.3 Long-Term		> 2 min	0
5.0 Waveform Distortion			
5.2 Voltage	0–100th Harmonic	steady-state	0–20%
5.3 Current	0–100th Harmonic	steady-state	0–100%
6.0 Waveform Notching	0–200 kHz	steady-state	
7.0 Flicker	< 30 Hz	intermittent	0.1–7%
8.0 Noise	0–200 kHz	intermittent	

Current Distortion caused by nonlinear load:

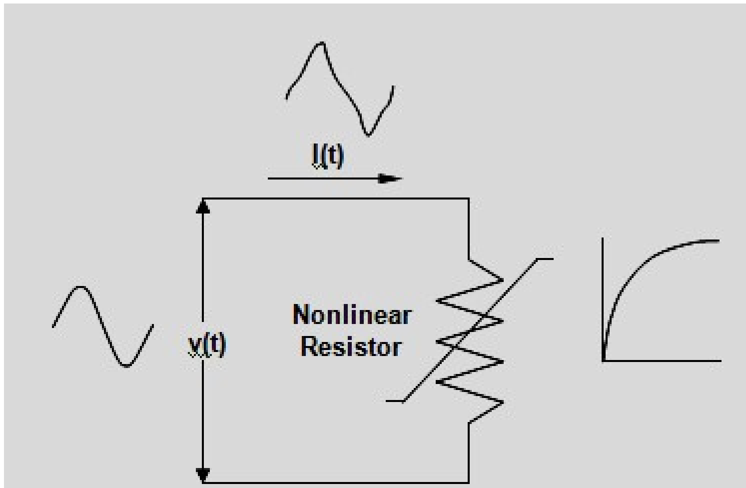

Fig.: Current Distortion caused by Nonlinear Load

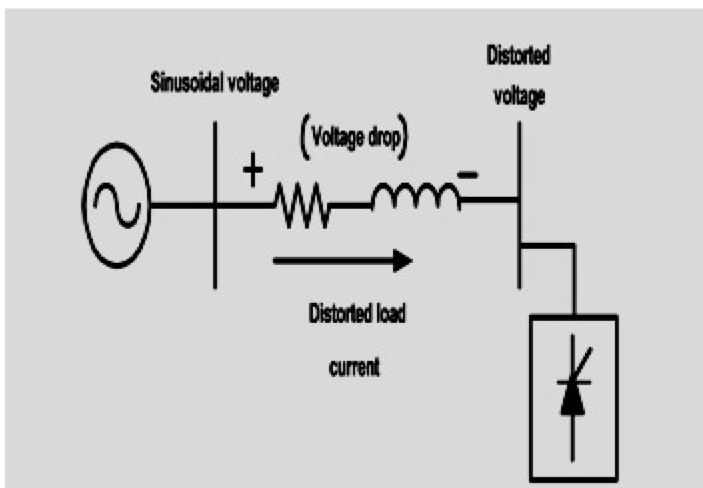

Fig.: Harmonic current flow through the system impedance result in harmonic voltage at the load bus

Common Sources of Harmonics:

- Rectifiers,
- DC motor drives,
- Adjustable Power Supplies,

- Uninterruptible Power Supplies (UPS),
- Arc furnaces,
- Static var generators,
- Cycloconverter,
- Static motor starters, and electronic lighting ballasts,
- Switching power supplies, etc.

Detrimental Effects of Harmonics:

- Detrimental effects of harmonics injected into the utility.

1. Excessive losses and heating in motors, capacitors and transformers connected to the system,
2. Insulation failure due to the overheating and over voltages,
3. Overloading and overheating of the neutral conductors with loss of conductor life and possible risk of fire,
4. Malfunctioning of sophisticated electronic equipments,
5. Higher dielectric stress and harmonic resonance, with the capacitors present in the system,
6. Saturation in transformer, and interference with the communication network.
7. Interference with the communication network.

Power Quality Standards:

- Various standards are set to limit the harmonics generated by nonlinear loads. IEEE standard 519 was first issued in 1991. It gave the first guidelines for system harmonics limitations and revised in 1991. It gave the first guidelines for system harmonics limitations and revised in 1992.
- The 5% voltage distortion limit was recommended below 69 kV, while the limit on current distortion is fixed in the range of 2.5% to 20% depending upon the size of the customer and system voltage. IEEE 519 standard limits harmonics primarily at the service entrance, while IEC 1000-3-2 is applied at the terminals of end-user equipment.

Table : Power Quality Standards

Performance	Standards
Classification of power quality	IEC 61000-2-5:1995; IEC 61000-2-1:1990; IEEE 1159:1995
Transients	IEC 61000-2-1:1990; IEEE c62.41:1991; IEEE 1159:1995; IEC 816:1984
Voltage sag/swell and interruptions	IEC 61009-2-1:1990; IEEE 1159:1995
Harmonics	IEC 61000-2-1:1990;IEEE 519:1992; IEC 61000-4-7:1991
Voltage flicker	IEC 61000-4-15:1997

Problems of power Electronic converter:

- Serious Problem of Power Electronic converter is drawing reactive power from the source, leads to under utilization of source capacity due to:

1. Increased losses in the transmission and distribution,
2. Overrated equipments within the AC system, due to larger current drawn for a given real power demand, and low efficiency due to more losses, and
3. Poor voltage regulation.

Classical Solution:

- Classically, shunt passive filters, consists of tuned LC filters and/or high pass filters are used to suppress the harmonics, and power capacitors are employed to improve the power factor of the utility/mains.
- The shunt passive filters are tuned most of the time on a particular harmonic frequency to be eliminated.

- So that it exhibits low impedance at the tuned frequency than the source impedance, to reduce the harmonic current flowing into the source (i.e. the filtering characteristics are determined by the impedance ratio of the source and passive filter).

Problems of Passive Filters:

1. The source impedance, which is not accurately known and varies with the system configuration, strongly influences the filtering characteristics of shunt passive filter.
2. The shunt passive filter acts as a sink to the harmonic current flowing from the source. In the worst case, shunt passive filter may fall in series resonance with the source impedance.
3. At specific frequency, an anti-resonance or parallel resonance may occur between the source impedance. And shunt passive filter, which is called harmonic amplification.
4. As both the harmonics and fundamental current component flow into the filter, the capacity of the filter must be rated by taking into account both the currents.
5. Increase in harmonic current component can be overload the filter.
6. Also, if a good level of correction is targeted; one needs as many filters as the number of harmonics to be eliminated.

Recent Trends:

- The sensitivity of these problems has attracted the attention of researchers to develop techniques with adjustable and dynamic components. Extensive research is being carried out in the field of harmonics and reactive power compensation, to overcome all these limitations.
- Recently, Active Power Filters (APFs) are seen as a viable alternative over the classical passive filters and static var compensators to compensate harmonics and reactive power requirement of nonlinear loads.
- Such equipments generally known as compensators used either Thyristor-Switched Capacitors (TSCs) or Thyristor-Controlled Reactors (TCRs) with fixed (permanently connected) power factor correcting capacitors. They also provide harmonic filtering, when combined with appropriate tuning reactors. But they were large systems involving a number of major components such as transformers, capacitors, reactors, switchgears, thyristors etc, resulting in considerable size and installation cost.

- The basic principle of shunt active filter was originally presented by Sasaki and Machida in 1971. The shunt active filter is controlled in such a way as to actively shape the source current into sinusoid by injecting the compensating current in phase opposition. This is considered the archetype of shunt active filters.
- Since a linear amplifier was used to generate the compensating current, its realization was unrealization was unreasonable due to low efficiency. In 1976, Gyugyi and Strycula presented a family of shunt and series filters, and established the concept of active filters consisting of PWM inverters using power transistors, but lacking on the part of control scheme for practical implementation.
- In the beginning, shunt active power filters were proposed to suppress the harmonic generated by large rated thyristor conveters and inverters used HVDC transmission systems. However, they could not be realized in real power systems due to non-availability of high-power, high speed switching devices in the 1970's.
- With remarkable development and switching speed and capacity of the power semiconductor devices in the 1980's, shunt active power filters using PWM inverters have been studied, with an attention to their practical implementation in real power systems. However, their practical uses were delayed due to the lack of better control strategies, high losses in the main circuit filter, higher initial cost and inferior efficiency.
- Advancement in power semiconductor and microelectronics technology have encouraged the researchers to develop the control strategies, taking into account transient states as well as steady states, high efficiency, and large capacity converters required in power circuit of the active filter.
- Today, remarkable progress in the capacity and switching speed of GTOs and IGBTs, in conjunction with microcomputers and digital signal processors (DSPs) have made it possible to realize APFs with computer control.

Topologies

- Various types of active power filters have been proposed in literature and are classified based on converter type, configurations and objective of installation. Mainly, two types of converter are used for development of active filters: a voltage source PWM converter and a current source PWM converter.

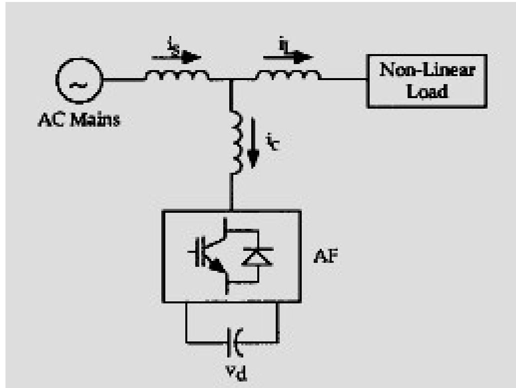

Fig. : Voltage source PWM converter based shunt active power filter

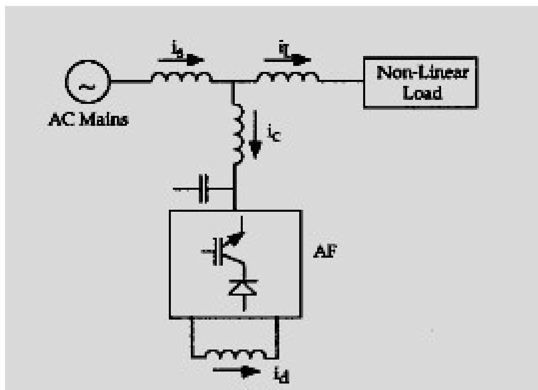

Fig.: Current source PWM converter based shunt active power filter

- The series active filter connected before the load in series with the mains, using matching transformer. It is mainly used to eliminate voltage harmonics, to reduce negative sequence voltage and regulate the voltage on three-phase system. It is mainly installed by utilities to compensate voltage harmonics and damaging harmonic propagation.

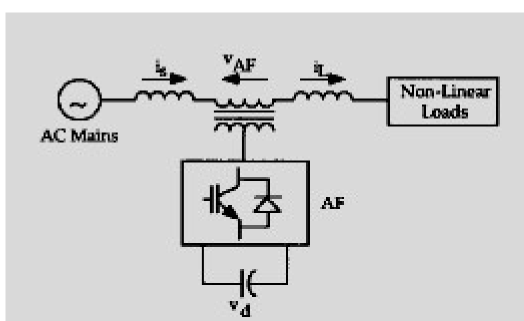

Fig.: Series active power filter

- The hybrid filters, which are the combination of an active series/shunt and a passive filter . The main purpose is to reduce the rating of active filter and initial cost. The advantage of these configurations is that they can be used with the existing passive filters and are considered as prospective alternatives to the shunt or series active filter used alone.

Hybrid Filters:

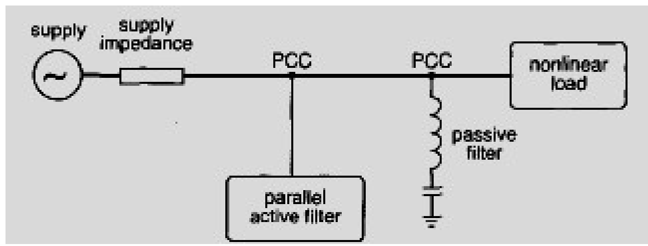

Fig.: Combination of shunt active and shunt passive filter

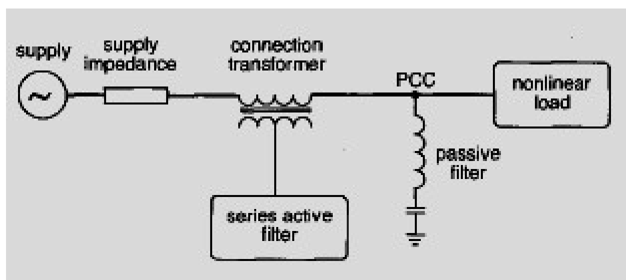

Fig..: Combination of series active and shunt passive filter

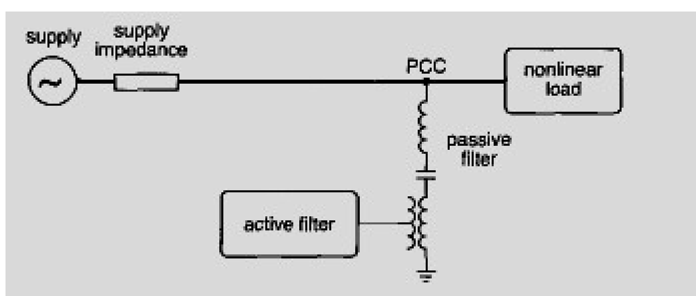

Fig.: Active filter connected in series with shunt passive filter

UPQC:

- Recently a new topology, combination of active series and active shunt filter is proposed known as Unified Power Quality Conditioner (UPQC) or Active Power Line Conditioner (APLC) [19, 56].

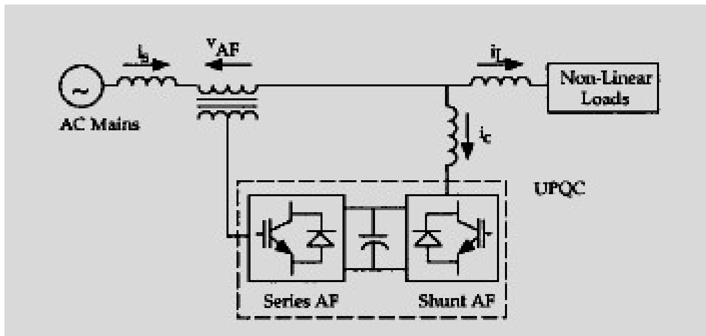

Fig.: Schematic diagram of unified power quality conditioner (UPQC)

Responsibilities:

Both customers and utilities responsible for the installation of APFs. Therefore, from the installation point of view APFs are classified into two groups:

- Active filters installed by individual customer in their own premises near the harmonic producing loads, and
- Active filters installed by utilities at the substation and/or on the distribution feeders.