PROBLEMS OF POWER QUALITY AND POWER SOLUTION

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PROBLEMS OF POWER QUALITY AND POWER SOLUTION

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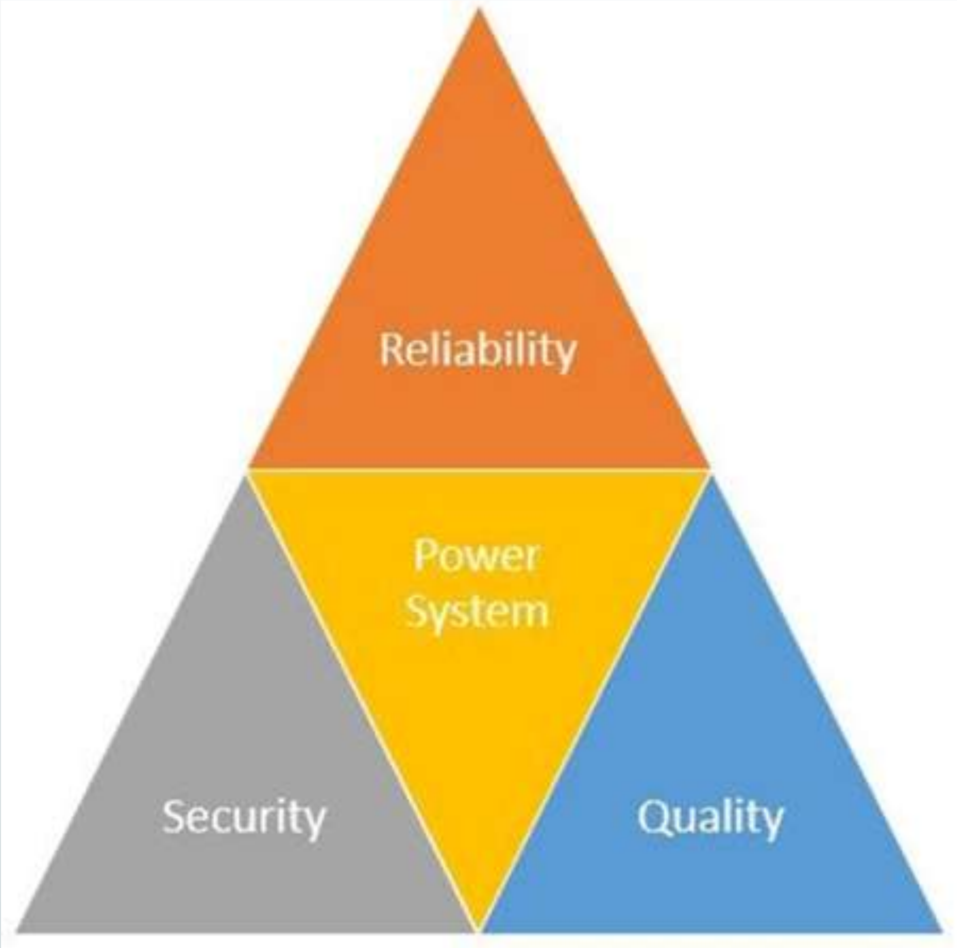
I. POWER SYSTEM RELIABILITY

The power system reliability is the probability of a normal electrical grid operation at a given time.

-Reliability is the likelihood that a system or component will perform its function without failure at any specified time.

-Be less loss and least interruption.

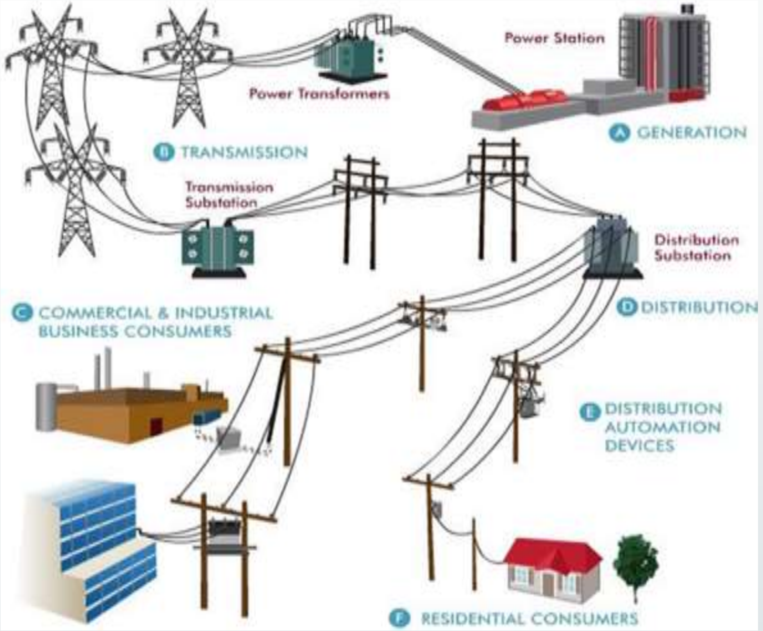
-Acceptable voltage & frequency at the end user equipment.



<u>Aim of The Electric Power System</u>:

- To generate electrical energy and to deliver this energy to end-user equipment at an acceptable voltage.
- Power quality becoming important to electricity consumers at all levels of usage.
- The end-users need to be aware to protect from quality disturbances by installing protective equipment.
- A power system has been divided into three independent areas of operation as follows:

1. **Generation System** : Facilities to the generation of electricity from economic sources (Power Station)
2. **Transmission system** : To transmit large energy blocks from generation facilities to specific geographical areas.(Main Primary substation)
3. **Distribution system** : Within a specific geographical area distribute the energy to individual consumers (Residential, Commercial and Industrial ,etc.)



Synchronization system for Generators

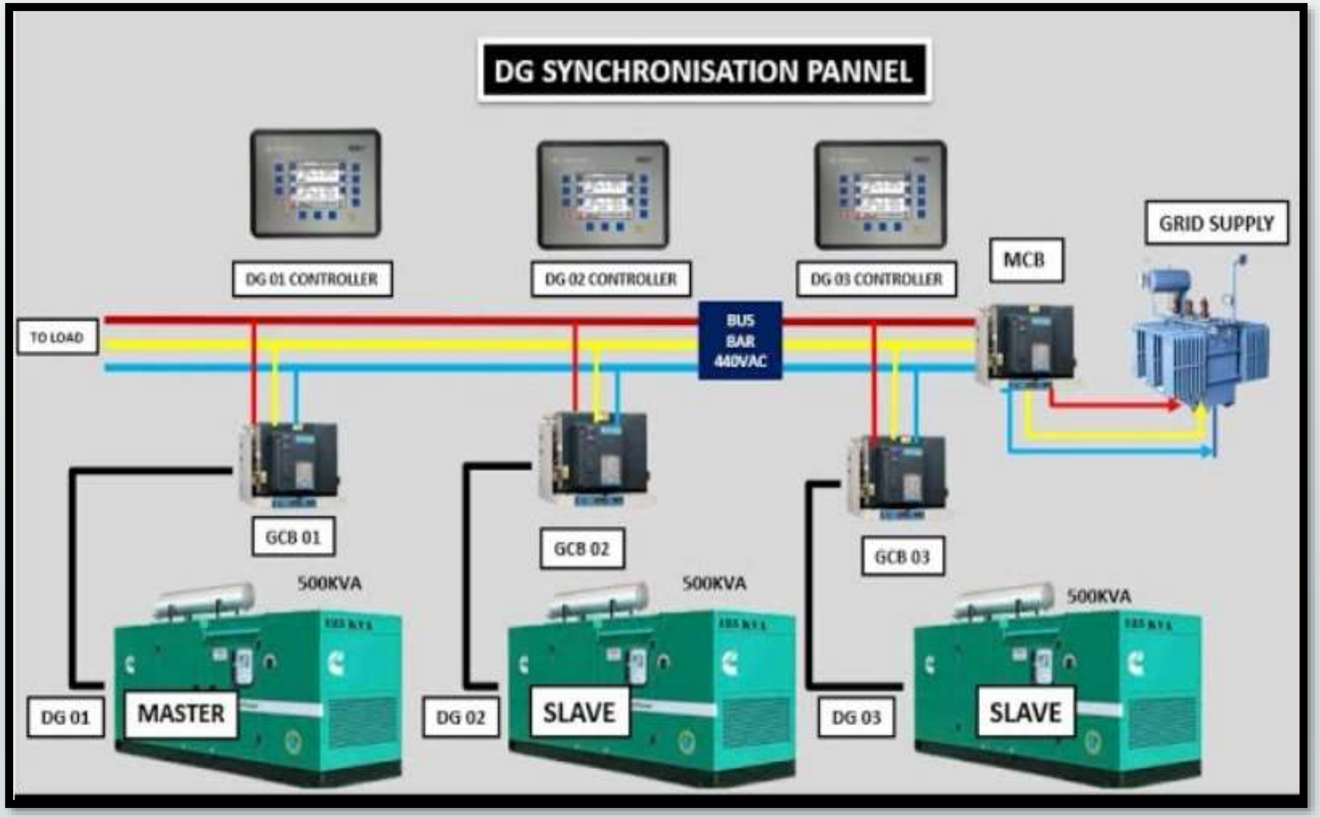
Generator synchronization is the process of matching parameters such as voltage, frequency, phase angle, phase sequence, and waveform of alternator (generator) or other source with a healthy or running power system. This is done before the generator is connected to the power system.

Requirement For Synchronization:

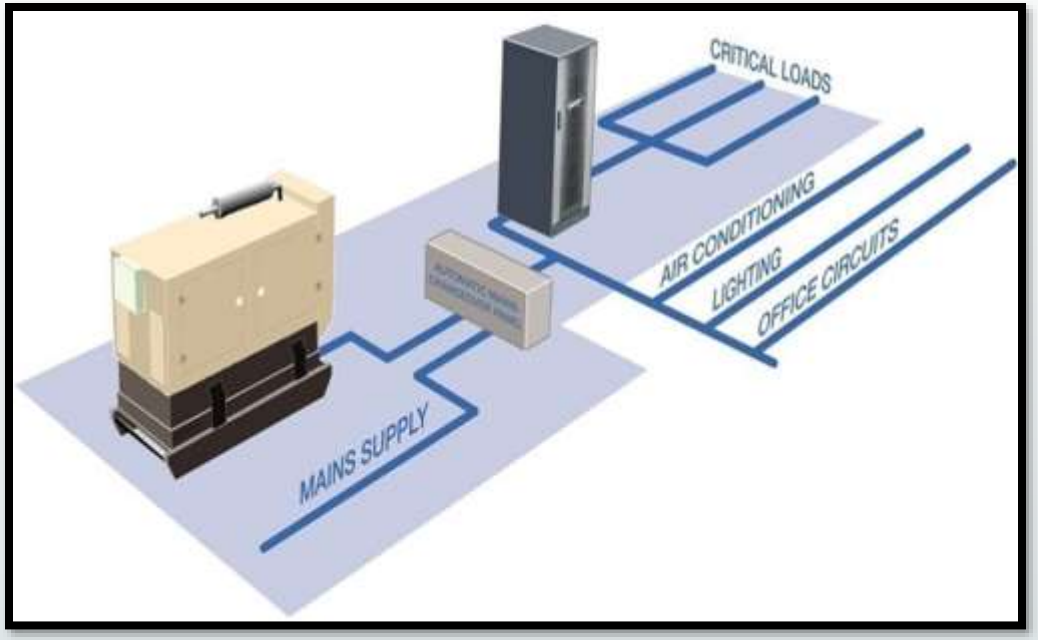
1- The frequency of all generators is equal.

2- The voltage of all generators is equal.

3- Match the sequence phase in all generators.



▪ Synchronization system for UPS and Generators



Data centers today invariably use UPS systems to protect their sensitive IT equipment from mains power aberrations and short-term power outages. However, longer-term blackouts are also a threat.

Accordingly, protection against both short- and long-term power outages is essential – and the only way to provide this comprehensively is to operate a UPS and a generator as a complementary pair. The UPS system shields the load from brief anomalies, while also giving the generator time to start up and come online if a blackout extends towards the UPS battery autonomy time.

During normal operation, power flows through the UPS – assuming it is an online type – to the load, while also keeping the UPS batteries charged. The generator, powered down, is connected to an Automatic Mains Failure (AMF) detection panel which initiates a generator start-up if a power cut becomes critically extended. Once the generator output has stabilized, it is switched on to the essential parts of the facility's load, including the UPS.

While the AMF should start the generator early enough to allow for this stabilization, it should not signal a start during every minor power supply disturbance. To avoid this, the AMF signal is typically delayed for 2 to 10 seconds after mains failure detection. Similarly, the AMF signal usually keeps the generator running for at least two minutes after mains power is restored, to ensure that it is truly stabilized.

Generator Compatible UPS systems

Achieving tight engine speed control is critical in these applications, as it allows synchronization between the UPS system and the backup generator. Synchronization problems between the UPS and the utility mains supply are rare because utility companies' generators are huge, so their inertia can absorb any sudden increase in load. By contrast, a small local generator subjected to the same load change will slow down until the governor compensates.

Overall, the generator's frequency range may be too wide for the UPS system to accept. In the worst case, synchronization may not be possible, either due to the frequency being out of limits or its slew rate being too fast for the UPS to follow without endangering the load. If this happens, most UPS systems will flag an alarm to warn the operator that if a fault occurs the load will not be transferred from the UPS to the raw generator feed.

- 1.5 x the nominal UPS capacity for the transformer-less UPS systems usually found in today's data centers and IT rooms.

- 3 x the nominal air conditioning running capacity.

- Capacities of other protected loads can be found from the manufacturers' specifications, or by measuring using a current clamp.

▪ Synchronization system for Transformer to Transformer

Requirements for Parallel Operation of Transformers

1) Parallel voltage ratio must be the same.
2) The polarity of the voltage must be the same.
3) The voltage impedance at full load must be the same.
4) The ratio of reactance to resistance must be the same.
5) The number of phases must be the same.
6) The transformer vector groups must be the same.

Disadvantages of Parallel Operation of Transformers.

- Risk of very high short-circuit currents.
- High probability of error due to technical confusion in the system.
- Since it is a complex system, a lot of auxiliary equipment is needed.
- Risk of formation of circulating currents between transformers.

❖ To achieve effective and efficient operation of the power system we need to consider good design, good installation and good operation, and good maintenance. During operation, system maintenance is a vital role in the generation and production of power and product. There are three types of maintenance.

❑ <u>Types of Maintenance</u>

- **Preventive Maintenance**

Preventive maintenance is the act of performing regularly scheduled maintenance activities to help prevent unexpected failures in the future. It is regular, planned maintenance scheduled according to usage or time-based triggers. The purpose of PM is to lessen the likelihood of equipment breakdowns. The major milestones of PM are testing, servicing, calibration, inspection, adjustment, alignment, and installation.

- **Corrective Maintenance**

Corrective maintenance (CM) involves the replacement or repair of equipment after it fails.

- **Predictive Maintenance**

Predictive maintenance is a technique that uses condition-monitoring tools and techniques to monitor the performance of a structure or a piece of equipment.

II. POWER QUALITY STANDARDS

- **IEEE (Institute of Electrical and Electronic Engineers)**

- IEEE P1433: Power quality definitions
- IEEE P1453: Voltage flicker
- IEEE P1564: Voltage sag indices
- IEEE 1159: Recommended practice for monitoring electric power quality
- IEEE 519: Recommended practices and requirements for harmonic control in electrical power system

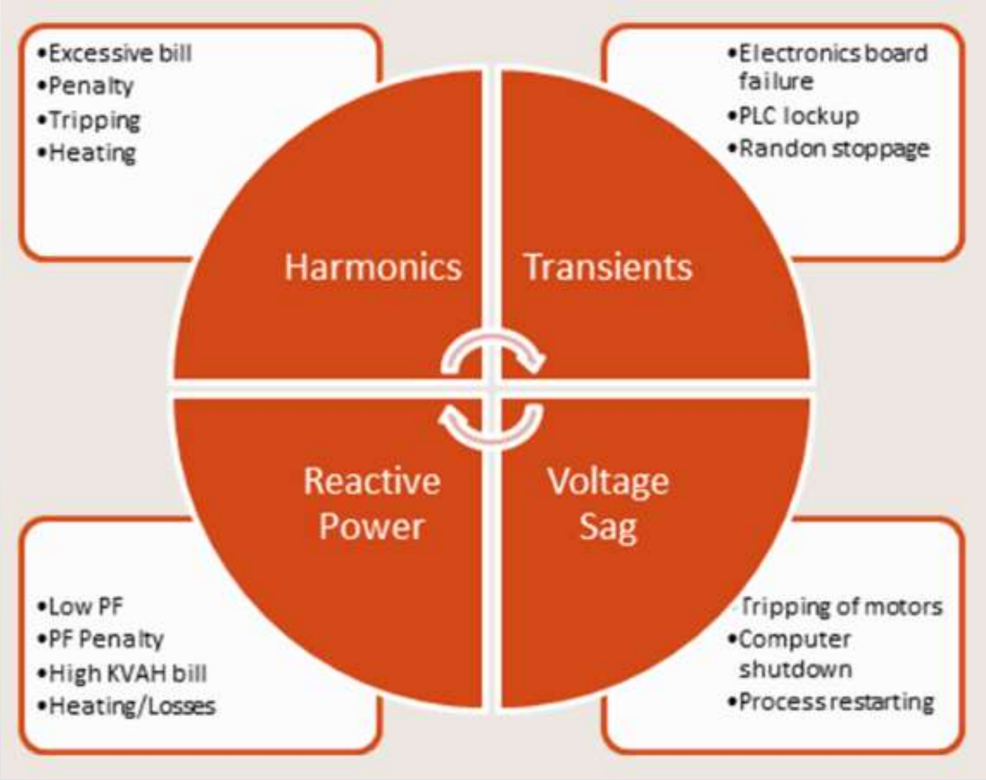
- **IEC (International Electrotechnical Commission)**

- IEC SC77A/WG1: Harmonics and other low-frequency disturbances
- IEC TC77/WG1: Terminology
- IEC SC77A/WG8: Electromagnetic interference related to the network frequency
- IEC SC77A/WG9: Power quality measurement methods
- Two organizations are involved:
  - IEEE (Institute of Electrical and Electronic Engineers) www.ieee.org
  - IEC (International Electro technical Commission) www.iec.ch

III. GENERAL CLASSES OF POWER QUALITY PROBLEM

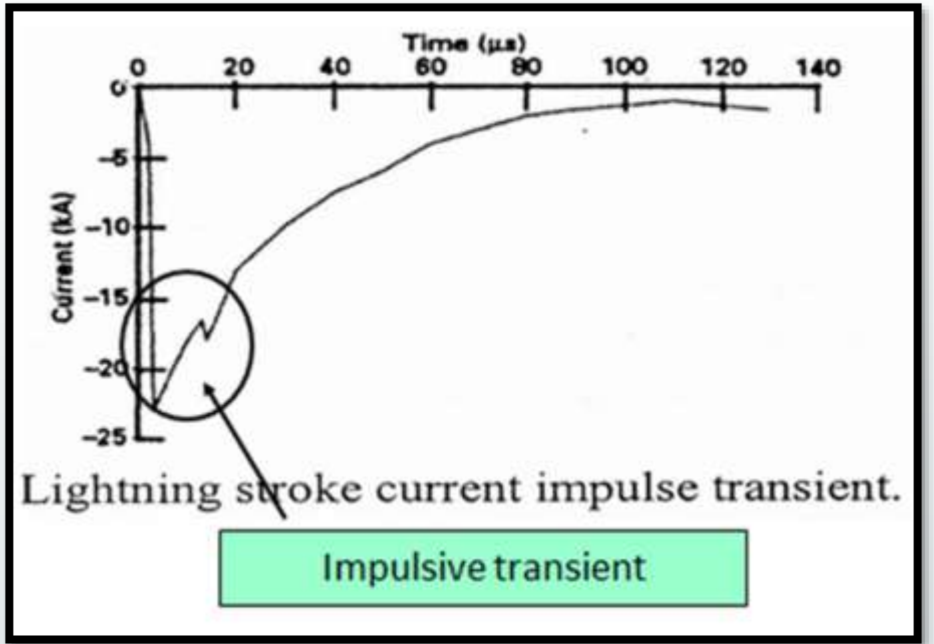
- **Transients**

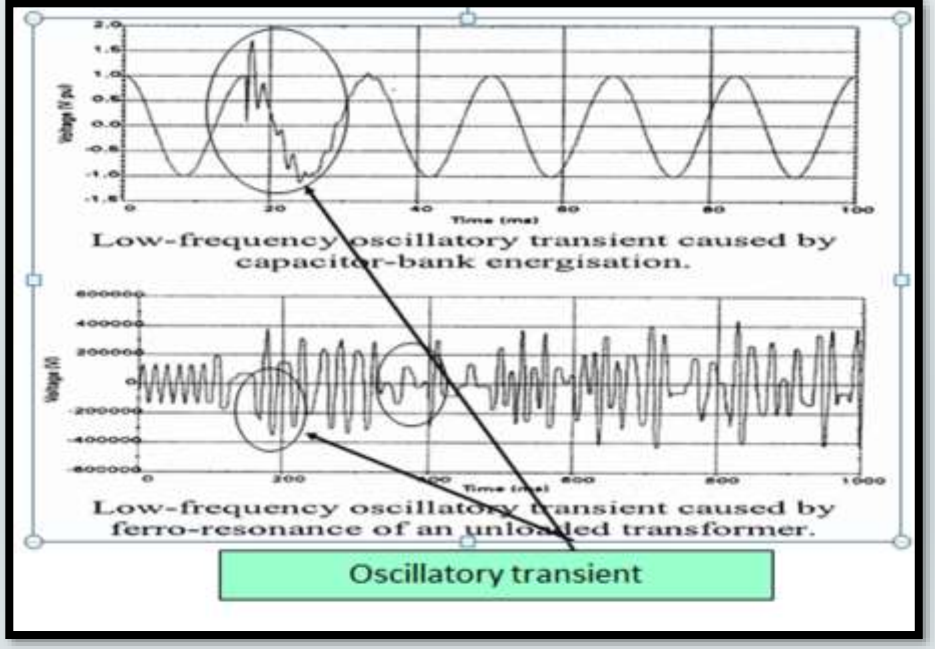
Undesirable momentary deviation of the supply voltage or load current. Also known as surges or spikes.



What are transients in power quality issues?

Transients may also occur as bursts rather than singular events. As with most power quality issues transients are often assumed to be generated by outside sources such as lightning strikes, load switching, and fault clearance within the utility supply equipment.





❑ <u>Two categories of transients:</u>

- **<u>Impulsive transients</u>**: a sudden, non-power frequency change in the steady-state condition of voltage, current or both, that is unidirectional in polarity (either +ve or –ve).

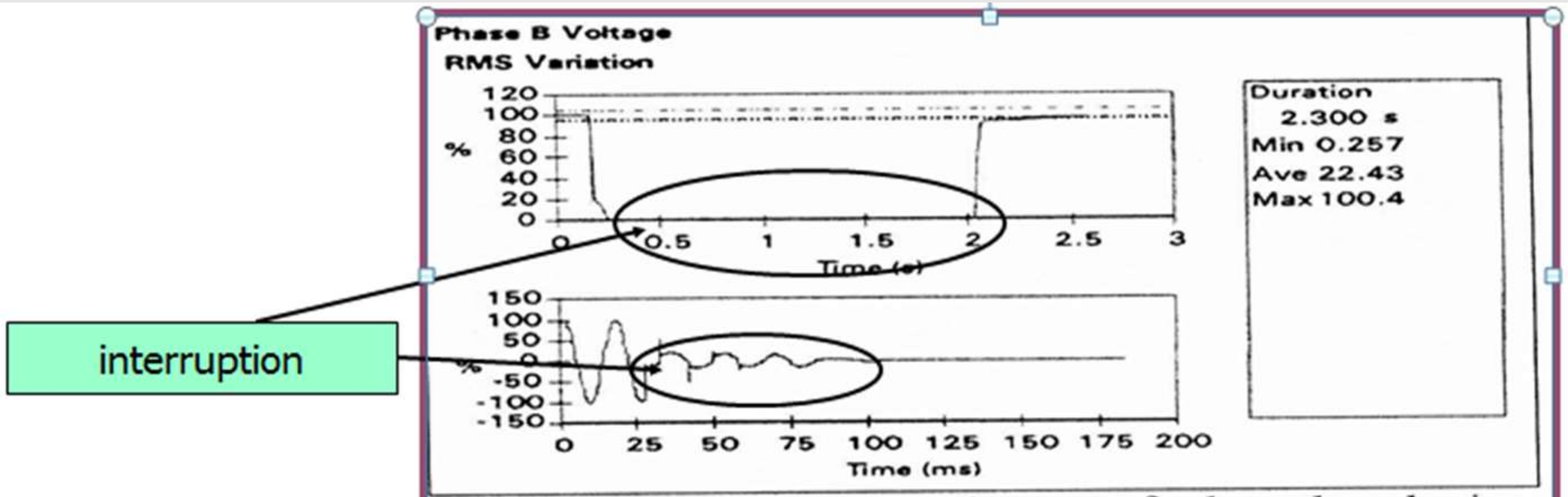
- **<u>Oscillatory transients</u>**: same definition as impulsive but the only difference is bidirectional in polarity (includes both +ve or –ve values).
  - *High-frequency oscillatory transient-* greater than 500kHz
  - *Medium-frequency oscillatory transient* – between 5kHz to 500kHz
  - *Low-frequency oscillatory transient* – less than 5kHz.

❑ Short Duration Voltage Variation

- Interruption
- Voltage Sags
- Voltage Swell

Interruption

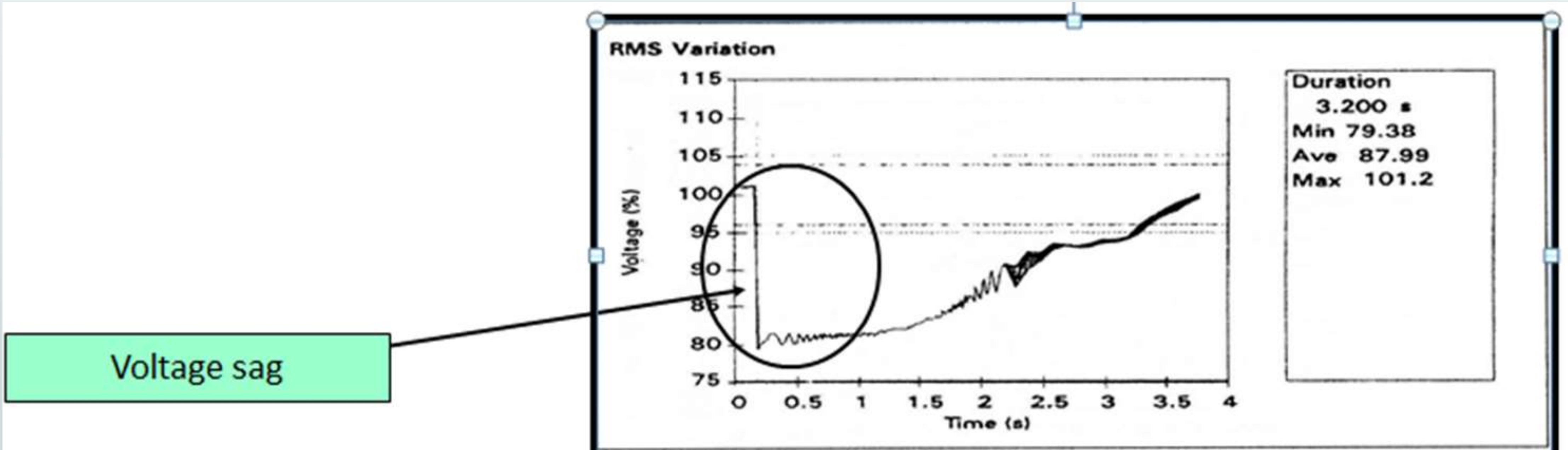
- Interruption, sag and swell. Each type can be designated as **instantaneous** (0.010-0.5 sec), **momentary** (0.5-3 sec) or **temporary** (3-60 sec)Interruption - a reduction in the supply voltage, or load current, to a level less than 0.1 p.u for a time less than 1 minute.
- It can caused by system faults, system equipment failures or control and protection malfunctions.



Momentary interruption due to a fault and reclosing.

Voltage sags

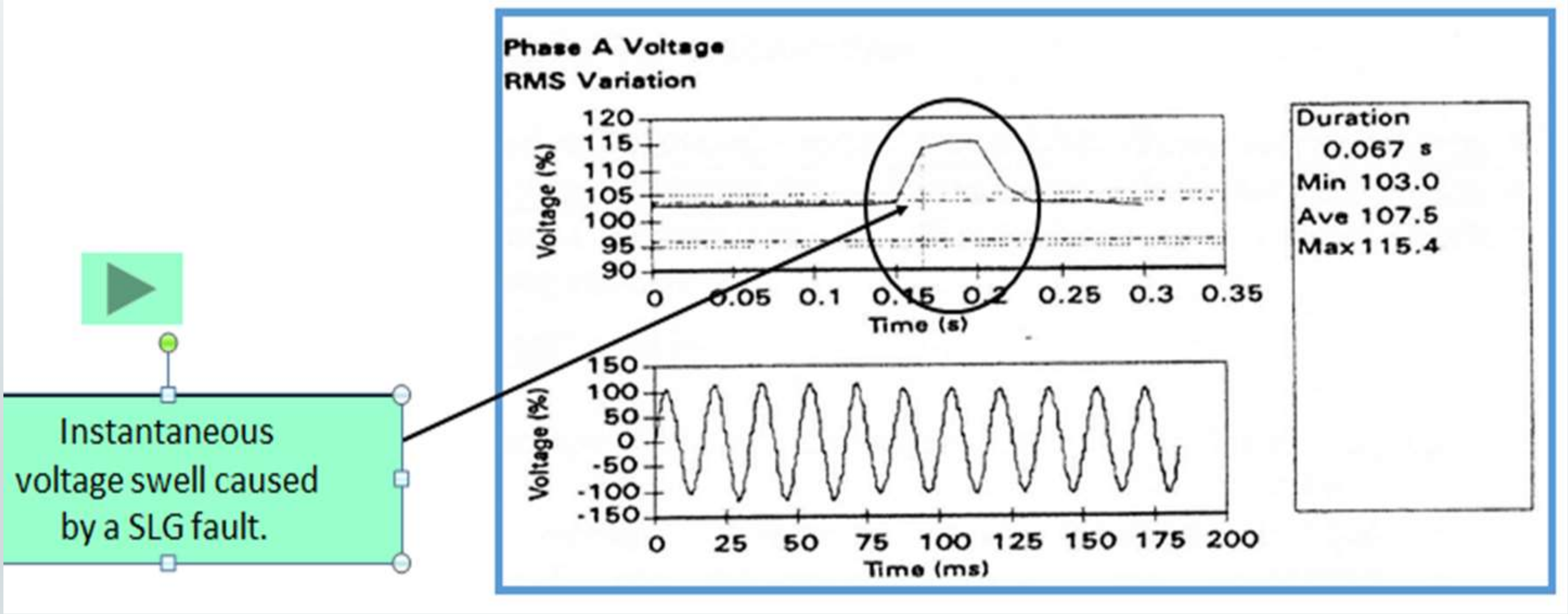
Decrease to between 0.1 to 0.9 p.u. in rms voltage at the power frequency for **durations from 0.5 cycles to 1 minute**. Also called *voltage dips*. Caused by faults, increased load demand and transitional events such as large motor starting.

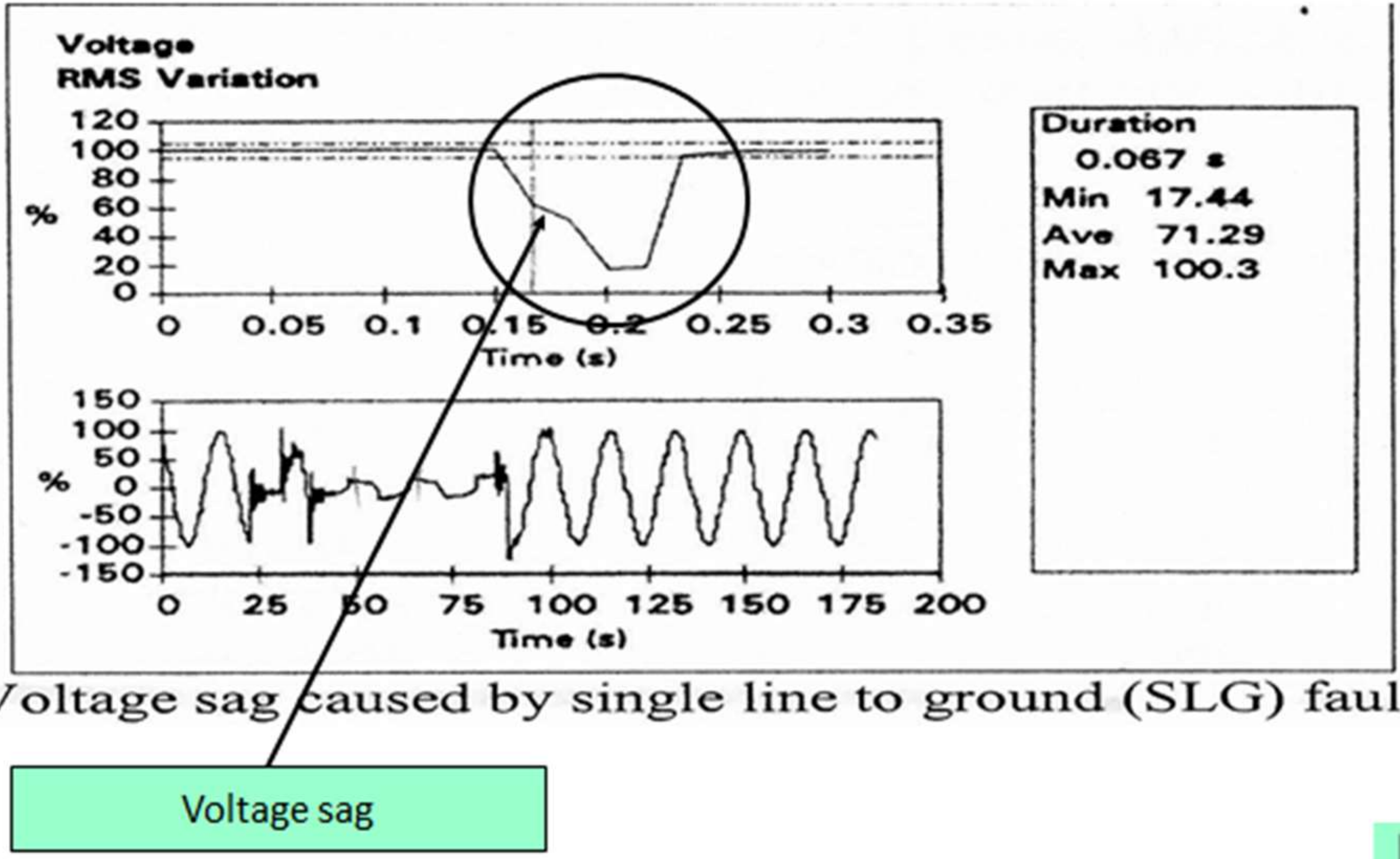


Temporary voltage sag caused by motor starting.

➢ Voltage swell

An **increase in rms voltage in the range of 1.1 to 1.8 p.u.** for duration **from 0.5 cycles to 1 minute**. Also called *momentary overvoltage*. Caused by system faults, load switching and capacitor switching.





Voltage sag caused by single line to ground (SLG) fault.

- **Long duration voltage variations: voltage deviation longer than 1 min.**

  Three types:

  - An increase in the rms ac voltage greater than 110% at power frequency for a duration of more than 1 minute
  - A decrease in rms ac voltage to less than 90% at power frequency for a duration of more than 1 minute
  - When voltage is 0 for a duration of more than 1 minute.

- **Voltage imbalance**
  - **Deviation of each phase from the average voltage of all three phases.**
  - Most equipment can tolerate a voltage imbalance of 2%.
  - Can cause network problems such as mal-operation of protection relays and voltage regulation equipment, and also overheating of motor and transformer.

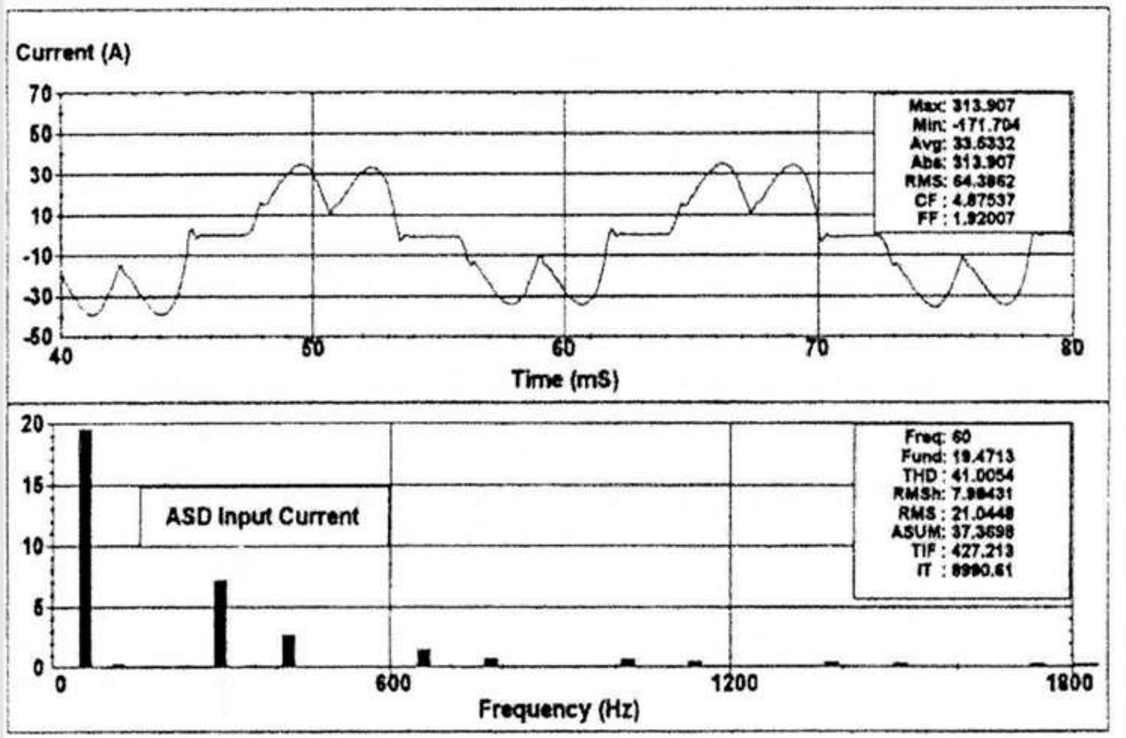
- **Waveform distortion**
  - **Steady-state deviation from an ideal sine wave of power frequency**.
  - 5 primary types of waveform distortion:

    -DC offset, Harmonics, Inter-harmonics, Notching and Noise.

❑ WAVEFORM DISTORTION

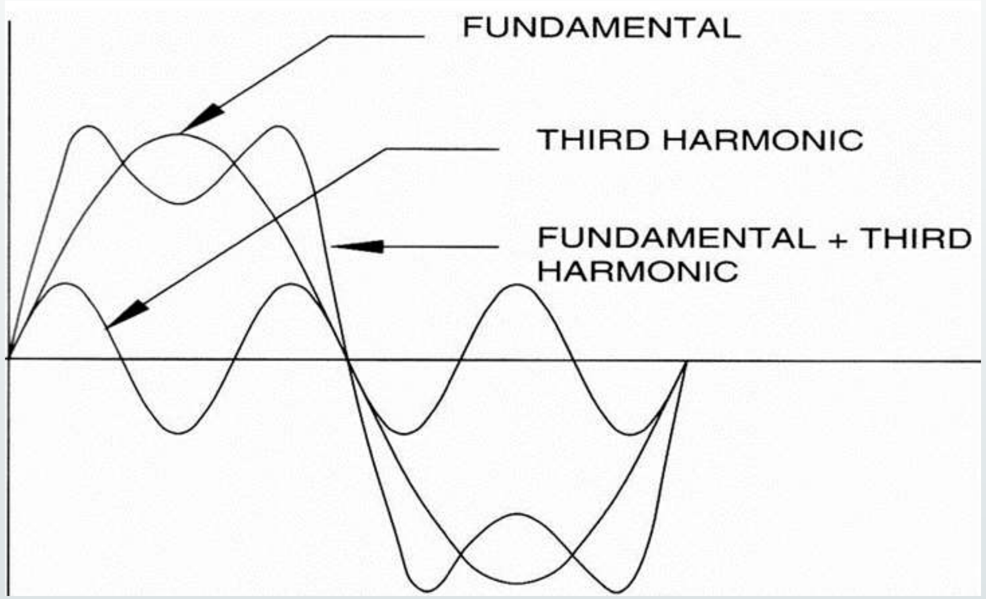
- **DC offset**
  - Presence of a dc voltage or current in an AC system.
  - Can result in corrosion of network and customer’s earthing system.

- **Harmonics**
  - Periodic sinusoidal distortions of the supply voltage or load current caused by non-linear loads.
  - Harmonics are measured in integral multiples of the fundamental supply frequency, 50Hz (i.e. 150Hz is third harmonic)
  - Harmonic current caused by nonlinear loads like adjustable speed drive, SMPS in computer, power electronic devices and medical test equipment.
  - Effect: overheating of X’mer, cable and motor; relay trip and incorrect measurement of V and I by meters.



Current waveform and harmonics of an adjustable-speed-drive.

Nonlinear load waveform
and harmonic content



Creation of nonlinear waveform by adding fundamental and third harmonic frequency waveform

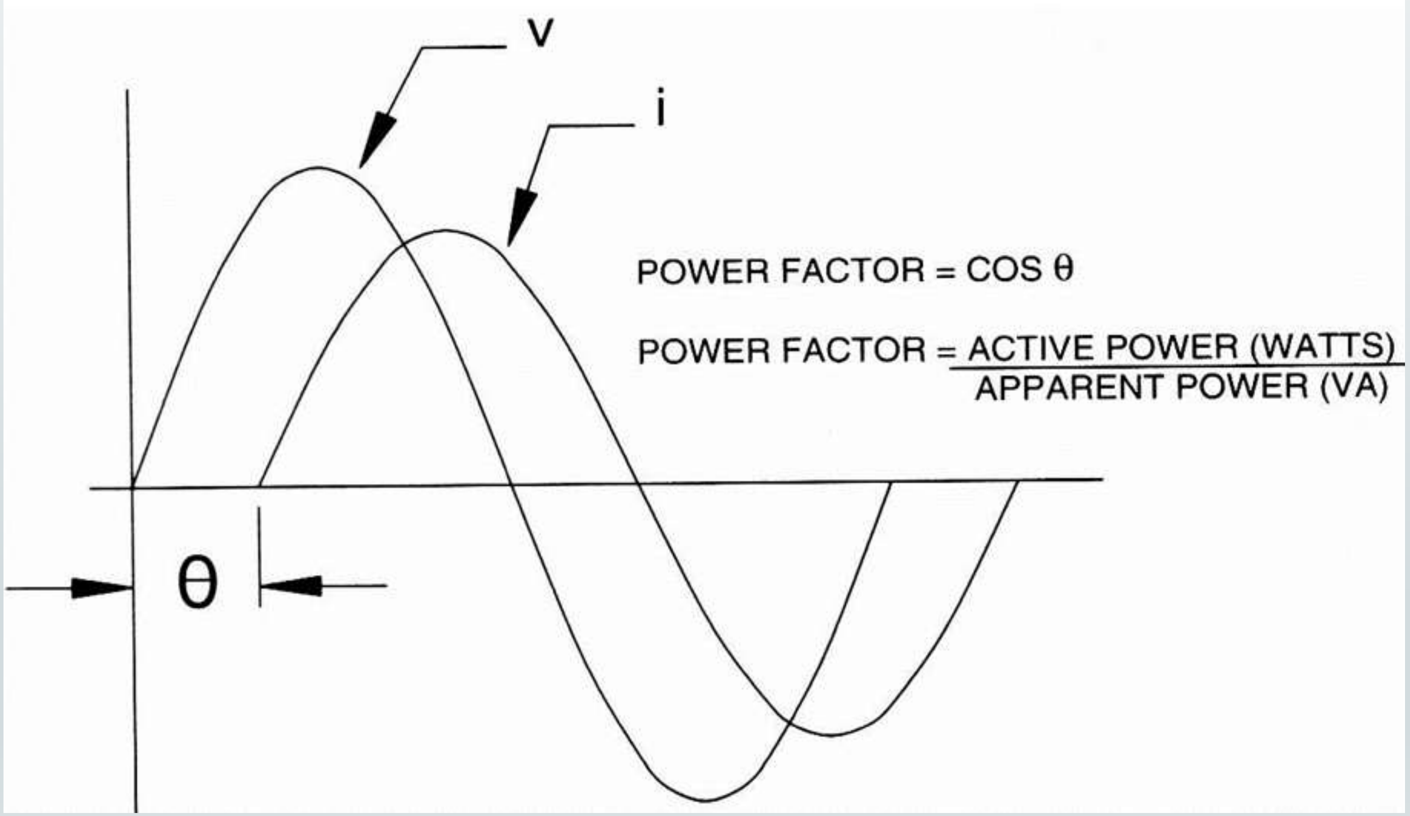
HARMONIC DISTORTION

- Distortion factor (THD):
  - Ratio of rms voltage or current harmonic content of a periodic wave to the rms of fundamental content of the wave, expressed as a percent. Also known as total harmonic distortion (THD).
  - % THD = $\dfrac{\sqrt{I_{rms}^{2} - I_{1,rms}^{2}}}{I_{1,rms}} x100$
  - *where : $I_{1,rms}$ is the fundamental sinusoidal input current and I_{rms} is the input utility rms current (may not be sinusoidal, depends on load)*

❑ Displacement power factor (DPF):

- Ratio between active power (W) to apparent power (VA) of the fundamental wave. DPF is the same as PF in a linear circuit with sinusoidal V and I. DPF is the cosine of displacement angle between V and I waveform.

  - **DPF = cos Φ**



❑ Power factor (PF):

- Ratio of total active power to total apparent power of composite wave including all harmonic components.

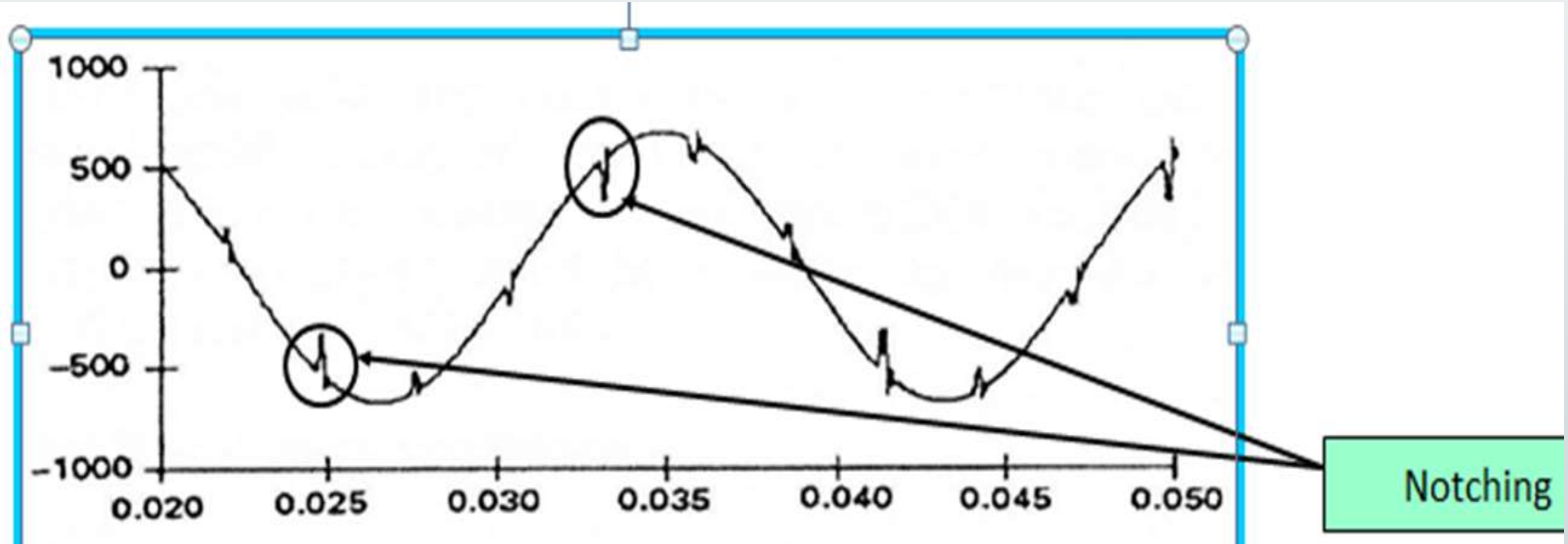
$$PF = \frac{I_{s1}}{I_s} DPF$$
$$= \frac{1}{\sqrt{1 + THD^2}} DPF$$

❑ Inter-harmonics

- Caused by waveforms that have frequency components that are not integral multiples of the fundamental frequency, 50Hz.
- The effects of inter-harmonics are light flicker, audible noise in TV sets, radios, and audio equipment, and vibration in rotating induction machines.

❑Notching

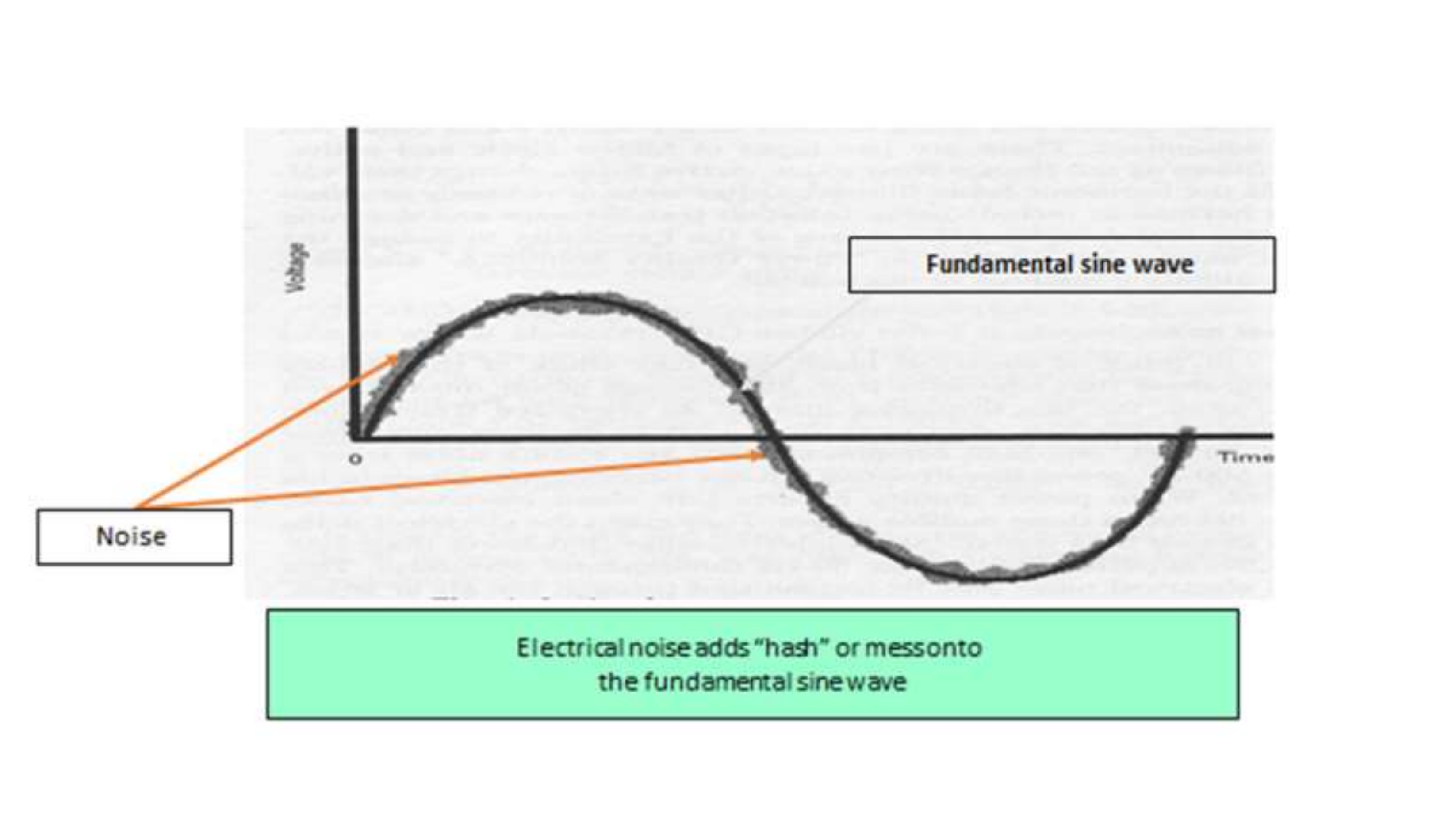
- It is a periodic voltage disturbance caused by the normal operation of power electronic devices when current is commutated from one phase to another (two phases of supply are effectively short-circuited for a short time).



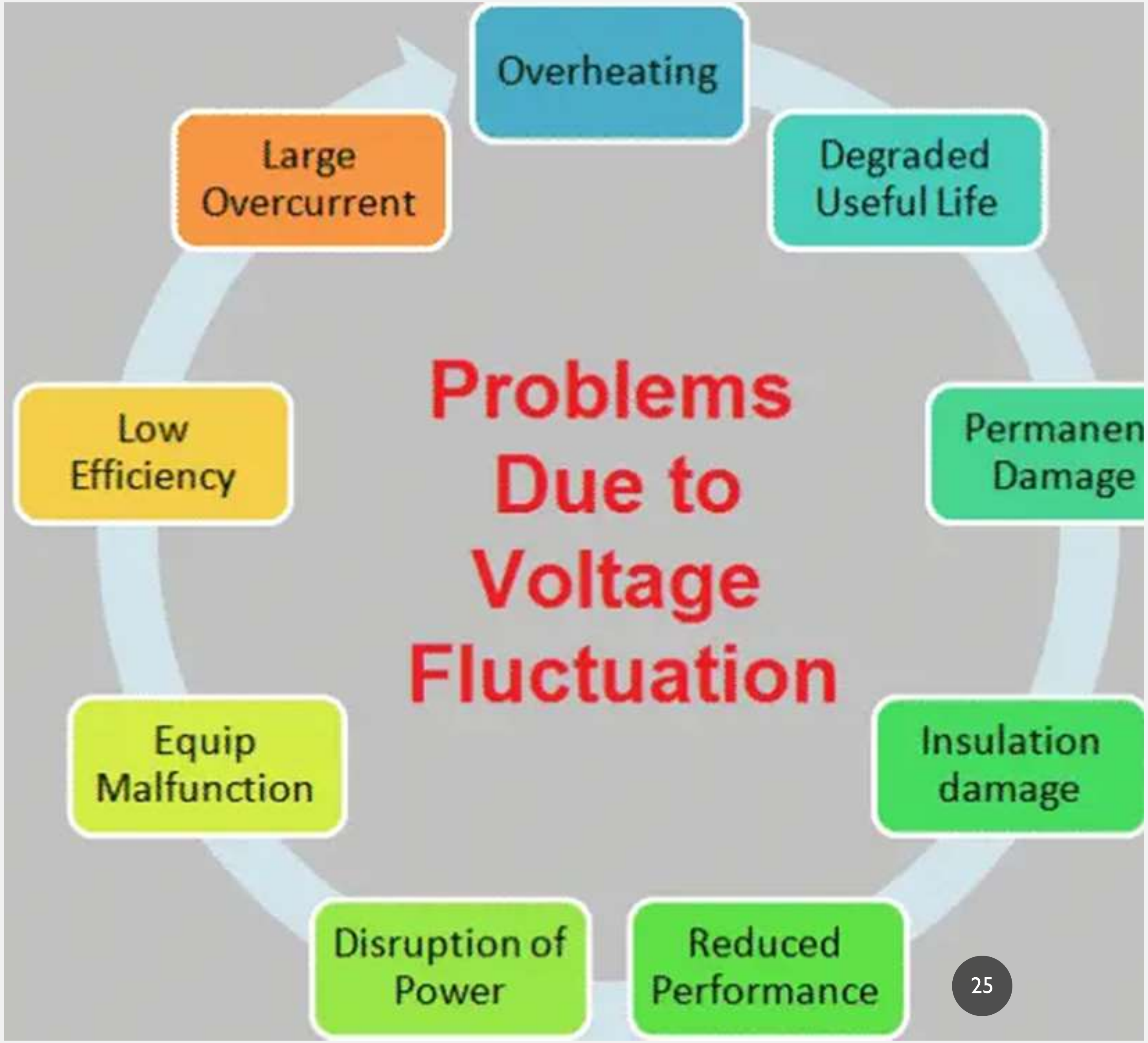
Voltage notching caused by a three-phase converter.

Electrical Noise

- Caused by a low voltage, high frequency (but lower than 200Hz) signal superimposed on 60Hz fundamental waveform.
- Cause: HV lines, start-up of large motor, radio and TV station, SMPS, fluorescent light, and power electronic devices.



- **Voltage Fluctuation**
  - Rapid changes in voltage within the allowable limits of the nominal voltage, e.g. 0.9 to 1.1 p.u.
  - Cause lamps to blink rapidly, often referred to as “flicker” and is visible to human eyes at flickering frequencies of 6-8Hz.
  - Use static VAR controllers (SVCs) to control voltage fluctuation frequency by controlling the amount of reactive power supplied to the equipment (i.e. arc furnaces).



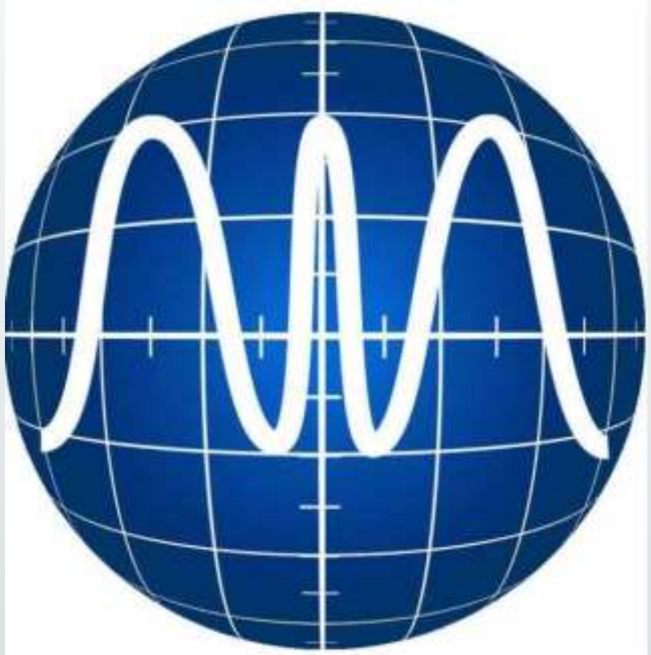
❑ **Power Frequency Variation**

Deviation of power system fundamental frequency from its nominal value (50Hz to 60Hz).

Sources:

Due to faults on the bulk power transmission system, a large block of load being disconnected, or a large source of generation going off-line.

Frequency regulation can be achieved by using devices, such as governors, automatic generating control, frequency relays, or energy storage systems. These can increase or decrease the power output of generators by adjusting the speed.



IV. SOURCES OF POWER QUALITY PROBLEMS

- **Nonlinear Load**
  - Any piece of equipment or appliances that increases and reduces its consumption of electricity
  - Example: power electronic devices, adjustable speed drive, electronic ballast for fluorescent lamp, and power supply for welding machine.
  - Nonlinear load, current, and voltage do not follow each other linearly. It occurs when the load is not pure resistance or inductive; instead, it has an electronic component to control the function of the equipment to meet the requirement of the load.
  - Result in creating harmonic distortion that causes overheating of equipment and can be susceptible to voltage dips (sag) if not adequately protected.
- **Sensitive Loads (IT and office equipment)**
  - The brain of a computer is integrated circuit (IC) chips. Chip is sensitive to changes in power supply.
  - Computers, microprocessors, and consumer electronic and telecommunication appliances use power supplies that consist of a switched mode power supply (SMPS) and are the cause of a significant increase in the level of 3^{rd}, 5^{th}, and 7th harmonic voltage distortion.
  - Any deviation from voltage can cause data to be corrupted or erased.

- **Arcing device**
  - Electric arc furnaces, arc welders, and electric discharge lamps are all forms of electric arcing device. These devices are *highly non-linear loads*.
  - All arcing devices are sources of harmonic distortion.
- **Load switching**
  - This type of transient might occur as the result of switching in a heavy single-phase load.
  - Other equipment can be protected from these switching transients by electrically isolating them from the affected equipment.

Large motor starting

- Dynamic nature of induction machines means that they draw current depending on the mode of operation.
- During starting, this current can be as high as six times the normal rated current. This increased loading on the local network has the effect of causing a voltage dip.
- Most modern motors employ a sophisticated power electronic converter ‘drive’, which controls the motor’s starting current to a reasonable level.
- Some lower-cost types of motors use series capacitors or resistors to reduce the starting current. These components are then switched out once the motor’s rated speed has been reached.
- Autotransformers are used to start some older motors. These have a variable secondary winding that allows the motor stator voltage to be controlled and hence the current drawn from the supply.

Inter-connected of Power System

- Increasing levels of interconnection in power systems is predicted in the future and are likely to have an effect on power quality. The problem can propagate and be difficult to isolate. Harmonics and flicker are examples of power quality problems that can be transferred from one utility to another through interconnection.

Lightning Strike and Environment Related Damage

- Lightning strikes are a cause of transient overvoltage often leading to faults on the electricity supply network.
- Lightning strikes that hit overhead lines often cause ‘flash-over’ to neighboring conductors as the insulators break down. The strike will therefore not only consist of a transient overvoltage but also fault-clearing interruptions and dips.

V. POWER QUALITY MEASUREMENT

Power quality measurement devices are used to monitor voltage, current, harmonics, and disturbances on electrical systems

- Digital Multimeter
- Oscilloscope
- Disturbance analyzer
- Spectrum and harmonic analyzer

iMC 784 Advanced Power Quality Analyzer

VI. SOLUTION TO POWER QUALITY PROBLEM

- **Earthing practices**
  - Power quality problem is caused by incorrect earthing practices.
  - Verification of earthing arrangement should be conducted in power quality investigation.

The choice of a neutral earthing system is dependent on requirements and objectives that are often contradictory to such an extent that sometimes several systems have to be created within one installation (islanding) in order to meet safety, maintainability, or operating requirements that are too dissimilar.

Earthing Systems

Different Earthing Systems:

There are three different main earthing arrangements explained in international standard IEC 60364:

- ❑ **TT System**
- ❑ **TN System**
  - ▪ **TN-C**
  - ▪ **TN-S**
  - ▪ **TN-C-S**
- ❑ **IT System**

Note:
C: Combined
S: Separated

XX

The first letter indicates the connection of the power supply to the earth.

- **T**: Direct connection to the earth
- **I**: No connection to the earth, except via a high impedance

The second letter indicates the connection of electrical device being supplied to the earth.

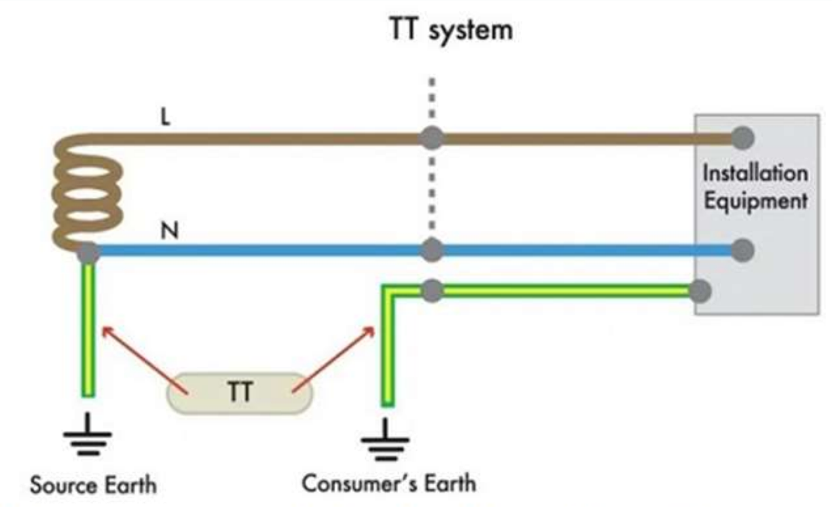
- **T**: Direct connection to the earth
- **N**: Direct connection to the neutral at the origin of installation which is connected to the earth.

TT EARTHING SYSTEM

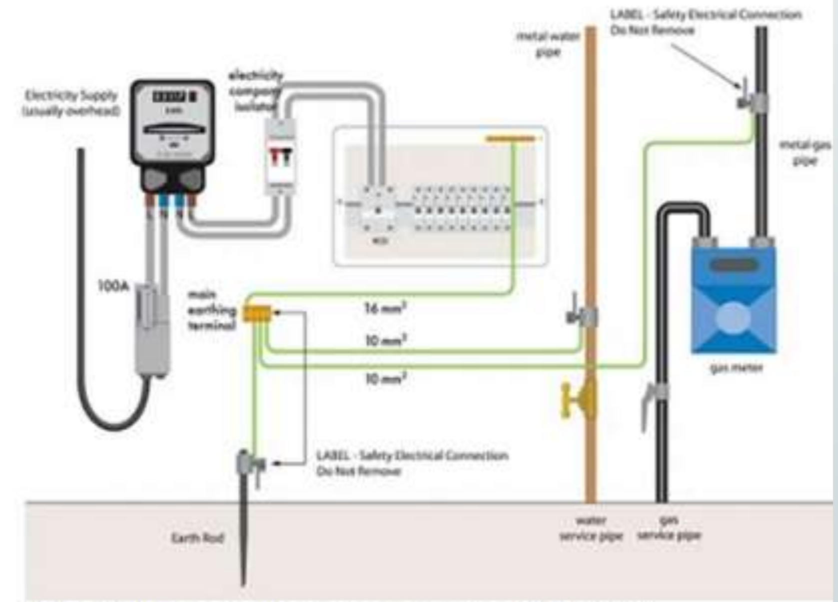
- 'T' is French for Terra, which translates to earth. The first 'T' of a TT earthing system relates to the earthing of the distributors transformer, the second 'T' is the earth electrode installed at the consumers installation.

- **TT earthing main characteristics:**

- It gets power from the public LV distribution network directly.
- No continual monitoring is required (a periodic check on the RCDs may be necessary).
- Special devices, known as residual current devices (RCDs), provide protection and reduce the chance of fire when set to less than 500 mA.
- Each insulation fault causes a power outage, but the outage is limited to the faulty circuit by connecting the RCDs in series (selected RCDs) or in parallel (parallel RCDs) (circuit selection).
- Loads or sections of the installation that create large leakage currents during operation require additional precautions to avoid nuisance tripping, such as supplying the loads with a separation transformer or using appropriate RCDs.



TT Earthing Basic connection diagram using IEC 60364

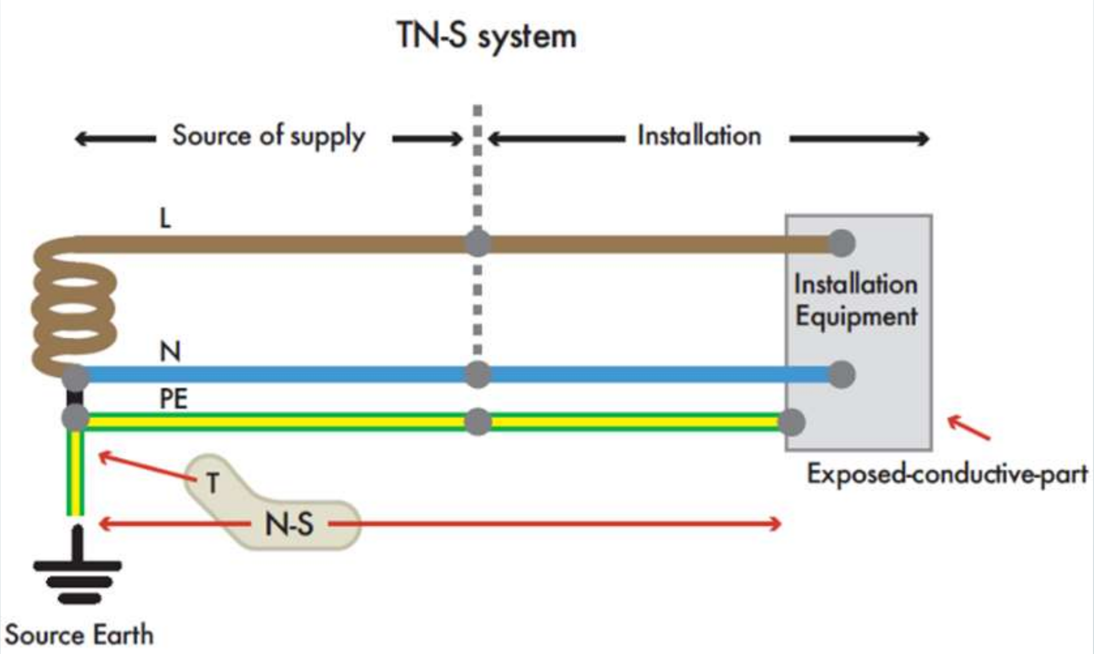


TT Earthing application diagram using IEC 60364

TN-S EARTHING SYSTEM

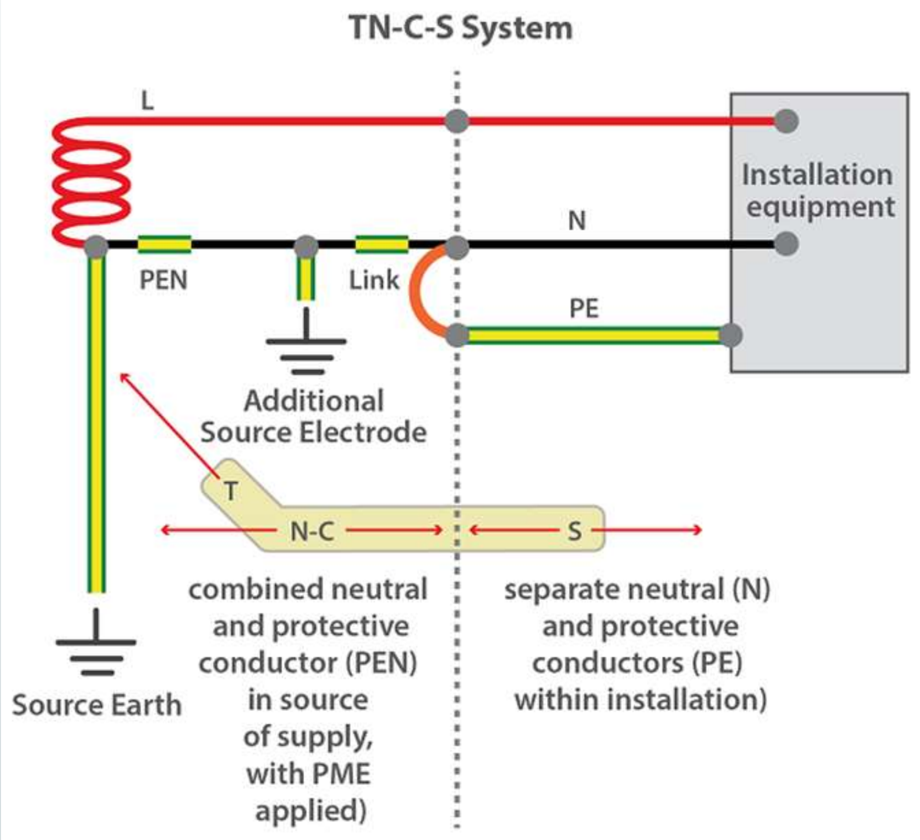
- **TN-S Earthing System**

  In this earthing system the neutral point at the supply side (transformer) is earthed at one point only and the electric supplier will provide a dedicated protective earthing conductor (PE), independent of the neutral conductor. The protective earthing conductor is connected between the supply earthing point and the customer electrical service panel, typically the connection is made through the metallic sheath of the supply power cable as shown in the figure.



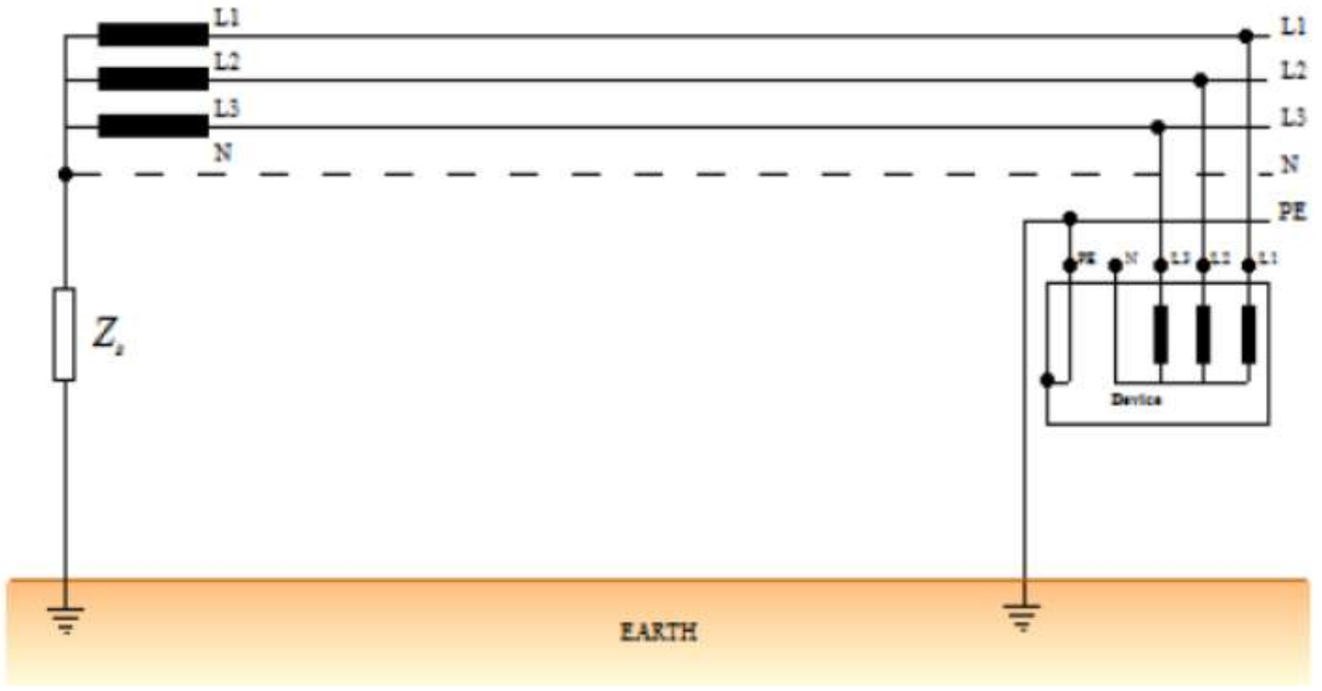
TN-C-S EARTHING SYSTEM

- In this earthing system, the electrical supplier will combine both the neutral and the protective earthing in only one conductor but multiple earthing points will be provided through the way till the customer electrical service panel as shown in the figure.
- In this arrangement, the supplier neutral/protective earthing conductor is also used to return the earth fault currents safely to the supply source.
- The supplier will provide an earthing terminal for the customer to connect his protective earthing conductor to the supplier neutral conductor as shown in the figure.



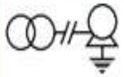
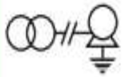
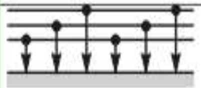
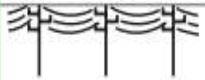
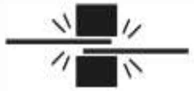
IT EARTHING SYSTEM

IT System: Impedance-earthed neutral



- ✓Impedance in order of 1-2 kΩ is connected permanently between the neutral point of the transformer LV winding and earth.
- ✓The reason of connecting impedance to neutral is to fix the potential of a small network with respect to earth and to reduce the level of overvoltage, such as transmitted surges from the MV windings, static charges, etc. with respect of earth.
- ✓Impedance slightly increases the first-fault current level.

Influence of Networks and Loads on the selection of System Earthing Arrangements

Type of network		Advised	Possible	Not advised
Very large network with high-quality earth electrodes for exposed conductive parts (10 Ω max.)			TT, TN, IT[a] or mixed	
Very large network with low-quality earth electrodes for exposed conductive parts (> 30 Ω)		TN	TN-S	IT[A TN-C
Disturbed area (storms) (e.g. television or radio transmitter)		TN	TT	IT[b]
Network with high leakage currents (> 500 mA)		TN[d]	IT[d] TT[c] [d]	
Network with outdoor overhead lines		TT[e]	TN[e] [f]	IT[f]
Emergency standby generator set		IT	TT	TN[g]
Type of loads				
Loads sensitive to high fault currents (motors, etc.)		IT	TT	TN[h]
Loads with a low insulation level (electric furnaces, welding machines, heating elements, immersion heaters, equipment in large kitchens)		TN[i]	TT[i]	IT
Numerous phase-neutral single-phase loads (mobile, semi-fixed, portable)		TT[j] TN-S		IT[j] TN-C[j]
Loads with sizeable risks (hoists, conveyers, etc.)		TN[k]	TT[k]	IT[k]
Numerous auxiliaries (machine tools)		TN-S	TN-C IT[lbis]	TT[l]

▪ Neutral Grounding Resistors

NGR Neutral Grounding Resistors are used in generating stations, power transformers, and long-line **shunt reactors**. The NGR is made of a material with a high-***temperature coefficient*** and its resistance remains fairly constant when large current flows through it.

Why is NGR used?

The neutral point's earthing is done to ensure the upstream breaker's tripping in case of an **earth fault**. This process of earthing the neutral point is called system grounding. System grounding can be done in three ways, **solid grounding**, resistance grounding, and **reactance grounding**. Each type of grounding system has its own pros and cons.

The enormous current flowing in the case of solid grounding can be limited if the impedance is created in the path of the fault current. The resistor resists the flow of electrons or current. Therefore, the **resistance** is added to the neutral grounding circuit. The value of the resistance is selected so that the earth fault current flowing through the equipment is not more than full rated current.

The **current transformer** is mounted in the neutral grounding circuit to detect the earth fault current in order to trip the circuit to isolate the faulty section.

- **Reducing the number of faults**

- Reducing the number of faults
- For example tree-trimming, animal guards, shielding wires, and replacing overhead lines by underground lines.
- Normally used to solve voltage dip problems.

- **Faster fault clearing**
- Need to improve protection techniques.
- Development of a new generation of circuit breakers and relays at the transmission level.

- **Static breaker**
- Allow the isolation of faulted circuits in the shortest possible time frame, while other nearby loads will improve the power quality of the network.

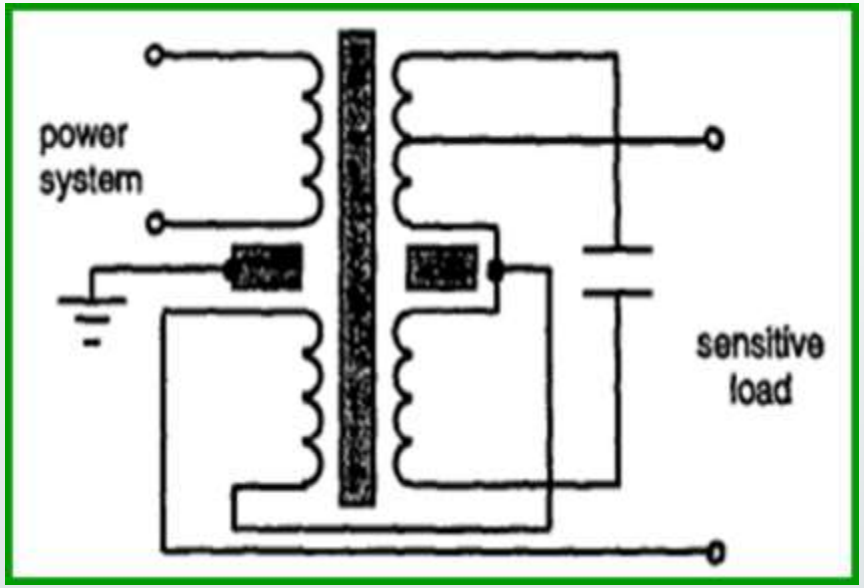
- **Transfer switch**
- Used to transfer a load connection from one supply to another, allowing the choice of two supplies for the load (or sub network).
- One of the supplies will handle the power disturbances on the system whereas the other one will be automatically switched on to reduce the possibility of supply disruption to the load.

VARIOUS LINE-VOLTAGE REGULATOR

1. CONSTANT VOLTAGE TRANSFORMER
2. TRANSFORMER WITH TAP CHANGER

❑ Transformer-based solution

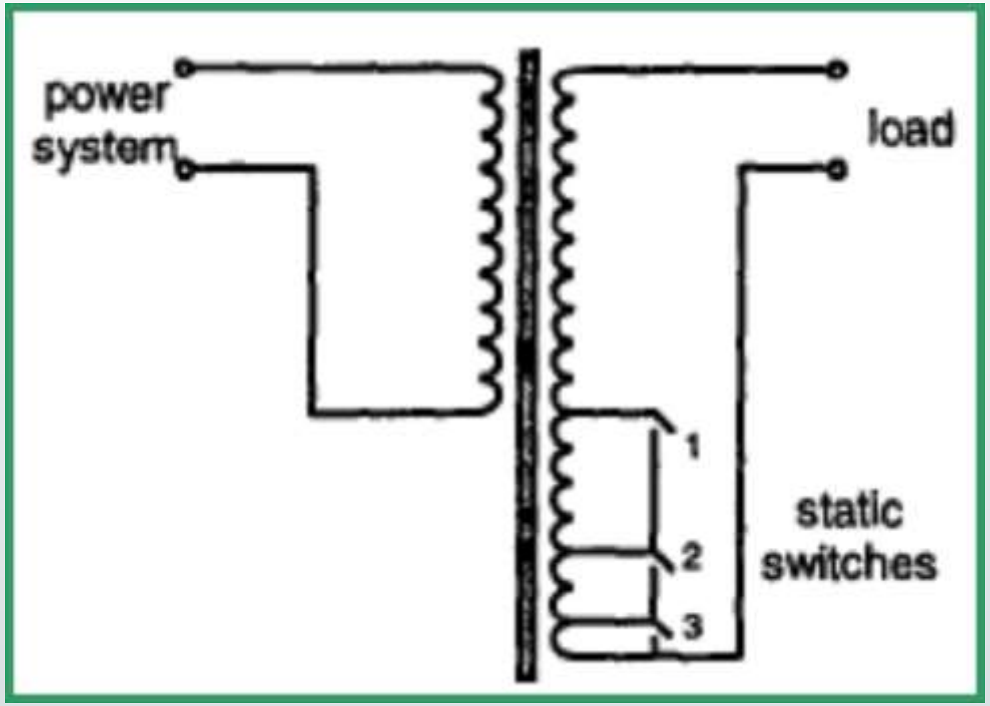
- **Ferro-resonant transformer**
  - Ferro-resonant transformer has 1:1 turns ratio and with a core that is highly magnetized close to saturation under normal operation.
  - This will **provide an output voltage which is not affected by input voltage variations** hence the output is not significantly affected by voltage sag.
  - In actual design, a capacitor connected to secondary winding to set the operating point above the knee of saturation curve.
  - Suitable for low-power, constant loads



Typical circuit for a ferro-resonant transformer

▪ Various Line-Voltage Regulator

- **Transformer with electronic tap changers**
  - Electronic tap changers can be mounted on txt for sensitive load to change its turn ratio according to change in input voltage.
  - They are connected in series on the distribution feeder and placed between supply and load.
  - Part of secondary winding is divided into number of sections which are connected or disconnected by fast static switches to allow regulation of secondary voltage in steps.
  - This will allow the output voltage to be brought back to level above 90% of nominal value even during severe sags.
  - Thyristor-based switches only turn on once per cycle, thus accomplish the compensation with a time delay of at least one half cycle.



Transformer with electronic tap changers

❑ Harmonic Filters

- **ACTIVE FILTER**
- **PASSIVE FILTER**

- **Active Filter**

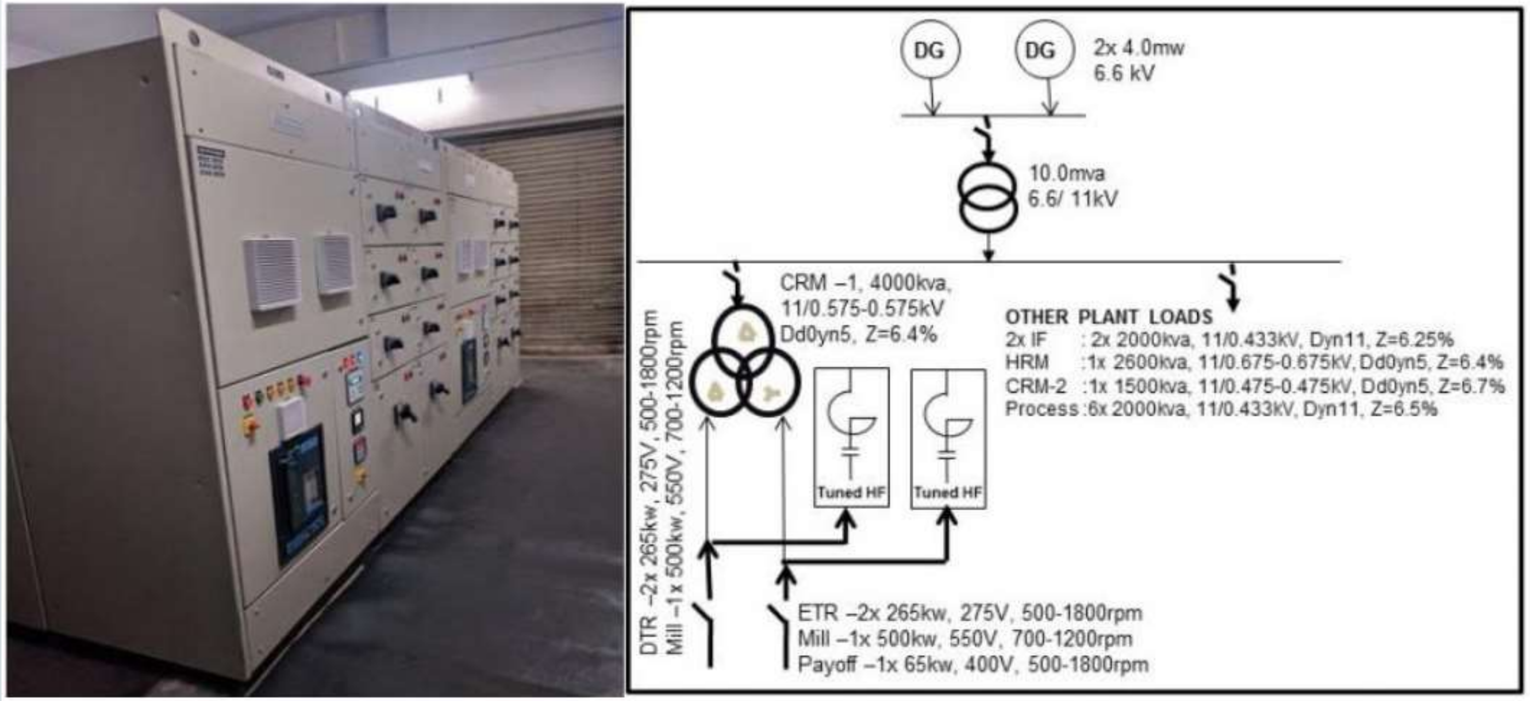
Active filter is a type of electronic filter that uses active components, including op-amps and transistors. They actually work with passive components as well like resistor and capacitors but not inductors.

- Referred to as active power line conditioners (APLCs).
- It conditions harmonic currents rather than block or divert them.
- Use an electronic (bridge inverter or rectifier) to monitor & sense harmonic currents and create counter-harmonic currents. Then, inject a counter-harmonic current to cancel out the harmonic current generated by the load.
- Also regulate sag and swell by eliminating source voltage harmonic.
- Most effective in compensating for unknown or changing harmonics.

Passive Filter

Passive filter are made of passive components (inductance ,capacitance , and resistance) tuned to the harmonic frequencies that are to be attenuated.

- A simple filter consists of discrete (static) capacitors and/or inductors.
- Designed to handle specific harmonics.
- Do not respond to changes in frequency.
- Referred as a trap or choke.
- Ineffective when harmonic changes due to load changes.



Passive Harmonic Filter

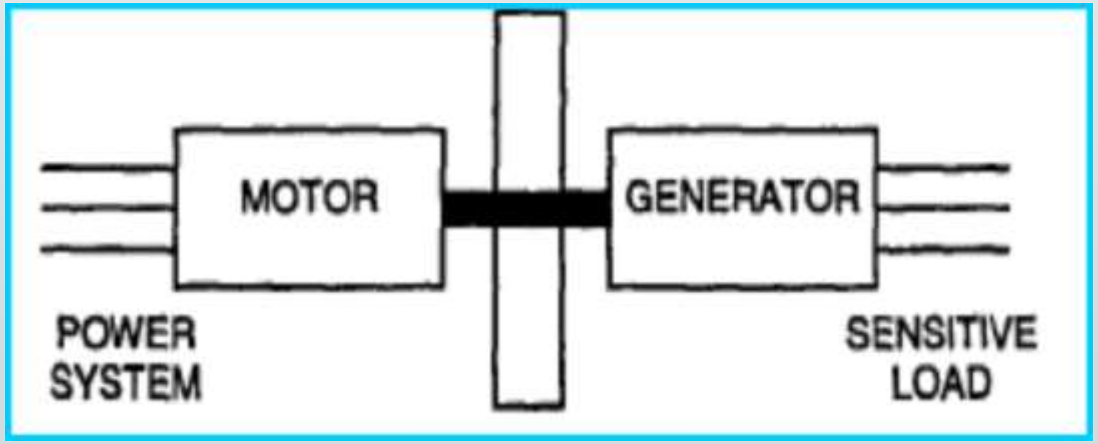
<u>Advantages of Passive filters</u>

-No power supply need.

-Less expensive

-High frequency

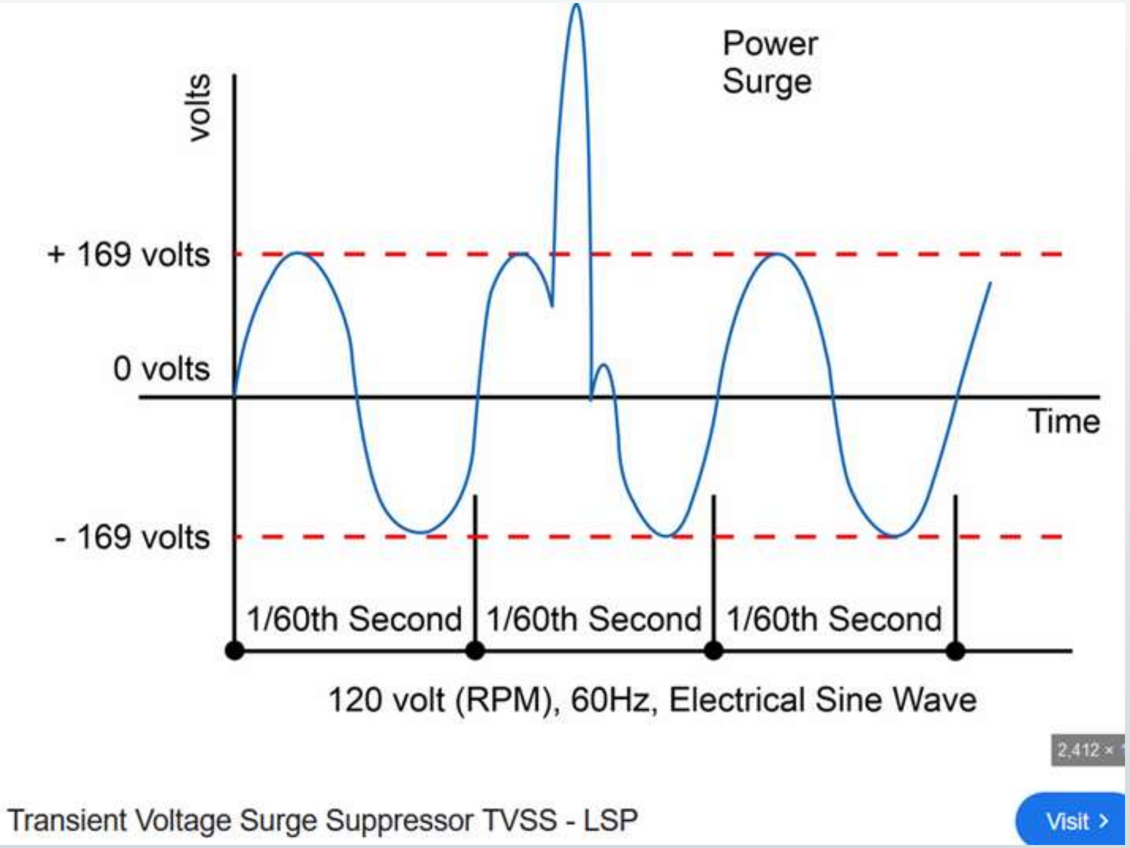
- **Motor-Generator Sets**
  - Consist of a motor supplied by power system, a synchronous generator supplying the load and a flywheel. All connected in common axis.
  - The rotational energy stored in flywheel can be used to perform steady-state voltage regulation and to support voltage during disturbances.
  - This system has high efficiency, low initial costs and enables long duration ride through (several seconds).
  - Only suit in industrial environment due to its size, noise and maintenance requirements.



Motor-generator set

SURGE SUPPRESSORS

- Protect sensitive equipment from being zapped by voltage surges or lightning strokes on power system.
- If located at utility side, it is called surge or lightning arrestor. If at end user side, it is called transient voltage surge suppressor (TVSS).
- Divert to ground or limit transient voltage caused by lightning or switching surges to a level that not harm equipment they are protecting.
- Utilities install arresters near equipment they want to protect while end users locate TVSS inside their facilities; between power outlet and sensitive electronic equipment.
- 2 basic types: crowbar and voltage-clamping devices.



Type 1 SPD

- **I_{imp}**: Impulse current

This is the peak value of a current of 10/350 µs waveform that the SPD is capable of discharging at least one time[3].

Why is I_{imp} important?

IEC 62305 standard requires a maximum impulse current value of 25 kA per pole for a three-phase system. This means that for a 3P+N network, the SPD should be able to withstand a total maximum impulse current of 100kA coming from the earth bonding.

- **I_{fi}**: Auto extinguish follow current

Applicable only to the spark gap technology. This is the current (50 Hz) that the SPD is capable of interrupting by itself after flashover. This current must always be greater than the prospective short-circuit current at the point of installation.

The Type 1 SPD is recommended in the specific case of service-sector and industrial buildings, protected by a lightning protection system or a meshed cage.
It protects electrical installations against direct lightning strokes. It can discharge the back-current from lightning spreading from the earth conductor to the network conductors.
Type 1 SPD is characterized by a 10/350 µs current wave.

Type 2 SPD

The Type 2 SPD is the main protection system for all low voltage electrical installations. Installed in each electrical switchboard, it prevents the spread of overvoltages in the electrical installations and protects the loads.

Type 2 SPD is characterized by an 8/20 µs current wave.

Type 3 SPD

These SPDs have a low discharge capacity. They must therefore mandatorily be installed as a supplement to Type 2 SPD and in the vicinity of sensitive loads.

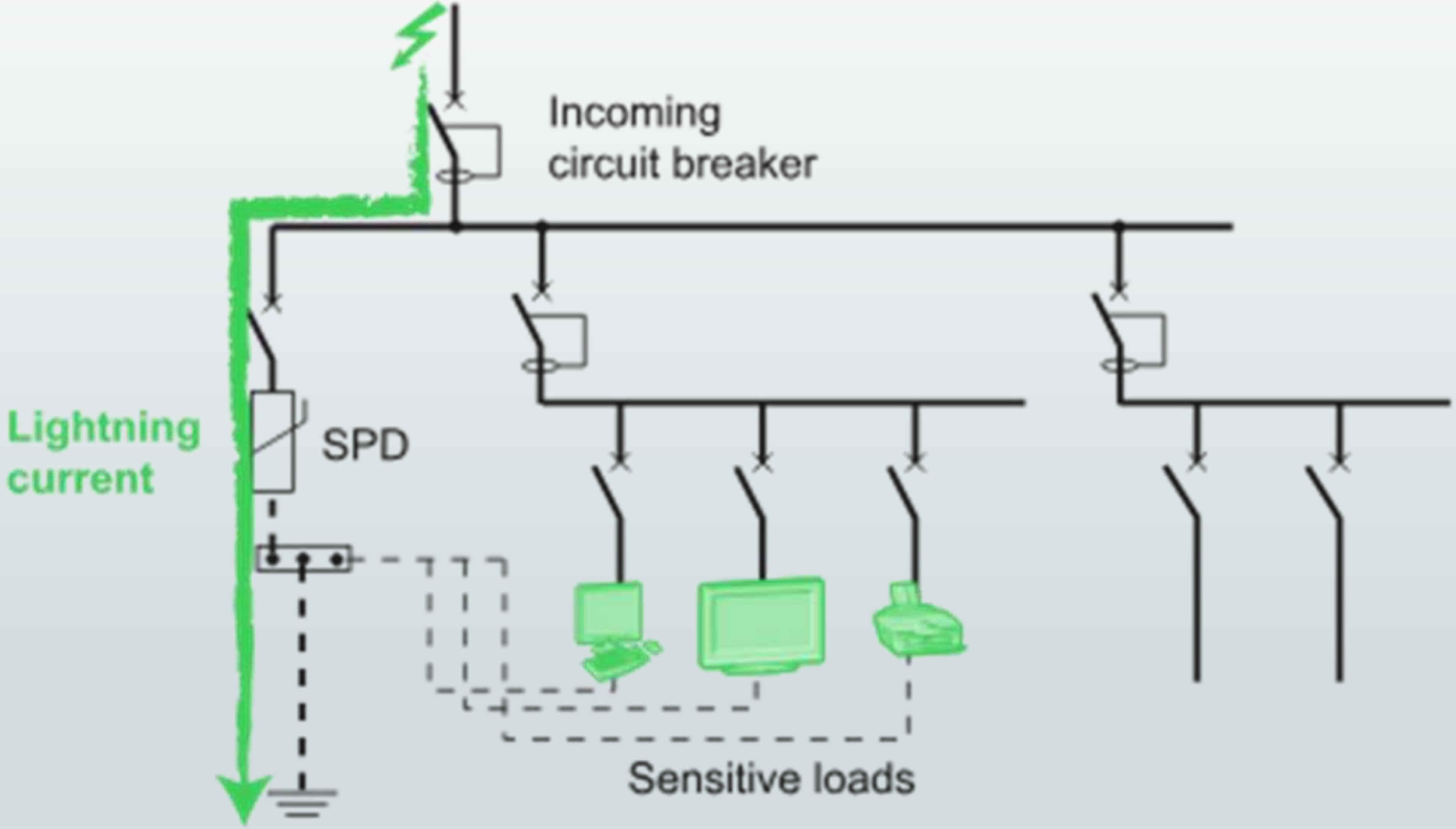
Type 3 SPD is characterized by a combination of voltage waves (1.2/50 µs) and current waves (8/20 µs).

Fig. J18 – SPD standard definition

	Direct lightning stroke	Indirect lightning stroke	
IEC 61643-1	Class I test	Class II test	Class III test
IEC 61643-11/2011	Type 1 : $\boxed{T1}$	Type 2 : $\boxed{T2}$	Type 3 : $\boxed{T3}$
EN/IEC 61643-11	Type 1	Type 2	Type 3
Former VDE 0675v	B	C	D
Type of test wave	10/350	8/20	1.2/50 + 8/20

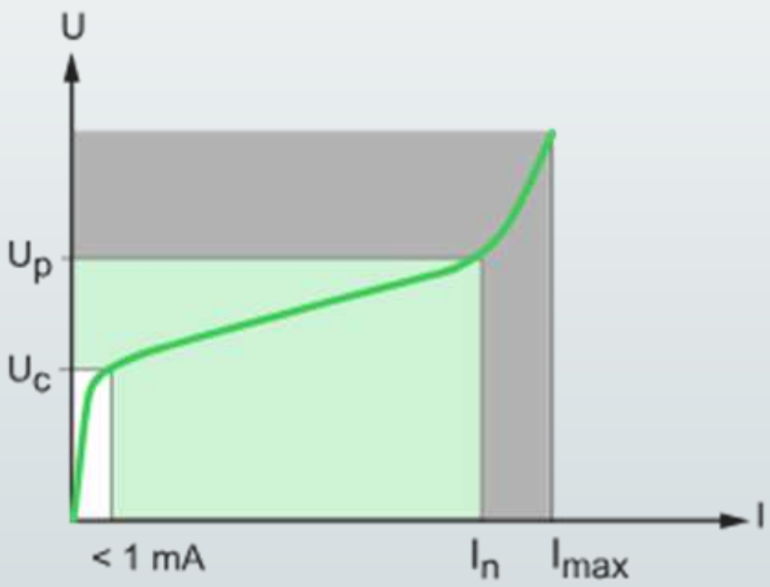
Note 1: There exist $\boxed{T1}$ + $\boxed{T2}$ SPD (or Type 1 + 2 SPD) combining protection of loads against direct and indirect lightning strokes.

Note 2: some $\boxed{T2}$ SPD can also be declared as $\boxed{T3}$.


Incoming
circuit breaker
Lightning
current
SPD
Sensitive loads

Characteristics of SPD

International standard IEC 61643-11 Edition 1.0 (03/2011) defines the characteristics and tests for SPD connected to low voltage distribution systems (see **Fig. J19**).



Main applications Low Voltage SPD

Very different devices, from both a technological and usage viewpoint, are designated by this term. Low voltage SPDs are modular to be easily installed inside LV switchboards.

There are also SPDs adaptable to power sockets, but these devices have a low discharge capacity.

SPD for communication networks

These devices protect telephone networks, switched networks and automatic control networks (bus) against overvoltages coming from outside (lightning) and those internal to the power supply network (polluting equipment, switchgear operation, etc.).

In green, the guaranteed operating range of the SPD.

Fig. J19 – Time/current characteristic of a SPD with varistor

What is a recloser?

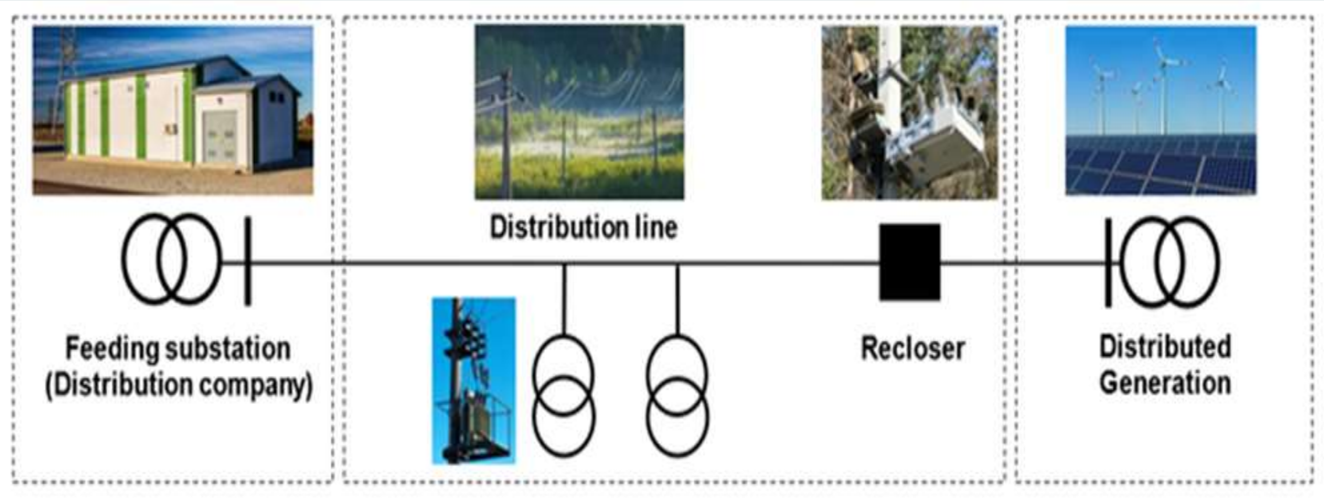
A recloser is an automatic, high-voltage electric switch. Like a circuit breaker on household electric lines, it shuts off electric power when trouble occurs, such as a short circuit. Where a household circuit breaker remains shut off until it is manually reset, a recloser automatically tests the electrical line to determine whether the trouble has been removed. If the problem was only temporary, then the recloser automatically resets itself and restores the electric power.
Reclosers are used throughout the power distribution system, from the substation to residential utility poles. They range from small reclosers for use on single-phase power lines, to larger three-phase reclosers used in substations and on high-voltage power lines up to 38,000 volts.
Standards for reclosers are defined by ANSI/IEEE C37.60.

Main Functions of Reclosers

Recloser can be used both to perform simple protective functions and complex algorithms for automation of distribution networks. Modern reclosers perform the following functions:

- Automatic disconnection of damaged line sections;
- Auto-reclosing;
- Automatic restore of power supply from the network of alternative power source
- local and remote network reconfiguration;
- Self-diagnostics;
- Measurement of network mode parameters;
- Keeping the logs of operational and emergency events in the line;
- Remote control.

The functions implemented by reclosers are not limited to the list above.



ISOLATION TRANSFORMER

What Is An Isolation Transformer And Why Is It Used?

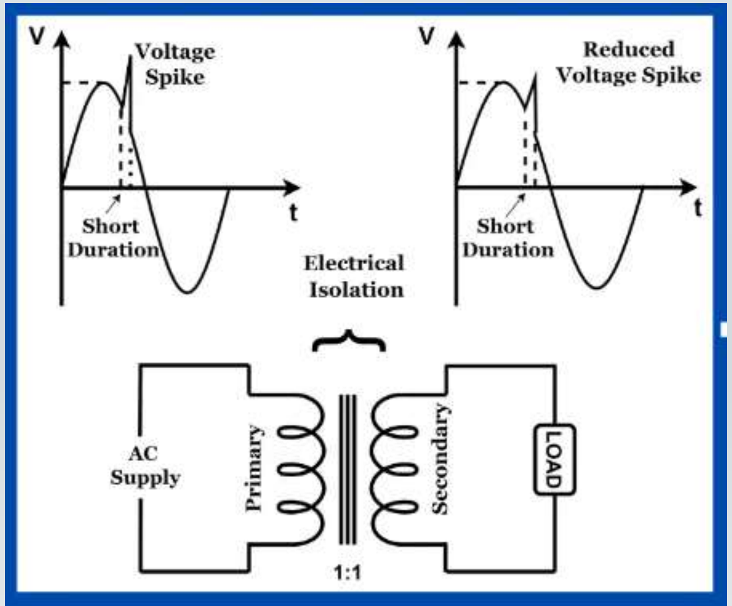
Principles of Isolation Transformers

Isolation transformers are static devices designed with separate primary and secondary windings. These windings keep the two circuits physically and electrically distinct. The device transfers electrical energy between the circuits using a mechanism known as magnetic induction. This process involves generating an electromotive force (EMF) in another circuit using a magnetic field, without altering the frequency.
Isolation transformers are employed in transmission and distribution networks to adjust voltage levels. In these networks, the voltage and current capacities on both the primary and secondary coils are equal. The primary function of an isolation transformer is to eliminate voltage spikes in supply lines. These spikes can cause service disruptions or damage to equipment.

Function of an Isolation Transformer

Isolation transformers offer physical and electrical separation between two circuits. They transmit electrical energy from the primary to the secondary using magnetic coupling, isolating and protecting electronic circuits and individuals from mainline electrical shocks.

An isolation transformer's main function is to mitigate voltage spikes in the supply lines. These spikes or transients can be caused by illumination, static electricity, or rapid voltage changes.



Types of Isolation Transformer:

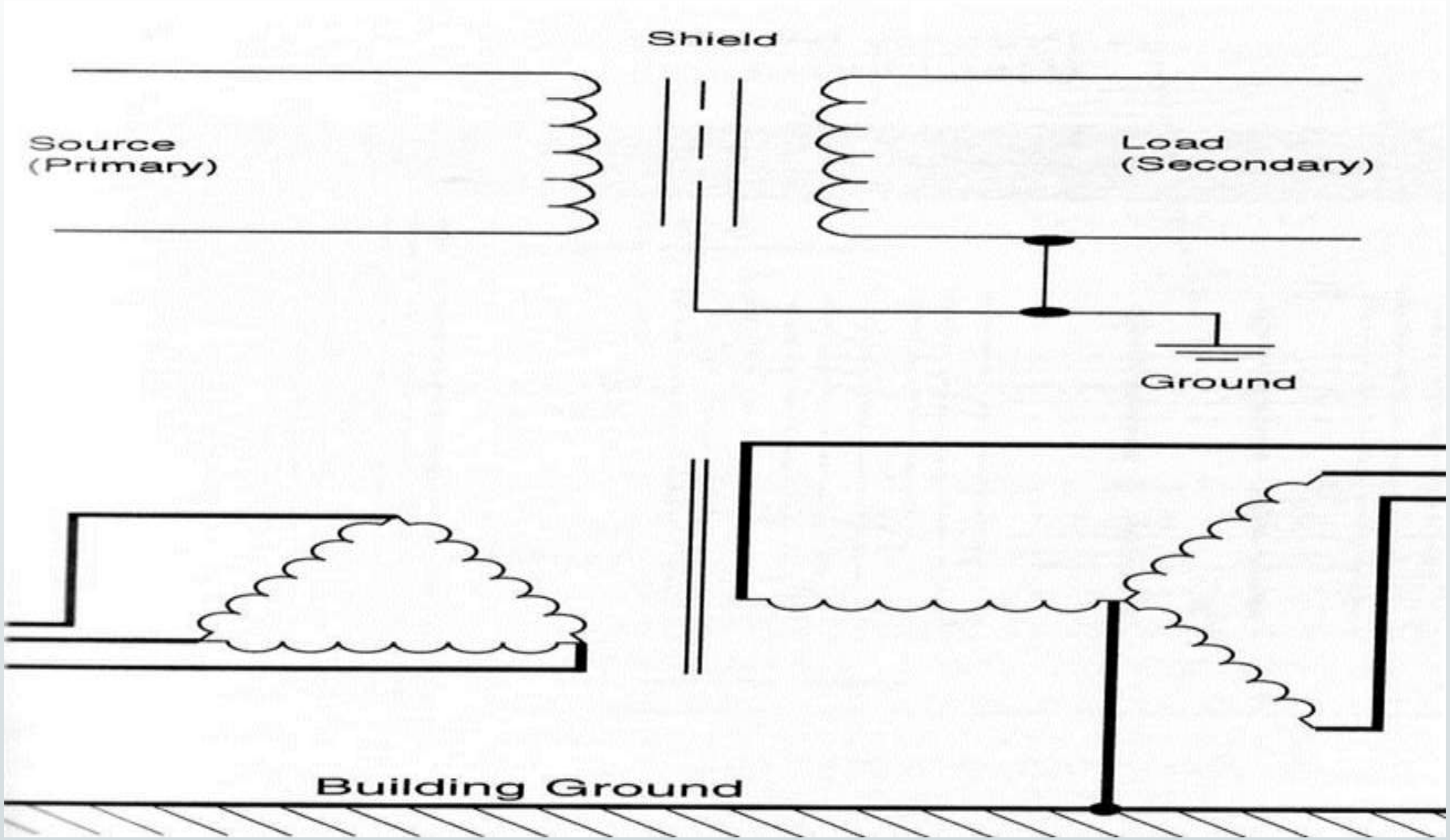
Isolation transformers can be categorized based on various factors such as construction, application, and specific features. Here are some common types of isolation transformers:

- Single-phase Isolation Transformer
- Three-phase Isolation Transformer
- Medical Grade Isolation Transformer
- Auto-transformer
- Shielded Isolation Transformer
- Isolation Transformers with Faraday Shield
- Isolation Transformers with Surge Protection
- Isolation Transformers with Harmonic Mitigation



Benefits of Isolation Transformers

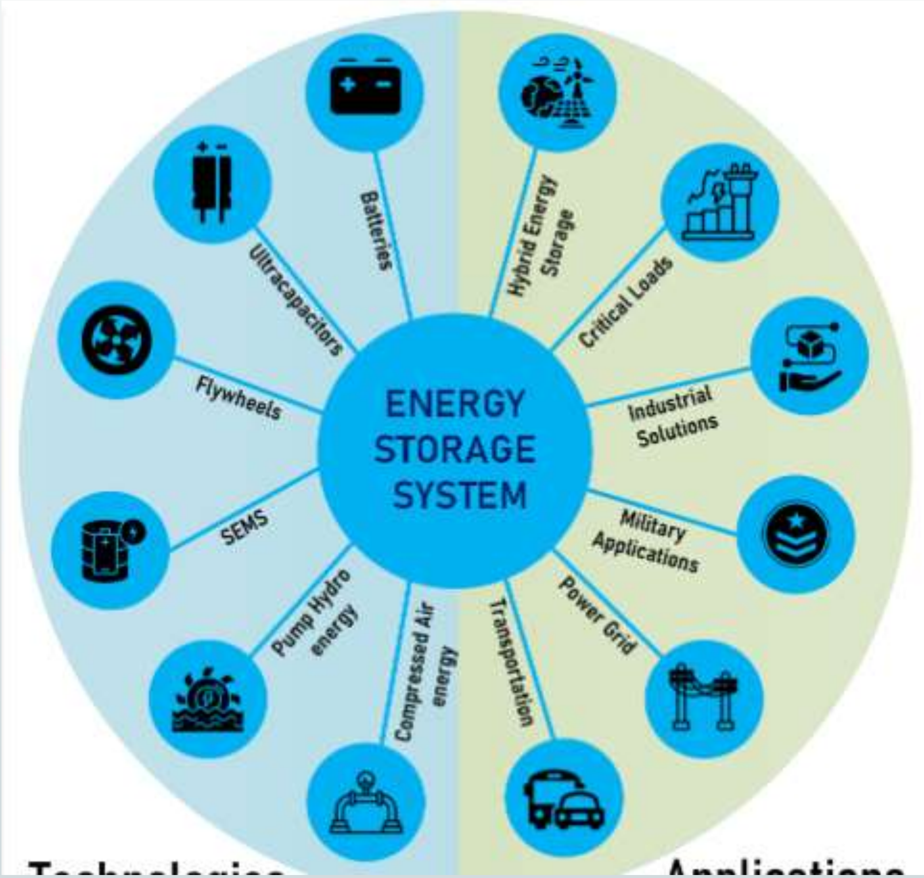
- Isolation transformers have 1:1 winding, so it will separate the primary and secondary windings. The isolation of different circuits can be achieved by using isolation transformers.
- Electric shocks can be prevented using isolation transformers. The protective casing provides protection to winding from dust and other external particles.
- Isolation transformers are one of the best and easiest to install types of transformers. Since no cooling oil is used (dry type transformer), they are highly safe and fireproof.
- Isolation transformers are best suitable in an environment where high-level protection is required. The external casing will protect the transform from all types of external factors.
- The noises and sounds from the electrical devices can be reduced using an isolation transformer.
- Isolation transformers also protect the people working around the transformer and it is one of the safest transformers that can be used in overcrowded areas.
- You can use isolation transformers for safe, reliable, and accurate measurements in various industries and businesses.
- They offer benefits such as reliable and safe equipment, reduced presence of power surges, reduced noise disruption, harmonic correction, prevention of earthing failures, and improved power quality.



1. Single-phase shielded isolation transformer
2. Three-phase delta-wye isolation transformer

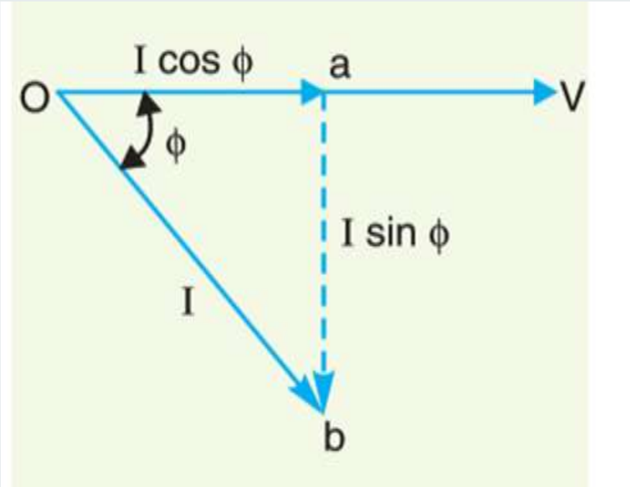
- **Energy storage system**

  - All electrical energy storage systems have the same basic components, interface with the power system, power conditioning system, charge/discharge control, and the energy storage medium itself.
  - Each storage medium has different characteristics, energy density, charge/discharge time, the effect of repeated cycling on performance and life, cost, and maintenance requirements.
  - Available energy storage systems:
  - Battery/advanced battery energy storage
  - Superconducting magnetic energy storage – used for very critical applications but its cost limits its use to industries where the losses are great during disturbances, for example, semiconductor fabrication.
  - Flywheel energy storage – high maintenance cost
  - Capacitor or ultra-capacitor storage



POWER FACTOR IMPROVEMENT

- Power Factor
- The cosine of angle between voltage and current in an a.c. circuit is known as power factor.
- (a) I cos ϕ in phase with V
- (b) I sin ϕ 90' out of phase with V



- For Inductive ckt , the current lags the voltage

  the p.f is lagging.
- For capacitive ckt. The current leads the voltage

  the p.f is leading.

- <u>Power Triangle</u>

- The power factor is defined by power triangle. The power factor of a circuit may also be defined as the ratio of active power to the apparent power.

$$\text{Power factor, } \cos\phi = \frac{OA}{OB} = \frac{\text{active power}}{\text{apparent power}} = \frac{\text{kW}}{\text{kVA}}$$

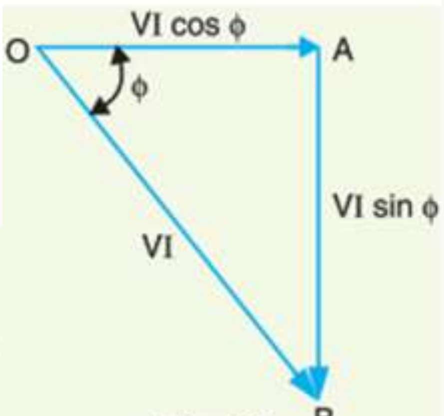


Fig. 6.2

$OA = VI\cos\phi$ and represents the *active power* in watts or kW

$AB = VI\sin\phi$ and represents the *reactive power* in VAR or kVAR

$OB = VI$ and represents the *apparent power* in VA or kVA

- The power factor can also be defined the ratio of resistance and impedance.

$$\text{Power factor} = \frac{R}{Z} = \frac{\text{Resistance}}{\text{Impedance}}$$

$$\text{Power factor} = \frac{VI\cos\phi}{VI} = \frac{\text{Active power}}{\text{Apparent Power}}$$

- For inductive load is power factor is lagging.
- For capacitive load is power factor is leading.
- For resistive load is unity power factor.

DISADVANTAGES OF LOW POWER FACTOR

- Large kVA rating of equipment
- Greater conductor size
- Large copper losses
- Poor voltage regulation
- Reduced handling capacity of system

CAUSES OF LOW POWER FACTOR

Low power factor is undesirable from economic point of view. Normally, the power factor of the whole load on the supply system in lower than 0·8. The following are the causes of low power factor:

AC induction motors

Arc lamps, electric discharge lamps and industrial heating furnaces operate at low lagging power factor.

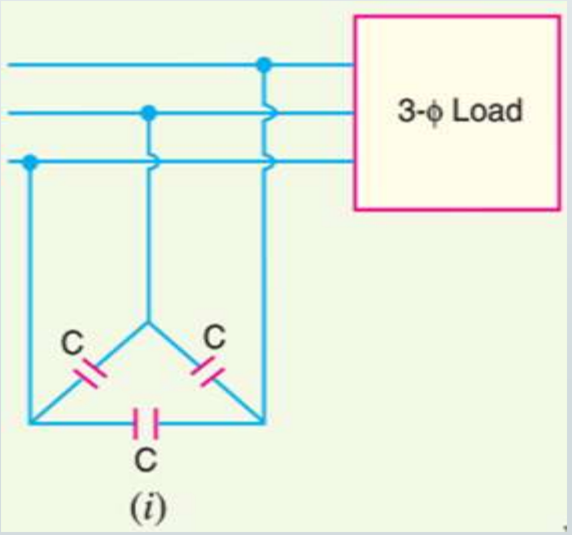
The load on the power system is varying ; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetization current. This results in the decreased power factor.

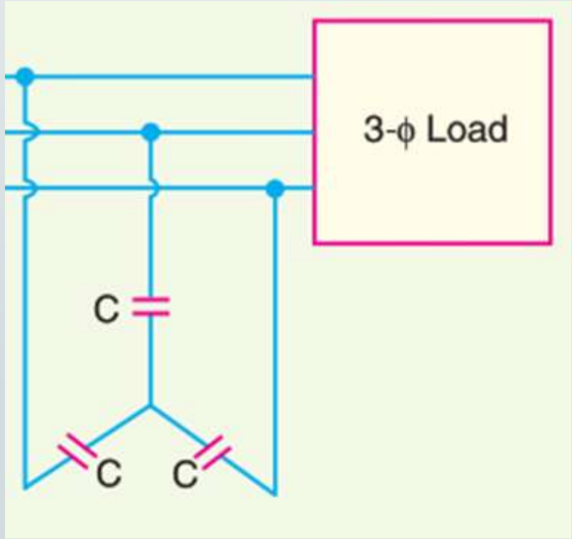
POWER FACTOR IMPROVEMENT

Power factor improvement can be achieved by the following equipment.

1. **Static capacitor**

The power factor can be improved by connecting capacitors in parallel with the equipment operating at a lagging power factor. The capacitor (generally known as static**





STATIC CAPACITORS ADVANTAGES & DISADVANTAGES

- Static capacitors are invariably used for power factor improvement in factories and buildings.
- **Advantages**

  (i) They have low losses.

  (ii) They require little maintenance as there are no rotating parts.

  (iii) They can be easily installed as they are light and require no foundation.

  (iv) They can work under ordinary atmospheric conditions.
- **Disadvantages**

  (i) They have short service life ranging from 8 to 10 years.

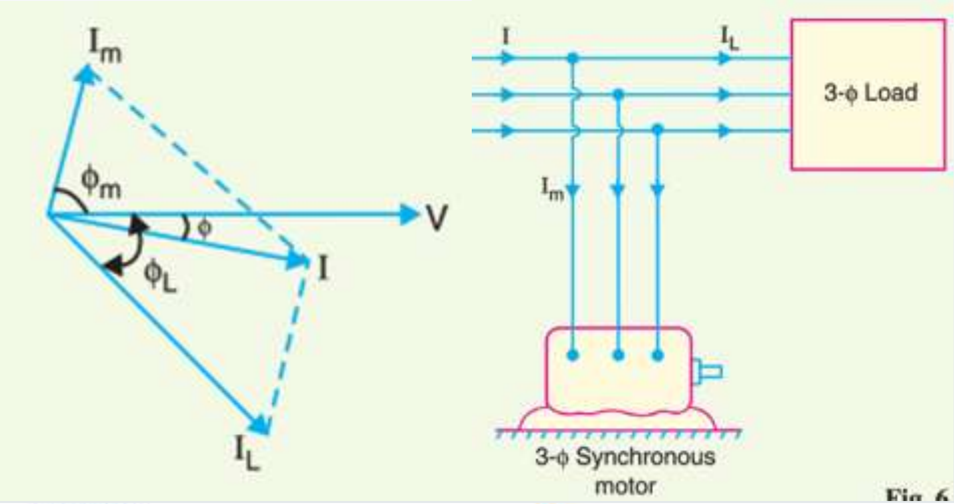
  (ii) They are easily damaged if the voltage exceeds the rated value.

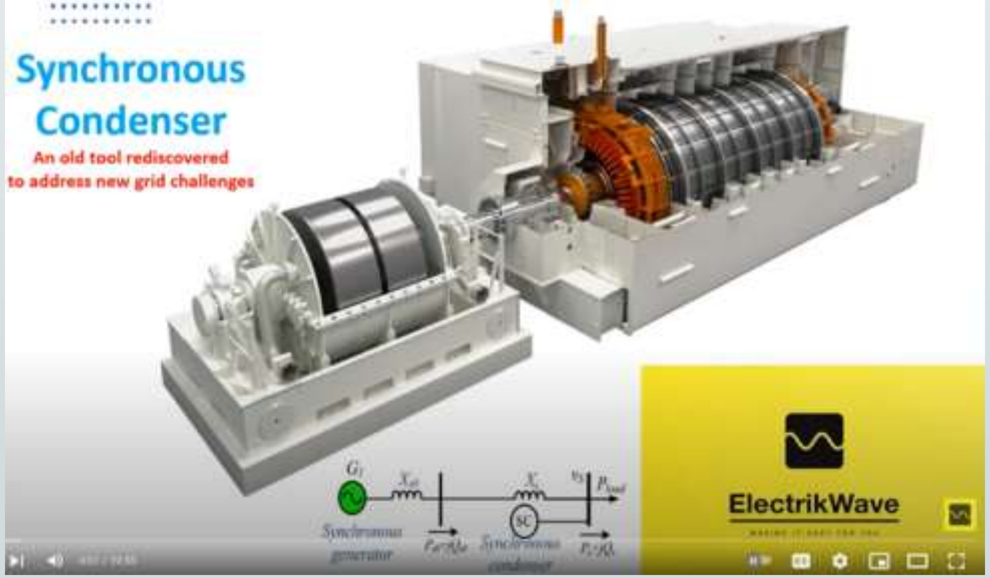
  (iii) Once the capacitors are damaged, their repair is uneconomical.

2. Synchronous condenser or motor

An over-excited synchronous motor running on no load is known as a synchronous condenser. When such a machine is connected in parallel with the supply, it takes a leading current that partly neutralizes the lagging reactive component of the load. Thus the power factor is improved

. Synchronous condensers are generally used at major bulk supply substations for power factor improvement.





- **Advantages**

  (i) By varying the field excitation, the magnitude of current drawn by the motor can be changed by any amount. This helps in achieving step-less control of the power factor.

  (ii) The motor windings have high thermal stability to short circuit currents.

  (iii) The faults can be removed easily.

- **Disadvantages**

  (i) There are considerable losses in the motor.

  (ii) The maintenance cost is high.

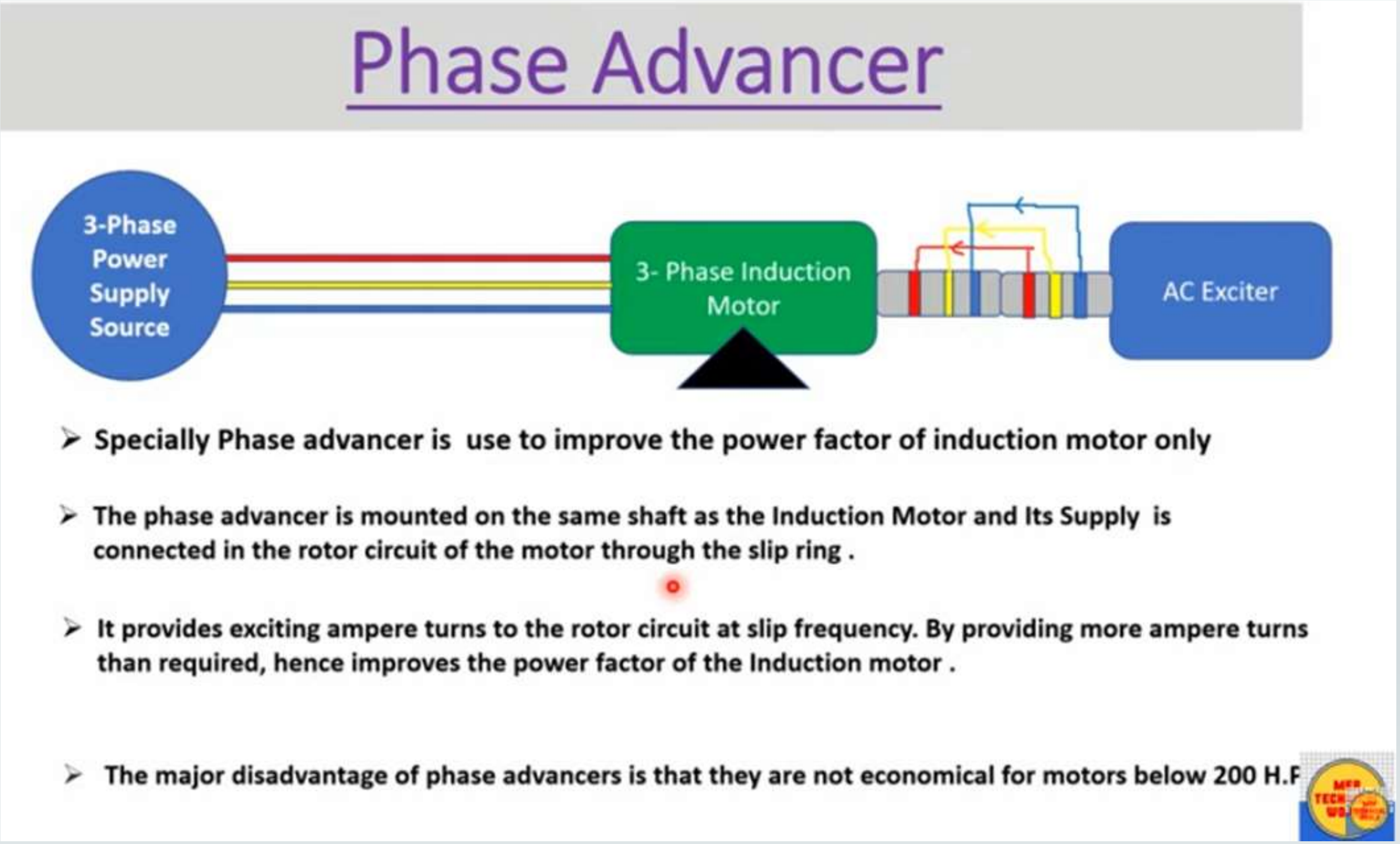
  (iii) It produces noise.

  (iv) Except in sizes above 500 kVA, the cost is greater than that of static capacitors of the same rating.

  (v) As a synchronous motor has no self-starting torque, therefore, auxiliary equipment has to be provided for this purpose.

- **3. Phase advancers.**

Phase advancers are used to improve the power factor of induction motors. The low power factor of an induction motor is due to the fact that its stator winding draws exciting current which lags behind the supply voltage by 90’. If the exciting ampere turns can be provided from some other a.c. source, then the stator winding will be relieved of exciting current and Static Capacitor the power factor of the motor can be improved.



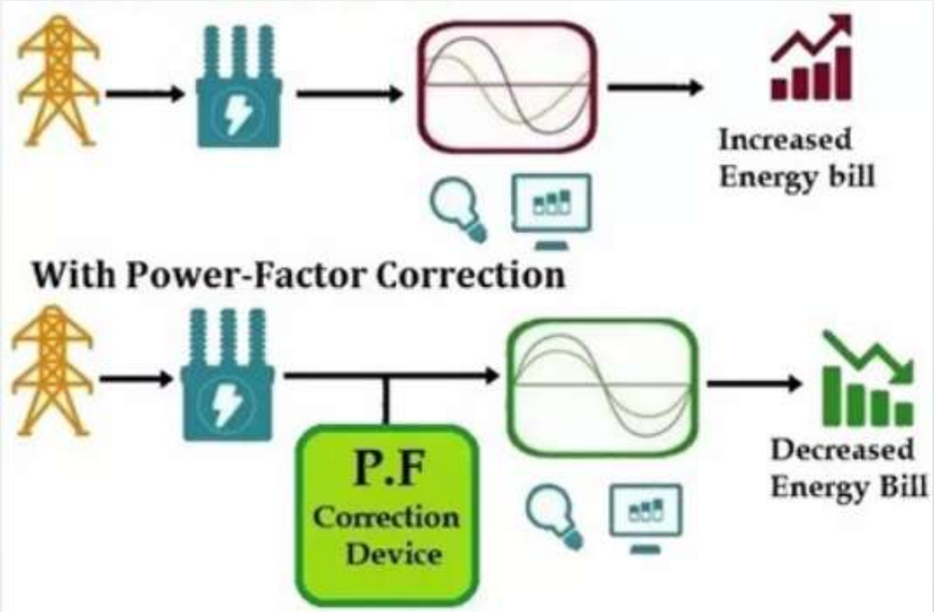
IMPORTANCE OF POWER FACTOR IMPROVEMENT

- For consumers.

Improvement of p.f. to a proper value results in the net annual saving for the consumer.

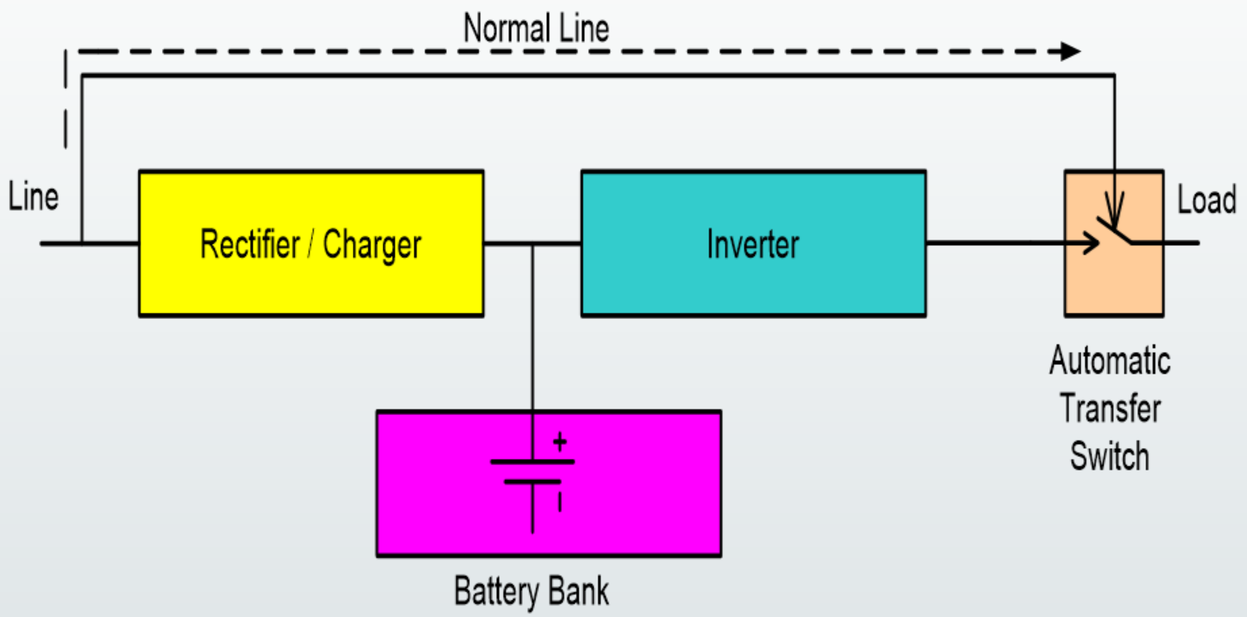
- For generating stations

Improved power factor increases the earning capacity of the power station.



UNINTERRUPTIBLE POWER SUPPLY

- Standby UPS
- Online UPS
- Hybrid UPS

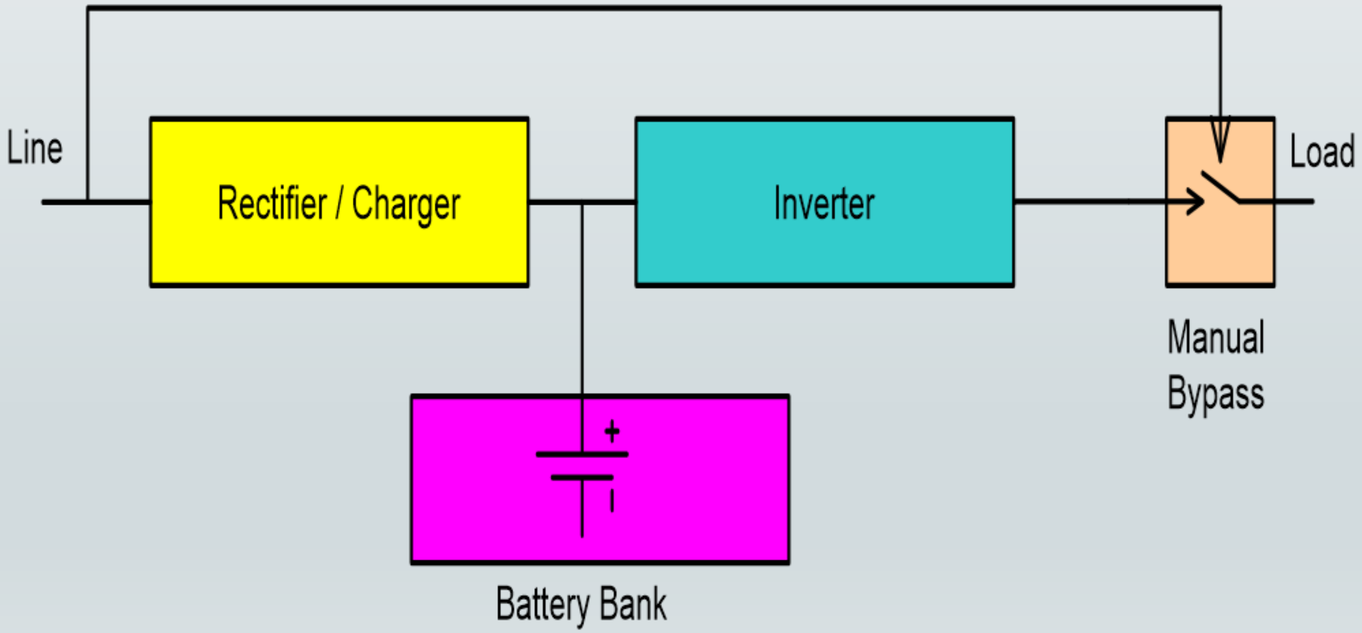


Standby UPS

Consists of rectifier, battery, inverter and static switches.
Static switch is controlled to allow load to be fed from main supply.
Switch open and close respectively below some predetermined level.
Then, the load will be fed from battery via inverter to ensure continuity of supply to the load.
Inverter output of a standby UPS must always operate in synchronism with the supply frequency to ensure a smooth transition from one supply to the other.

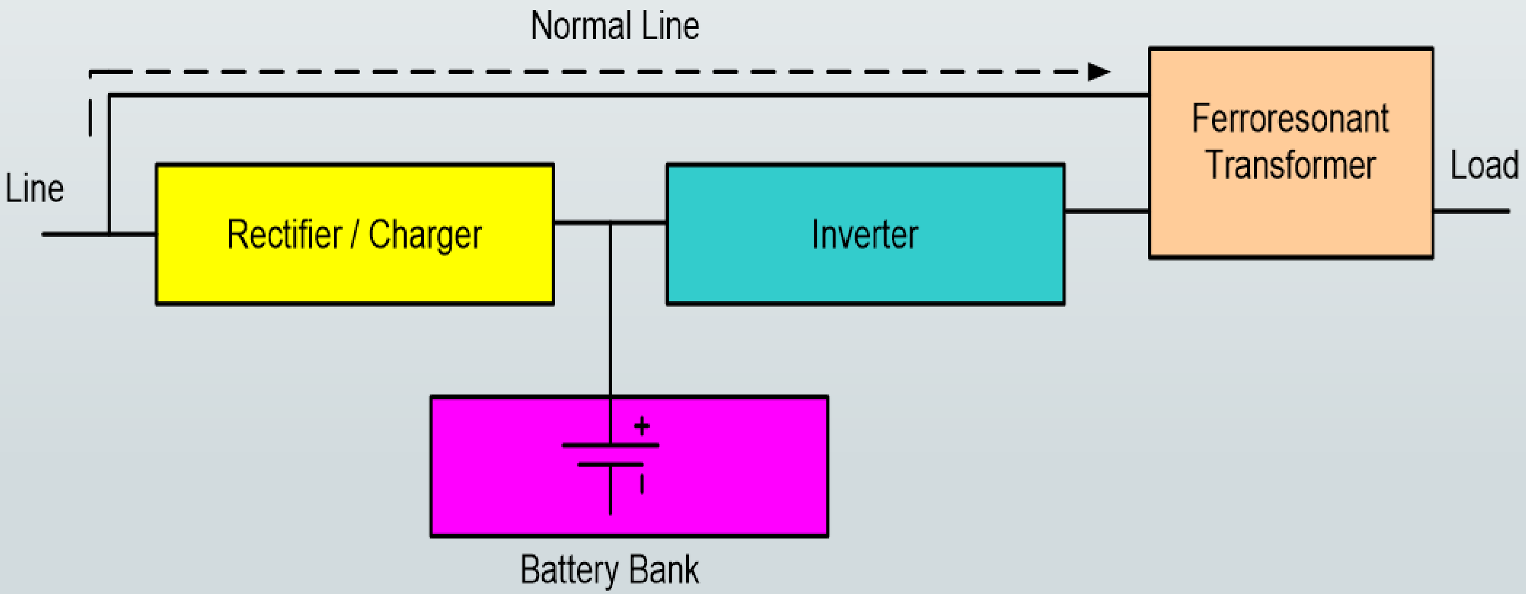
ONLINE UPS

Load is always fed from the UPS; in this way the load is isolated from the main supply at all times.
Expensive and have high operating losses.
It is very similar to a standby system from view of schematic, but with a manual transfer switch in place of the static transfer switches.



HYBRID UPS

Configuration similar to standby UPS system.
The only exception is some form of voltage regulator, such as ferro-resonance transformer where it is used in place of the static switches.
The transformer provides regulation to the load and momentary ride-through when the transfer from main supply to standby UPS is made.



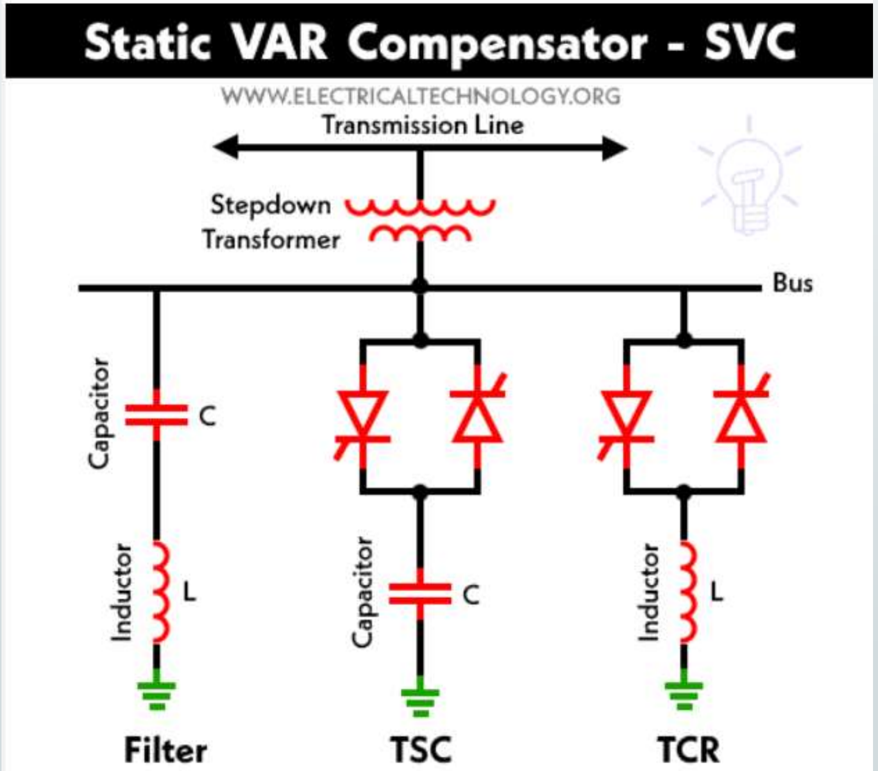
Hybrid UPS

DUAL FEEDERS WITH STATIC TRANSFER

STATIC SVCs
STATCOM
DVR

Static VAR compensator (SVC)
Supply of VARs by static VAR compensator (SVC)

In transmission applications, the SVC is used to regulate the grid voltage. If the power system's reactive load is capacitive (leading), the SVC will use thyristor-controlled reactors to consume VARs from the system, lowering the system voltage.

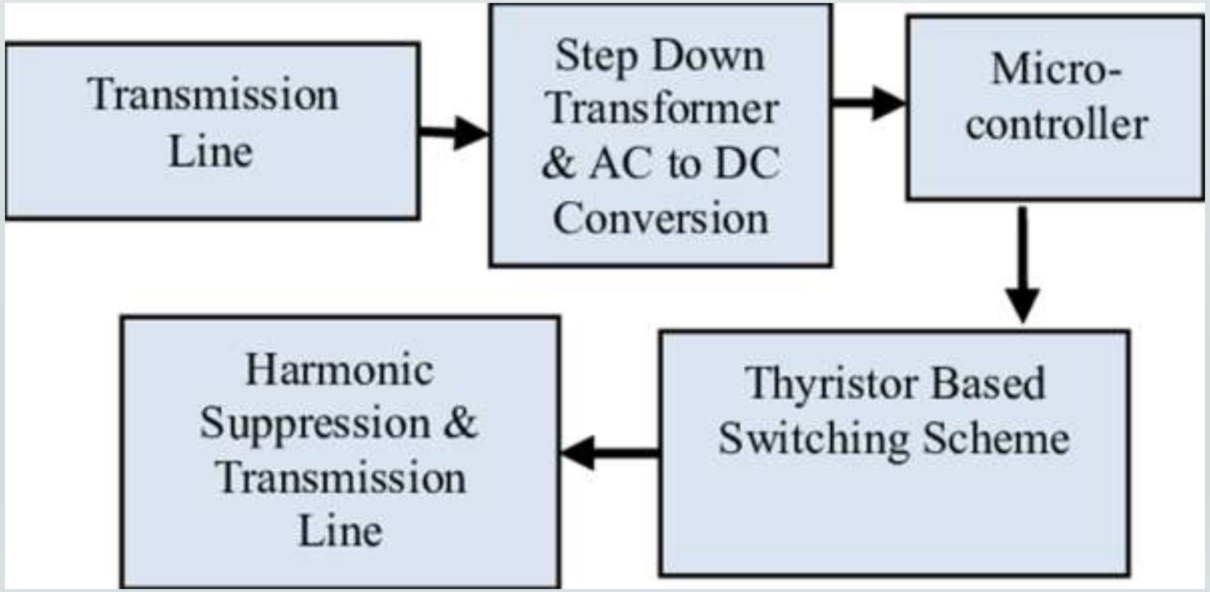


Working Principle of Static Var Compensator

Its role in electronic power supply systems is to improve the power factor of the grid, reduce the losses of power transformers and transmission lines, improve power supply efficiency, and improve the power supply environment.

The benefits of SVC to power transmission:

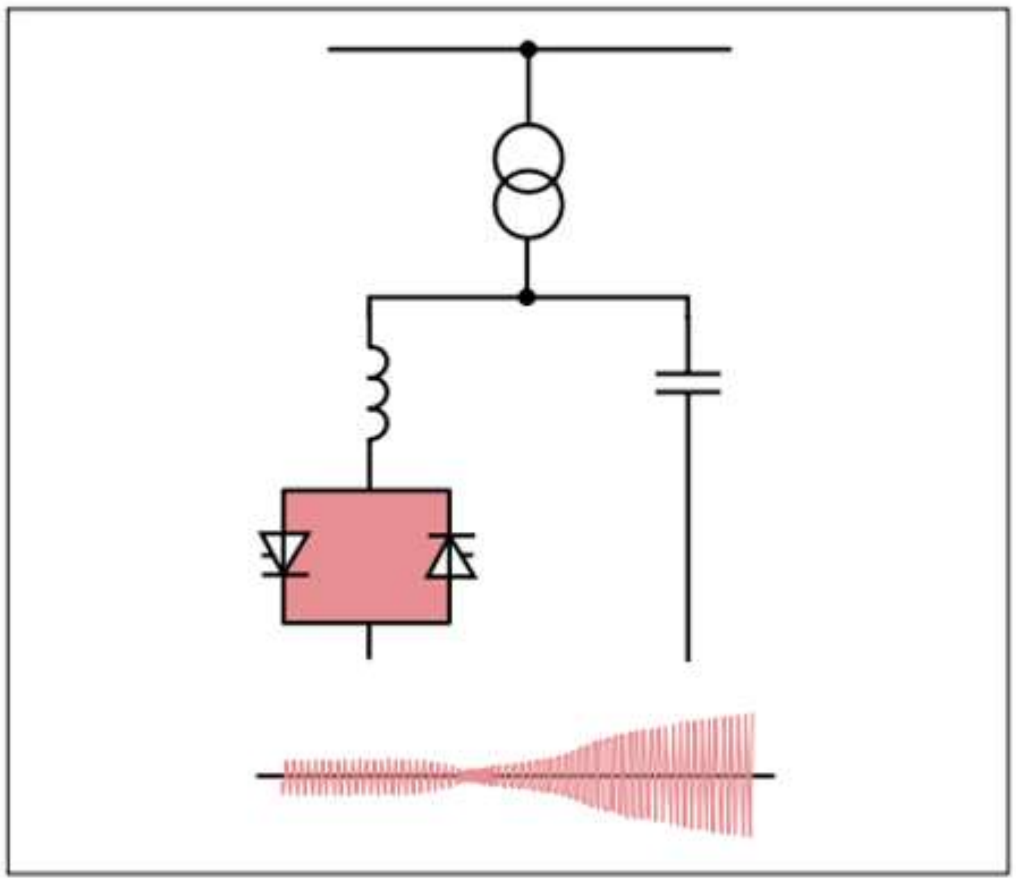
- Stabilized voltages in weak systems
- Reduced transmission losses
- Increased transmission capacity, to reduce, defer or eliminate the need for new lines
- Higher transient stability limit
- Increased damping of minor disturbances
- Greater voltage control and stability
- Power oscillation damping



Thyristor controlled reactor and fixed capacitor, TCR/FC

A reactor and thyristor valve are incorporated in each single-phase branch. Power is changed by controlling the current through the reactor via the thyristor valve. The on-state interval is controlled by delaying triggering of the thyristor valve relative to the natural zero current crossing.

A thyristor controlled reactor (TCR) is used in combination with a fixed capacitor (FC) when reactive power generation or alternatively, absorption and generation is required. This is often the optimum solution for sub-transmission and distribution.



TCR/FCs are characterized by

- Continuous control
- No transients
- Elimination of harmonics by tuning the FCs as filters
- Compact design

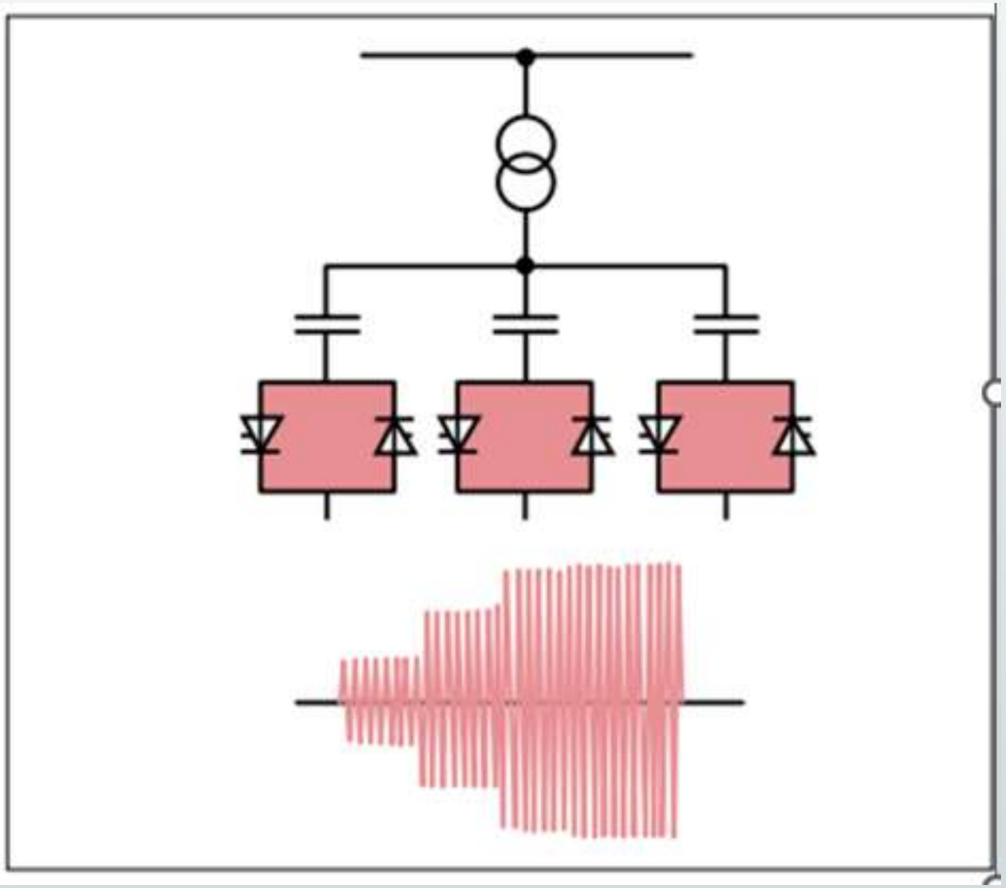
Thyristor switched capacitor, TSC

A shunt capacitor bank is divided into an appropriate number of branches. Each branch is individually switched on or off via a thyristor valve. Switching takes place when the voltage across the thyristor valve is zero, making it virtually transient-free.

Disconnection is effected by suppressing the firing pulses to the thyristors which will be blocked when the current reaches zero.

TSCs are characterized by

- Stepped control
- No transients
- No harmonics
- Low losses
- Redundancy and flexibility



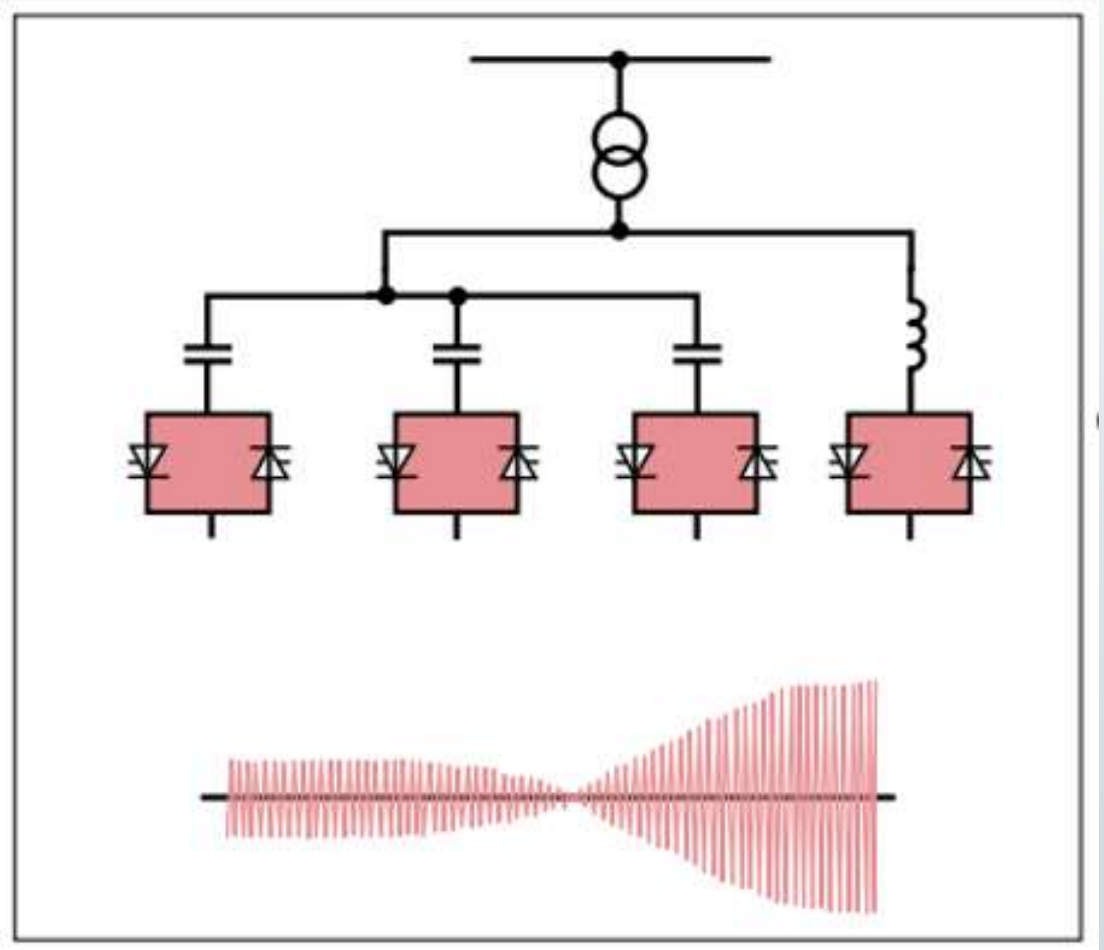
Thyristor controlled reactor/Thyristor switched capacitor, TCR/TSC

A combined TCR and TSC is the optimum solution in many cases. With a TCR/TSC compensator, continuously variable reactive power is obtained across the entire control range plus full control of both the inductive and the capacitive parts of the compensator.

The principal benefit is optimum performance during major disturbances in the power system, such as line faults and load rejections.

TCR/TSC combinations are characterized by

- Continuous control
- No transients
- Elimination of harmonics via filters or TSR (thyristor switched reactor) control
- Low losses
- Redundancy
- Flexible control and operation



To STAY ALIVE, you have to STAY ALERT