ADITYA COLLEGE OF ENGINEERING & TECHNOLOGY

INTRODUCTION TO POWER QUALITY

By

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Surampalem.

- A quick review on what we discussed in last class
- Today's Discussion on
- **Unit–I:Introduction**
- Overview of power quality
- Concern about the power quality
- General classes of power quality
- voltage quality problems
- Transients
- Long–duration voltage variations
- Short–duration voltage variations
- Voltage unbalance
- Waveform distortion
- Voltage fluctuation
- Power frequency variations.

Power Quality = Voltage Quality

- *power* quality however, it is actually the quality of the voltage that is being addressed in most cases.

- The power supply system can only control the quality of the voltage; it has no control over the currents that particular loads might draw. Therefore, the standards in the power quality area are devoted to maintaining the supply voltage within certain limits.

- The current resulting from a short circuit causes the voltage to sag or disappear completely, as the case may be.

- Currents from lightning strokes passing through the power system cause high-impulse voltages that frequently flash over insulation and lead to other phenomena, such as short circuits.

- Distorted currents from harmonic-producing loads also distort the voltage as they pass through the system impedance. Thus a distorted voltage is presented to other end users.

Concerned about Power Quality

- The quality of power can have a direct economic impact on many industrial consumers
- revitalizing industry with more automation and more modern equipment. This usually means electronically controlled, energy-efficient equipment that is often much more sensitive to deviations in the supply voltage than were its electromechanical predecessors.
- It is not uncommon for a single, commonplace, momentary utility breaker operation to result in a $10,000 loss to an average-sized industrial concern by shutting down a production line that requires 4 hours to restart.
- In the semiconductormanufacturing industry, the economic impacts associated with equipment Sensitivity to momentary voltage sags resulted in the development of a whole new standard for equipment ride-through (SEMI Standard F-47, *Specification for Semiconductor Process Equipment Voltage Sag Immunity*).
- Meeting customer expectations and maintaining customer confidence are strong motivators. With today's movement toward deregulation and competition between utilities, The loss of a disgruntled customer to a competing power supplier can have a very significant impact financially on a utility

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Power Quality Over View

There are different definitions for power quality.

- According to Utility, power quality is reliability.

- According to load aspect, it is defined as the power supplied for satisfactory performance of all equipment i.e., all sensitive equipment. This depends upon the end user

- According to end user point of view, it is defined as,

"any power problem manifested in voltage, current, or frequency deviations that result in failure or miss operation of customer equipment"

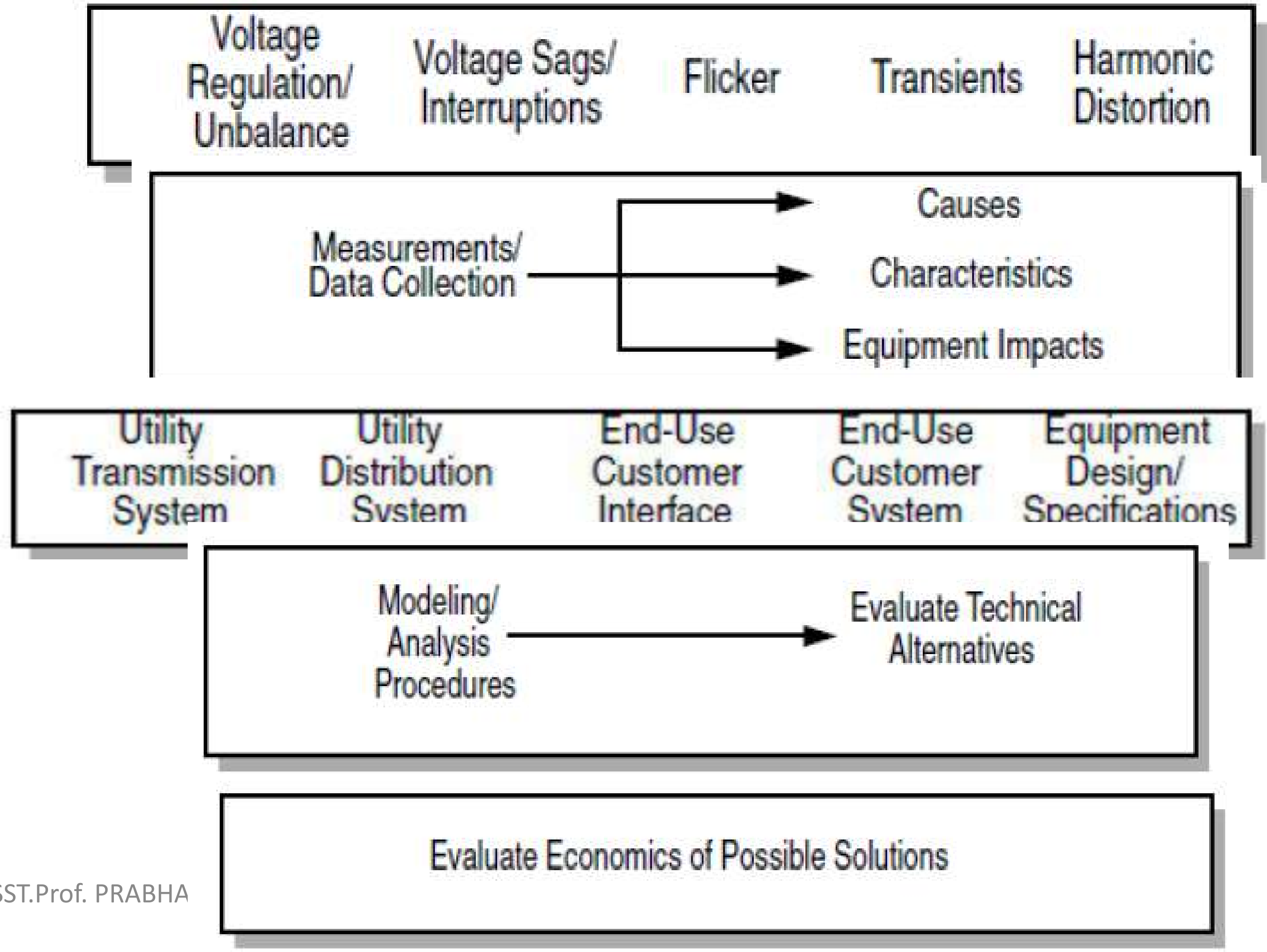
- In IEEE dictionary, power quality is defined as
- "the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment".

- IEC (International Electrotechnical Commission), it is defined as, " set of parameters

defining the properties of the power supply as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (magnitude, frequency, waveform).The power supply system can only control the quality of the voltage; it has no control over the currents that particular loads might draw. Therefore, the standards in the power quality are related to maintaining the supply voltage within certain limits

The Power Quality Evaluation Procedure

The following gives the general steps that are often required in a power quality investigation, along with the major considerations that must be addressed at each step.



General Classes of Power Quality Problems

The IEEE Standards Coordinating Committee 22 (IEEE SCC22) has led the main effort in the United States to coordinate power quality standards

(i) Conducted low-frequency phenomena

- Harmonics, inter harmonics
- Signal systems (power line carrier)
- Voltage fluctuations (flicker)
- Voltage dips and interruptions
- Voltage imbalance (unbalance)
- Power frequency variations
- Induced low-frequency voltages
- DC in ac networks

(ii) Radiated low-frequency phenomena

- Magnetic fields
- Electric fields

(iii)Conducted high-frequency phenomena

- Induced continuous-wave (CW) voltages or currents
- Unidirectional transients
- Oscillatory transients

(iv) Radiated high-frequency phenomena

- Magnetic fields
- Electric fields
- Electromagnetic fields
- Continuous waves
- Transients

(v) Electrostatic discharge phenomena (ESD)

(vi) Nuclear Electromagnetic Pulse (NEMP)

Transients

It is an event that is undesirable and momentary in nature. It is the sudden change in one steady state operating condition to another.

Transients can be classified into two categories:

1. Impulsive and
2. Oscillatory

Impulsive Transient

- An impulsive transients a **sudden non–power frequency change** in the steady-state condition of voltage, current, or both that is unidirectional in polarity (either positive ornegative).

- Impulsive transients are normally characterized by their rise and decay times. Due to high frequency nature, the shape of impulsive transients may be changed quickly by circuit components and may have significant different characteristics when viewed from different parts of the power system. They are generally not conducted far from the source.

- Impulsive transients **can excite the natural frequency of power system circuits** and produce oscillatory **transients.**

Source: lightning

Oscillatory Transient

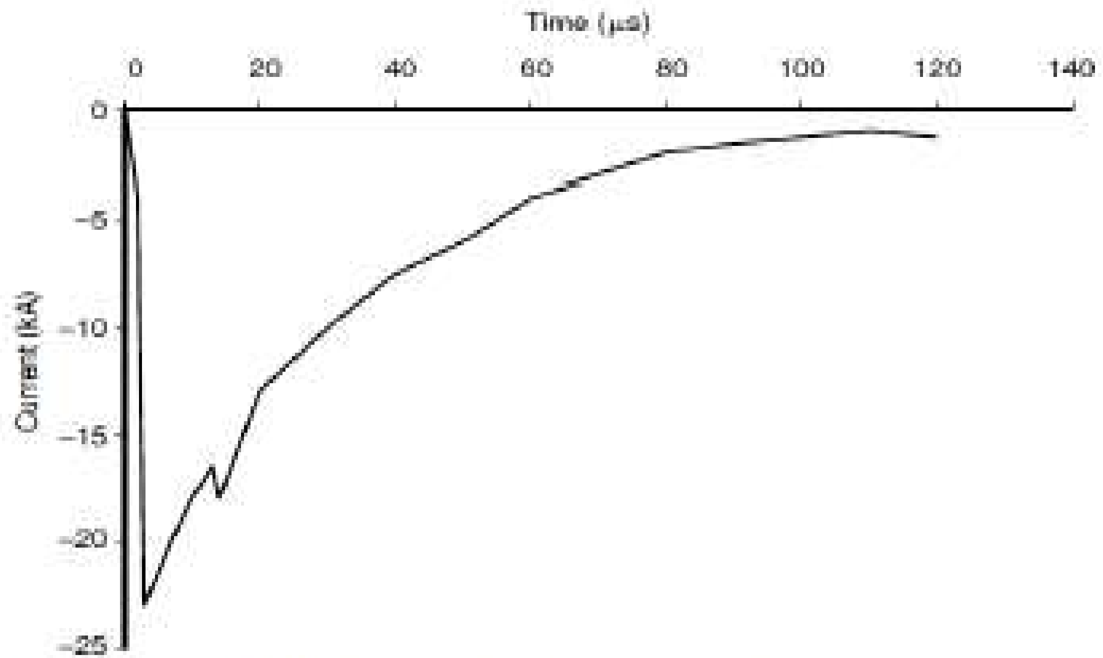
An oscillatory transient is a sudden, non–power frequency change in the steady-state condition of voltage, current, or both, that includes **both positive and negative polarityvalues**. Instantaneous value of oscillatory transient changes polarity rapidly.

It can be classified into 3 types,

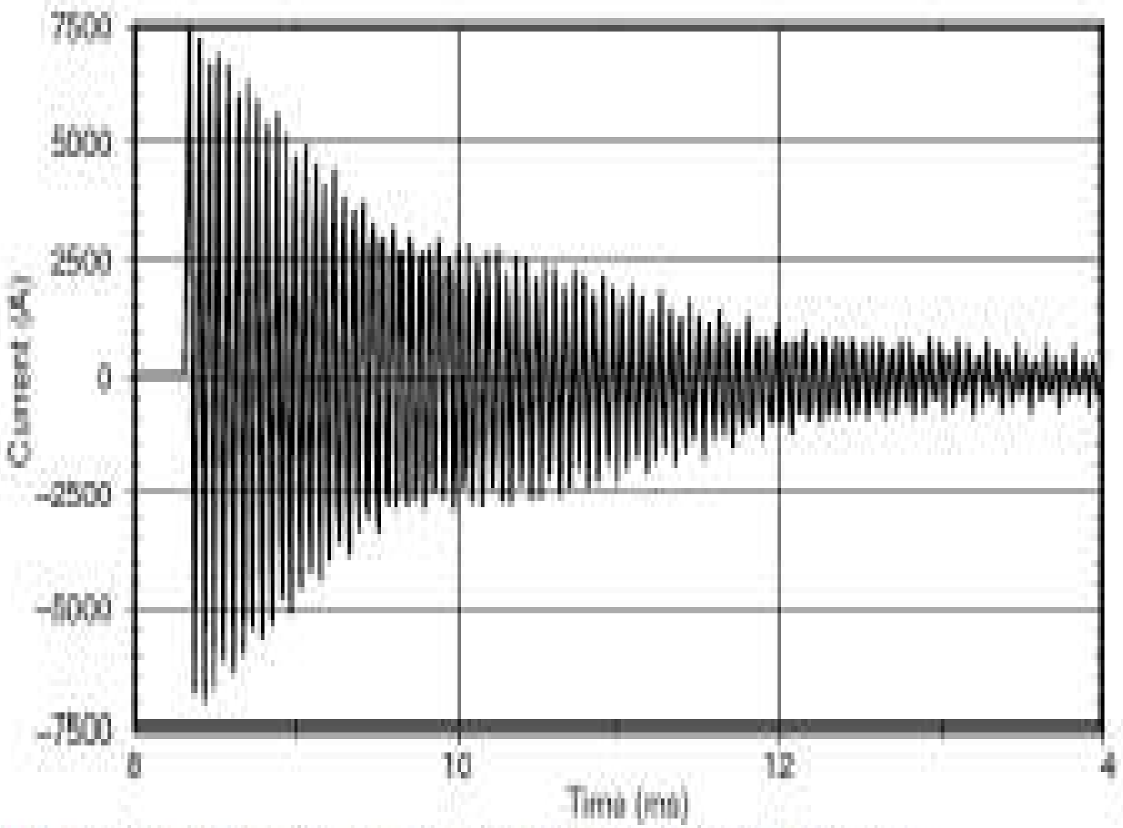
1. **High-frequency Transients**: These have frequency components **greater than 500kHz** and a typical duration measured **in microseconds** (or several cycles of theprincipal frequency)

2**. Medium**-frequency Transients: These have frequency **components between 5 and 500kHz** with duration measured in **the tens of microseconds** (or several cycles ofthe principal frequency).

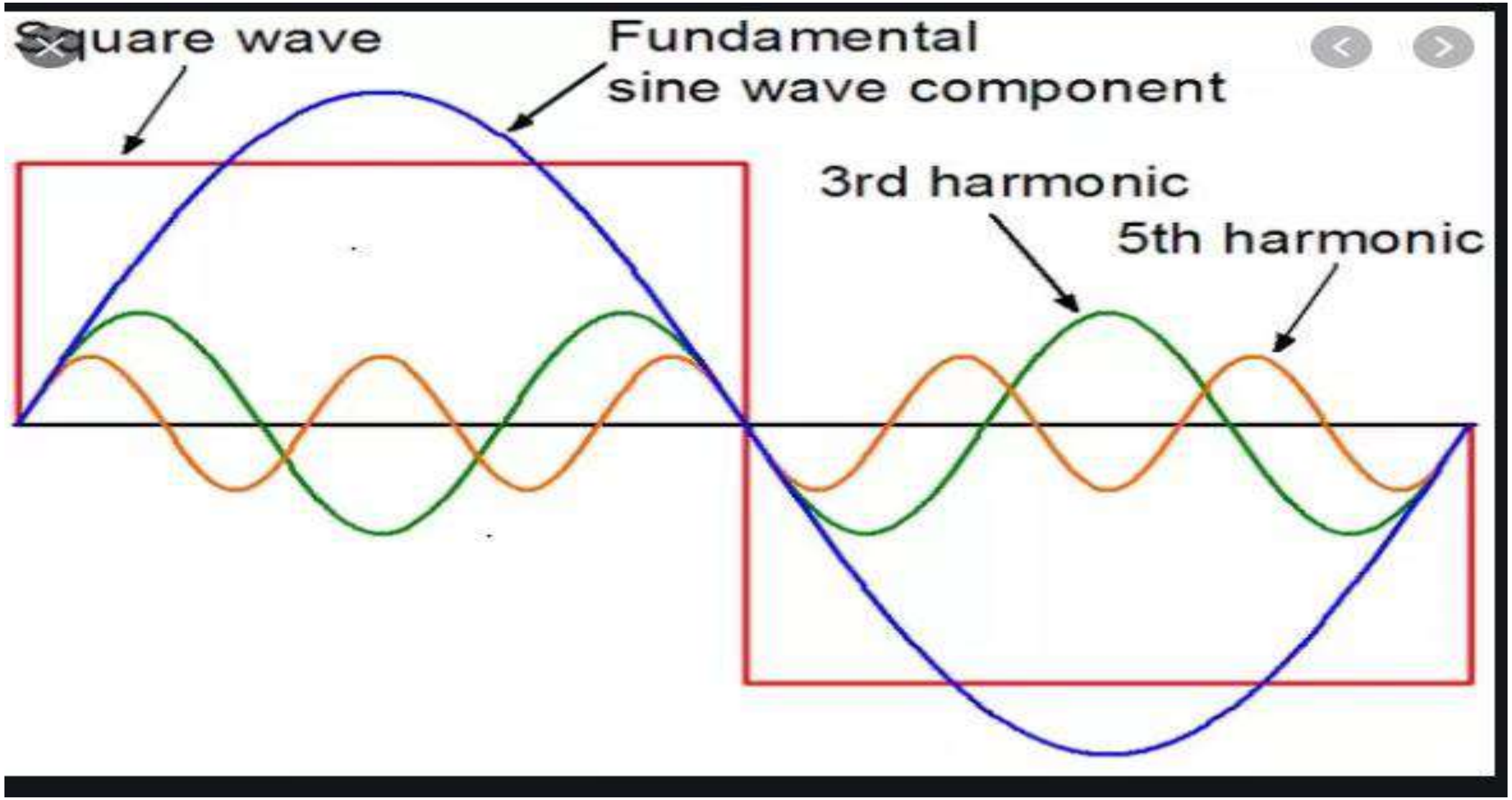
3. **Low**-frequency Transients: These have frequency components **less than 5 kHz,and a duration from 0.3 to 50 ms .**



[Fig.Lightning stroke current impulsive transient]



[Fig. Oscillatory Transient caused due to back-to-back capacitor switching]


Square wave
Fundamental
sine wave component
3rd harmonic
5th harmonic

Long-Duration Voltage Variations

When the **rms value of voltage deviates** for duration **more than 1 minute**, it is termed as long duration voltage variation.

Sources: Load variations, System switching operation It may be categorized into following types.

1. **Over Voltage:** An overvoltage is an increase in the **rms ac voltage greater than 110 percent** at the power frequency for duration longer than 1 min.

Sources:

(a) Overvoltage is usually the **result of load switching** (e.g., switchingoff a large load or energizing a capacitor bank).

(b) **Incorrect tap settings on transformers** can also result in system over voltages.

2. **Under Voltage:** An under voltage is a decrease in the **rms ac voltage to less than 90 percent** at the power frequency for a duration longer than 1 min.

Sources:

A load switching on or a capacitor bank switching off.

3. **Sustained Interruptions:** When the **supply voltage becomes zero** for a period of time in excess of 1 min, the long-duration voltage variation is considered a sustained interruption.

Short-Duration Voltage Variations

When the rms value of voltage deviates for duration less than 1 minute, it is termed as long duration voltage variation. Each type of variation can be designated as ***instantaneous,momentary,*** or ***temporary,*** depending on its duration.

It may be categorized into following types

1. **Interruption:**

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

Sources:

Interruptions can be the result of power system faults, equipment failures, and control malfunctions.

2. **Sags(dips):**

A *sag* is a decrease in rms voltage or current between **0.1 and 0.9** pu at the power frequency for durations from **0.5 cycle to 1 min**.

Sources:

Voltage sags are result of system faults and also can be caused by energization of heavy loads or starting of large motors.

3. **Swells:** A*swell* is defined as an increase to between **1.1 and 1.8 pu** in rms voltage or current at the power frequency for durations from **0.5 cycle to 1 min**.

Sources:

Voltage swells occur from temporary voltage rise on the unfaulted phasesduringan SLG fault. Swells can also be caused by switching off a large load or energizinglarge capacitor bank.

Voltage Imbalance

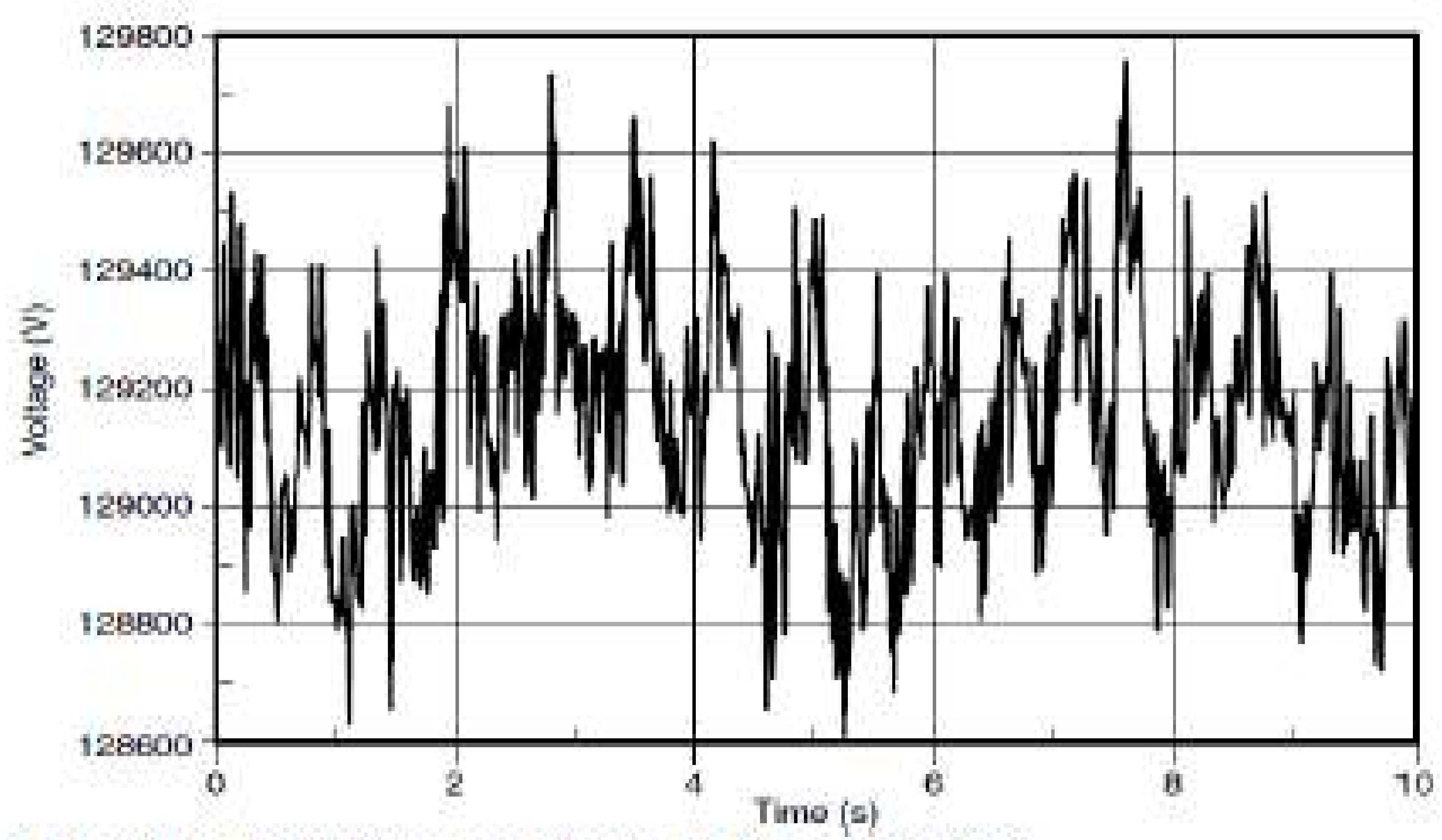
- Voltage imbalance (also called voltage unbalance) is defined as **the maximum deviation from the average of the three-phase voltages or currents, divided by the average of the three-phase voltages or currents, expressed in percent.**

- The ratio of either **the negative- or zero-sequence component to the positive-sequence** component can be used to specify the percent unbalance.

- The source of voltage unbalances is single-phase loads on a three-phase circuit.

- Voltage unbalance can also be the result of **blown fuses in one phase of a three-phase capacitor bank.**

- **Severe voltage unbalance** (greater than 5 percent) can result from single-phasing conditions.



[Fig. voltage fluctuations caused by an arc furnace operation]

- **Waveform Distortion**
- Waveform distortion is defined as a steady-state deviation from an ideal sine wave of power frequency.

There are five primary types of waveform distortion:

- 1. DC offset
- 2. Harmonics
- 3. Inter harmonics
- 4. Notching
- 5. Noise

1. DC offset:
The presence of a dc voltage or current in an ac power system is termed dc offset.

Sources : Asymmetric electronic converters and geo magnetic disturbance

Effects:
(a) It may **saturate the transformer core** causing additional heating and loss of transformer life.
(b) Direct current may also cause the **electrolytic erosion of grounding electrodes** and other connectors.

2.Harmonics
Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the supply frequency (fundamental frequency).

Sources: Non-linear loads and devices

Effects: Fundamental frequency deviation

2.Harmonics

Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the supply frequency (fundamental frequency).

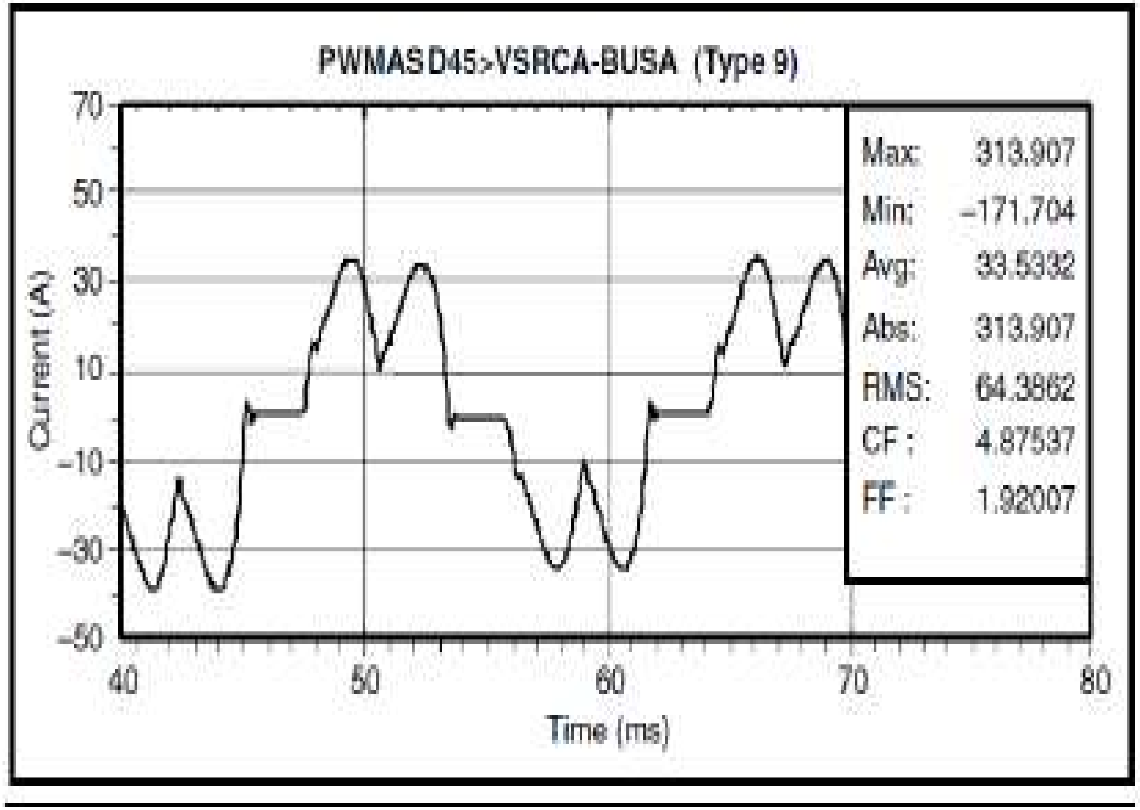
For measuring effective value of harmonic distortion THD (total harmonic distortion) and TDD (total demand distortion) is most commonly used .

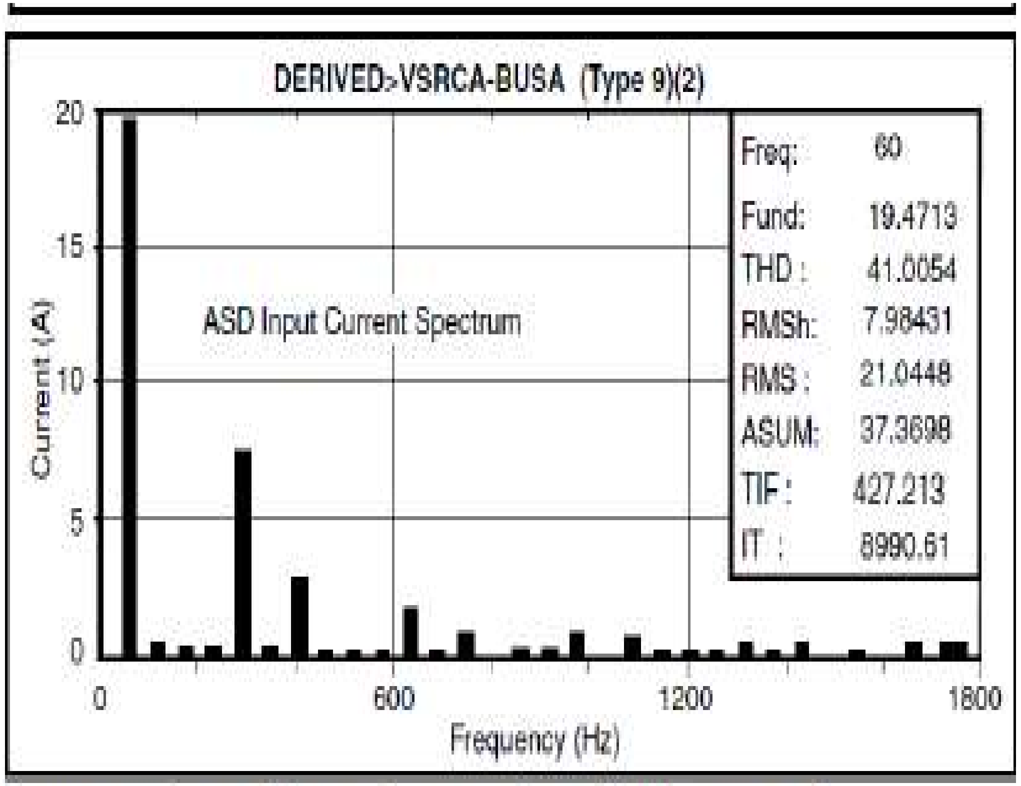
THD is expressed as fundamental magnitude of harmonic current.

TDD is expressed percentage of rated load current.

5.Noise

Any unwanted electrical signal whose broad band spectral content is lower than 200KHZ which is either imposed upon Voltage or current in phase conductors or on a natural conductor is called noise





Current waveform and harmonic spectrum for an ASD input current]

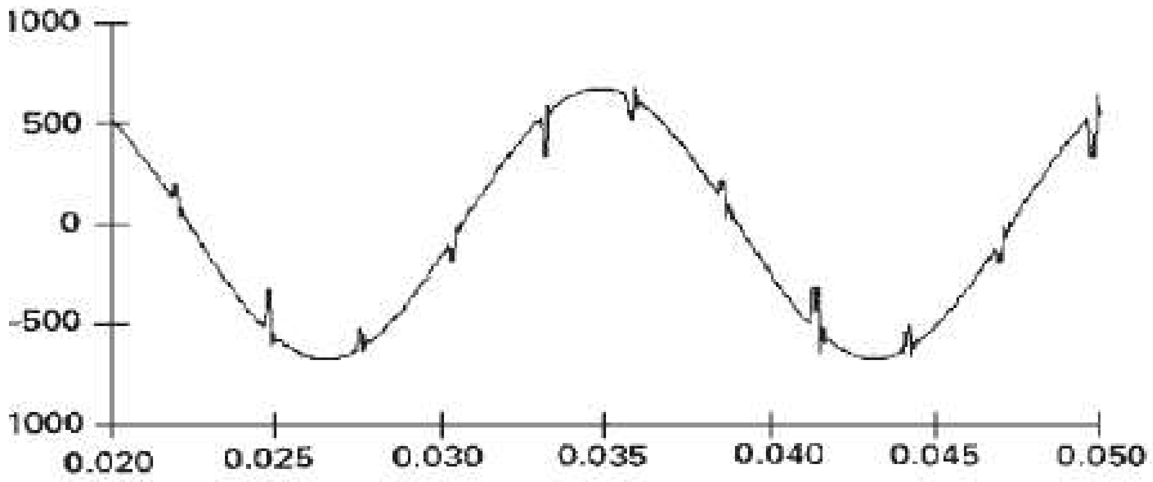
3. Inter harmonics

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 inter harmonics.

Sources: Static frequency converter, cyclo converters, induction furnaces, and arcing devices. Power line carrier signals can also be considered as inter harmonics.

4. Notching

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



[Fig.Voltage notching caused by a three-phase converter]

An example of voltage notching from

- A three-phase converter that produces continuous dc current.
- The notches occur when the current commutates from one phase to another.
- During this period, there is a momentary short circuit between two phases, pulling the voltage as close to zero as permitted by system impedances

Noise

Voltage Fluctuation

- Voltage fluctuations are systematic variations of the voltage envelope or a series of random voltage changes, the magnitude of which does not normally exceed the voltage range **0.9 to1.1 pu.**

- Voltage fluctuations are characterized as a series of random or continuous voltage fluctuations.

- Loads that can exhibit continuous, rapid variations in the load current magnitude can cause

- **voltage variations that are often referred to as flicker**.

The term flicker is derived from the impact of the voltage fluctuation on lamps such that they are perceived by the human eye to flicker.
To be technically correct, voltage fluctuation is an electromagnetic phenomenon while flicker is an undesirable result of the voltage fluctuation in some loads.

Power Frequency Variations

Power frequency variations are defined as the deviation of the power system fundamental frequency from it specified nominal value (50 or 60 Hz).

- **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.
- On modern interconnected power system, frequency variations are rare.

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- Assignment link
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- Once you completed those follow next class link

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THANK YOU
WE WILL CONTINUE IN NEXT CLASS

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Unit–II: Voltage imperfections in power systems

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- A quick review on what we discussed in last class
- Today's Discussion on
- **Unit–II: Voltage imperfections in power systems**
- Power quality terms
- Voltage sags
- Voltage swells and interruptions
- Sources of voltage
- sag, swell and interruptions
- Nonlinear loads
- IEEE and IEC standards.
- Source of transient over voltages
- Principles of over voltage protection
- Devices for over voltage protection
- Utility capacitor switching transients

- Active filter
- Common mode voltage
- Coupling
- Crest factor
- Critical load
- Current distortion
- Differential mode voltage
- Distributed generation (DG)
- Drop out
- Dropout voltage
- Electromagnetic Compatibility (EMC)
- Equipment grounding conductor
- Failure mode
- Fast tripping
- Fault
- Fault, transient
- Ferro resonance
- Flicker
- Frequency deviation
- Frequency response
- Fundamental (component)
- Ground
- Ground electrode
- Ground grid
- Ground loop
- Ground window
- Harmonic (component)
- Harmonic content
- Harmonic distortion
- Harmonic filter
- Harmonic number
- Harmonic resonance
- Impulse
- Impulsive transient
- Instantaneous
- Instantaneous reclosing
- Inter harmonic (component)

- Interruption, momentary (electrical power systems)
- Interruption, momentary (power quality monitoring)
- Interruption, sustained (electrical power systems)
- Interruption, sustained (power quality)
- Interruption, temporary
- Isolated ground
- Isolation
- ITI curve
- Linear load
- Long-duration variation
- Rectifier
- Resonance
- Sag
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- Shield
- Shielding
- Shielding (of utility lines)
- Short-duration variation
- Signal reference grid (or plane)
- Sustained
- Swell
- Sympathetic tripping
- Synchronous closing
- Temporary
- Total Demand Distortion (TDD)
- Total disturbance level
- Total Harmonic Distortion (THD)
- Transient
- Triplen harmonics

- Voltage dip
- Voltage distortion
- Voltage interruption
- Voltage regulation
- Voltage magnification
- Waveform distortion

· power quality terms are described below.

Active filter: Consists of a number of power electronic devices for eliminating harmonic distortion.

Common mode voltage: The noise voltage that appears equally from current carrying conductor to ground.

Coupling:

A circuit element, or elements, or a network that may be considered common to the input mesh and the output mesh and through which energy may be transferred from one to another.

Crest factor :A value reported by many power quality monitoring instruments representing the ratio of the crest value of the measured waveform to the root mean square of the fundamental

Critical load:

Devices and equipment whose failure to operate satisfactorily jeopardizes the health or safety of personnel, and/or results in loss of function, financial loss, or damage to property deemed critical by the user.

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Current distortion: Distortion in the ac line current.

Differential mode voltage:
The voltage between any two of a specified set of active conductors.

Distortion: Any deviation from the normal sine wave for an AC quantity

Distributed generation (DG):
Generation dispersed throughout the power system as opposed to large, central station power plants. DG typically refers to units less than 10 megawatts (MW) in size that are interconnected with the distribution system rather than the transmission system.

Drop out:
A loss of equipment operation (discrete data signals) due to noise, sag, or interruption

Dropout voltage:
The voltage at which a device will release to its de energized position (for this document, the voltage at which a device fails to operate).

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Electromagnetic Compatibility(EMC):

The ability of a device, equipment, or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

Equipment grounding conductor:

The conductor used to connect the non–current carrying parts of conduits, raceways, and equipment enclosures to the grounded conductor (neutral) and the grounding electrode at the service equipment (main panel) or secondary of a separately derived system (e.g., isolation transformer).

Failure mode: The effect by which failure is observed.

Fast tripping:

Refers to the common utility protective relaying practice in which the circuit breaker or line recloser operates faster than a fuse can blow.

Fault: Generally refers to a short circuit on the power system.

Fault, transient:

A short circuit on the power system usually induced by lightning, tree branches, or animals, which can be cleared by momentarily interrupting the current

Ferro resonance:

An irregular, often chaotic type of resonance that involves the nonlinear characteristic of iron-core (ferrous) inductors. It is nearly always undesirable when it occurs in the power delivery system, but it is exploited in technologies such as constant-voltage transformers to improve the power quality.

Flicker:

An impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time.

Frequency deviation:

An increase or decrease in the power frequency. The duration of a frequency deviation can be from several cycles to several hours.

Frequency response:

In power quality usage, generally refers to the variation of impedance of the system, or a metering transducer, as a function of frequency.

Fundamental (component): The component of order one (50 to 60 Hz) of the Fourier series of a periodic quantity.

Ground:

A conducting connection, whether intentional or accidental, by which an electric circuit or electrical equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth. It is used for establishing and maintaining the potential of the earth (or of the conducting body) or approximately that potential, on conductors connected to it, and for conducting ground currents to and from earth (or the conducting body).

Ground electrode:

A conductor or group of conductors in intimate contact with the earth for the purpose of providing a connection with the ground.

Ground grid:

A system of interconnected bare conductors arranged in a pattern over a specified area and on or buried below the surface of the earth. The primary purpose of the ground grid is to provide safety for workers by limiting potential differences within its perimeter to safe levels in case of high currents that could flow if the circuit being worked became energized for any reason or if an adjacent energized circuit faulted. Metallic surface mats and gratings are sometimes utilized for the same purpose. This is not necessarily the same as a signal reference grid.

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Ground loop:
A potentially detrimental loop formed when two or more points in an electrical system that are nominally at ground potential are connected by a conducting path such that either or both points are not at the same ground potential.

Ground window:
The area through which all grounding conductors, including metallic raceways, enter a specific area.

Harmonic (component): Integer multiple of fundamental frequency.

Harmonic content:
The quantity obtained by subtracting the fundamental component from an alternating quantity.

Harmonic distortion: Periodic distortion of the sine wave.

Harmonic filter:

On power systems, a device for filtering one or more harmonics from the power system. Most are passive combinations of inductance, capacitance, and resistance. Newer technologies include active filters that can also address reactive power needs.

Harmonic number:

The integral number given by the ratio of the frequency of a harmonic to the fundamental frequency.

Harmonic resonance:

A condition in which the power system is resonating near one of the major harmonics being produced by nonlinear elements in the system, thus exacerbating the harmonic distortion.

Impulse:

A pulse that, for a given application, approximates a unit pulse or a Diac function.When used in relation to monitoring power quality, it is preferable to use the term impulsive transient in place of impulse.

Impulsive transient:

A sudden, non power frequency change in the steady state condition of voltage or current that is unidirectional in polarity (primarily either positive or negative).

Instantaneous:

When used to quantify the duration of a short-duration variation as a modifier, this term refers to a time range from one-half cycle to 30 cycles of the power frequency.

Instantaneous reclosing:
A term commonly applied to reclosing of a utility breaker as quickly as possible after an interrupting fault current. Typical times are 18 to 30 cycles.

Inter harmonic (component):
A frequency component of a periodic quantity that is not an integer multiple of the frequency at which the supply system is designed to operate (e.g., 50 or 60 Hz).

Interruption, momentary (electrical power systems):
An interruption of a duration limited to the period required to restore service by automatic or supervisory controlled switching operations or by manual switching at locations where an operator is immediately available. Such switching operations must be completed in a specified time not to exceed 5 min.

Interruption, momentary (power quality monitoring):

A type of short-duration variation. The complete loss of volt (<0.1 pu) on one or more phase conductors for a time period between 30 cycles and 3 s.

Interruption, sustained (electrical power systems):

Any interruption not classified as a momentary interruption

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Interruption, sustained (power quality):

A type of long-duration variation. The complete loss of voltage (<0.1 pu) on one or more phase conductors for a time greater than 1 min.

Interruption, temporary:

A type of short-duration variation. The complete loss of voltage (<0.1pu) on one or more phase conductors for a time period between3 s and 1 min.

Isolated ground:

An insulated equipment grounding conductor run in the same conduit or raceway as the supply conductors. This conductor is insulatedfrom the metallic raceway and all ground points throughout its length. It originates at an isolated ground-type receptacle or equipment input terminal block and terminates at the point where neutral and ground are bonded at the power source.

Isolation:

Separation of one section of a system from undesired influences of other sections.

ITI curve:

A set of curves published by the Information Technology Industry Council (ITI) representing the withstand capabilities of computers connected to120-V power systems in terms of the magnitude and duration of the voltage disturbance. The ITI curve replaces the curves originally developed by the ITI's predecessor organization, the Computer Business Equipment Manufacturers Association (CBEMA).

Linear load:

An electrical load device that, in steady-state operation, presents an essentially constant load impedance to the power source throughout the cycle of applied voltage.

Long-duration variation:

A variation of the rms value of the voltage from nominal voltage for a time greater than 1 min. Usually further described using a modifier indicating the magnitude of a voltage variation (e.g., undervoltage, overvoltage, or voltage interruption).

Low-side surges:

A term coined by distribution transformer designers to describe the current surge that appears to be injected into the transformer secondary terminals during a lightning strike to grounded conductors in the vicinity.

Momentary:

When used to quantify the duration of a short-duration variation as a modifier, refers to a time range at the power frequency from 30 cycles to 3 s.

Noise:

Unwanted electrical signals that produce undesirable effects in the circuits of the control systems in which they occur.

Nominal voltage:

A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class.

Nonlinear load:

Electrical load that draws current discontinuously or whose impedance varies throughout the cycle of the input ac voltage waveform.

Normal mode voltage:

A voltage that appears between or among active circuit conductors.

Notch:

A switching (or other) disturbance of the normal power voltage waveform, lasting less than a half-cycle, which is initially of opposite polarity than the waveform and is thus subtracted from the normal waveform in terms of the peak value of the disturbance voltage. This includes complete loss of voltage for up to a half-cycle.

Oscillatory transient:

A sudden, non power frequency change in the steady state condition of voltage or current that includes both positive- or negative polarity value.

Overvoltage:

When used to describe a specific type of long-duration variation, refers to a voltage having a value of at least 10 percent above the nominal voltage for a period of time greater than 1min.

Passive filter:

A combination of inductors, capacitors, and resistors designed to eliminate one or more harmonics. The most common variety is simply an inductor in series with a shunt capacitor, which short-circuits the major distorting harmonic component from the system.

Phase shift:

The displacement in time of one voltage waveform relative to other voltage waveform(s).

Power factor, displacement:

The power factor of the fundamental frequency components of the voltage and current waveforms.

Power factor (true):

The ratio of active power (watts) to apparent power (volt-amperes).

Plt:

The long-term flicker severity level as defined by IEC 61000-4-15, based on an observation period of 2 h.

Pst:

The short-term flicker severity level as defined by IEC 61000-4-15, based on an observation period of 10 min. A Pst value greater than 1.0 corresponds to the level of irritability for 50 percent of the persons subjected to the measured flicker.

Pulse:

An abrupt variation of short duration of a physical quantity followed by a rapid return to the initial value.

Pulse Width Modulation (PWM):

A common technique used in inverters to create an ac wave form by controlling the electronic switch to produce varying width pulses. Minimizes power frequency harmonic distortion in some applications, but care must be taken to properly filter out the switching frequencies, which are commonly 3 to 6 kHz.

Reclosing:

The common utility practice used on overhead lines of closing the breaker within a short time after clearing a fault, taking advantage of the fact that most faults are transient, or temporary.

Recovery time:

The time interval needed for the output voltage or current to return to a value within the regulation specification after a step load or line change. Also may indicate the time interval required to bring a system back to its operating condition after an interruption or dropout.

Recovery voltage:

The voltage that occurs across the terminals of a pole of a circuit-interrupting device upon interruption of the current

Rectifier:

A power electronic device for converting alternating current to direct current.

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 non harmonic, is probably the most frequent excitation source. Also, various short-circuit and open-circuit faults can result in resonant conditions.

Sag :

A decrease to between 0.1 and 0.9 pu in rams voltage or current at the power frequency for durations of 0.5 cycle to 1 min.

Shield:

As normally applied to instrumentation cables, refers to a conductive sheath (usually metallic) applied, over the insulation of a conductor or conductors, for the purpose of providing means to reduce coupling between the conductors so shielded and other conductors that may be susceptible to, or which may be generating, unwanted electrostatic or electromagnetic fields (noise).

Shielding:

Shielding is the use of a conducting and/or ferromagnetic barrier between a potentially disturbing noise source and sensitive circuitry. Shields are used to protect cables (data and power) and electronic circuits. They maybe in the form of metal barriers, enclosures, or wrappings around source circuits and receiving circuits.

Shielding (of utility lines):

The construction of a grounded conductor or tower over the lines to intercept lightning strokes in an attempt to keep the lightning currents out of the power system.

Short-duration variation:

A variation of the rms value of the voltage from nominal voltage for a time greater than one-half cycle of the power frequency but less than or equal to 1 min. (e.g., sag, swell, or interruption) and possibly a modifier indicating the duration of the variation (e.g., instantaneous, momentary, or temporary).

Signal reference grid (or plane):

A system of conductive paths among interconnected equipment, which reduces noise-induced voltages to levels that minimize improper operation. Common configurations include grids and planes.

Sustained:

Refers to the time frame associated with a long-duration variation (i.e., greater than 1 min).

Swell:

A temporary increase in the rms value of the voltage of more than 10 percent of the nominal voltage, at the power frequency, for durations from 0.5cycle to 1 min.

Sympathetic tripping:

When a circuit breaker on an un faulted feeder section trips unnecessarily due to back feed into a fault elsewhere. Most commonly occurs when sensitive ground faultrelaying is employed.

Synchronous closing:

Generally used in reference to closing all three poles of a capacitor switch in synchronism with the power system to minimize transients.

Temporary:

When used to quantify the duration of a short-duration variation as a modifier, refers to a time range from 3 s to 1 min.

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.

Total disturbance level:

The level of a given electromagnetic disturbance caused by the superposition of the emission of all pieces of equipment in a given system.

Total Harmonic Distortion (THD):
The ratio of the root mean square of the harmonic content to the rms value of the fundamental quantity, expressed as a percent of the fundamental.

Transient:
Pertaining to or designating a phenomenon or a quantity that varies between two consecutive steady states during a time interval that is short compared to the time scale of interest. A transient can be a unidirectional impulse of either polarity or a damped oscillatory wave with the first peak occurring in either polarity.

Triplen harmonics:
A term frequently used to refer to the odd multiples of the third harmonic, which deserve special attention because of their natural tendency to be zero sequence

Voltage dip: sag.

Voltage distortion: Distortion of the ac line voltage.

Under voltage:

When used to describe a specific type of long-duration variation, refers to a measured voltage having a value at least 10 percent below the nominal voltage for a period of time greater than 1 min. In other contexts, such as distributed generation protection, the time frame of interest would be measured in cycles or seconds.

Voltage change:

A variation of the root mean square or peak value of a voltage between two consecutive levels sustained for definite but unspecified durations.

Voltage fluctuation: A series of voltage changes or a cyclical variation of the voltage envelope.

Voltage imbalance (unbalance):

A condition in which the three-phase voltages differ in amplitude or are displaced from their normal 120 degree phase relationship or both. Frequently expressed as the ratio of the negative sequence or zero-sequence voltage to the positive-sequence voltage, in percent.

Voltage interruption:

Disappearance of the supply voltage on one or more phases. Usually qualified by an additional term indicating the duration of the interruption (e.g., momentary, temporary, or sustained).

Voltage regulation:

The degree of control or stability of the rms voltage at the load. Often specified in relation to other parameters, such as input-voltage changes, load changes, or temperature changes.

Voltage magnification:

The magnification of capacitor switching oscillatory transient voltage on the primary side by capacitors on the secondary side of a transformer

Waveform distortion:

A steady-state deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation

Sources of over voltage

- Capacitor switching
- Magnification of capacitor-switching
- transients
- Lightning
- Ferro resonance
- switching transients

Capacitor switching

- Capacitor switching is one of the most common switching events on utility systems.
- Capacitors are used to provide reactive power (in units of vars) to correct the power factor, which reduces losses and supports the voltage on the system.
- Alternative methods such as the use of rotating machines and electronic var compensators are much more costly or have high maintenance costs. Thus, the use of capacitors on power systems is quite common and will continue to be
- One drawback to the use of capacitors is that they yield oscillatory transients when switched. Some capacitors are energized all the time (a fixed bank), while others are switched according to load levels

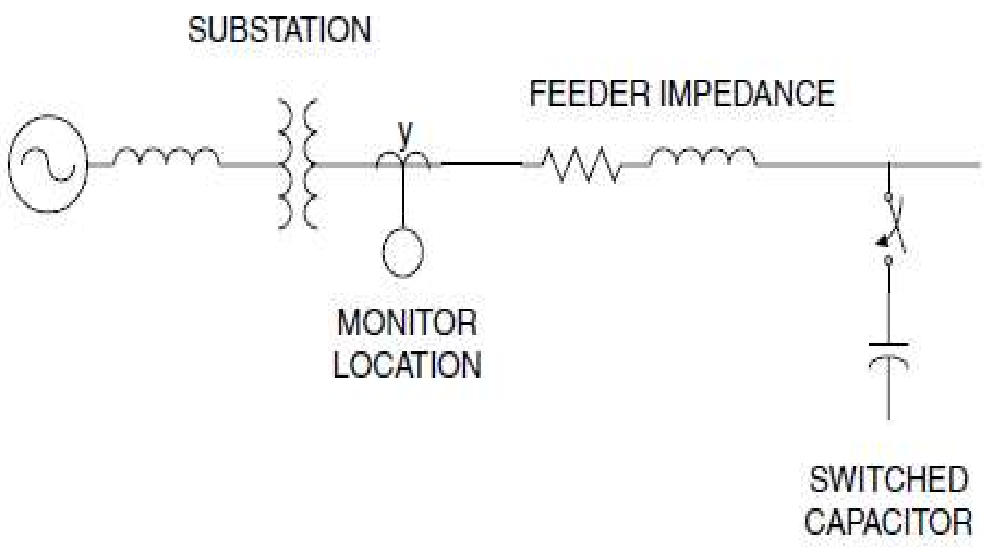


Figure 4.1 One-line diagram of a capacitor-switching operation corresponding to the waveform in Fig. 4.2.

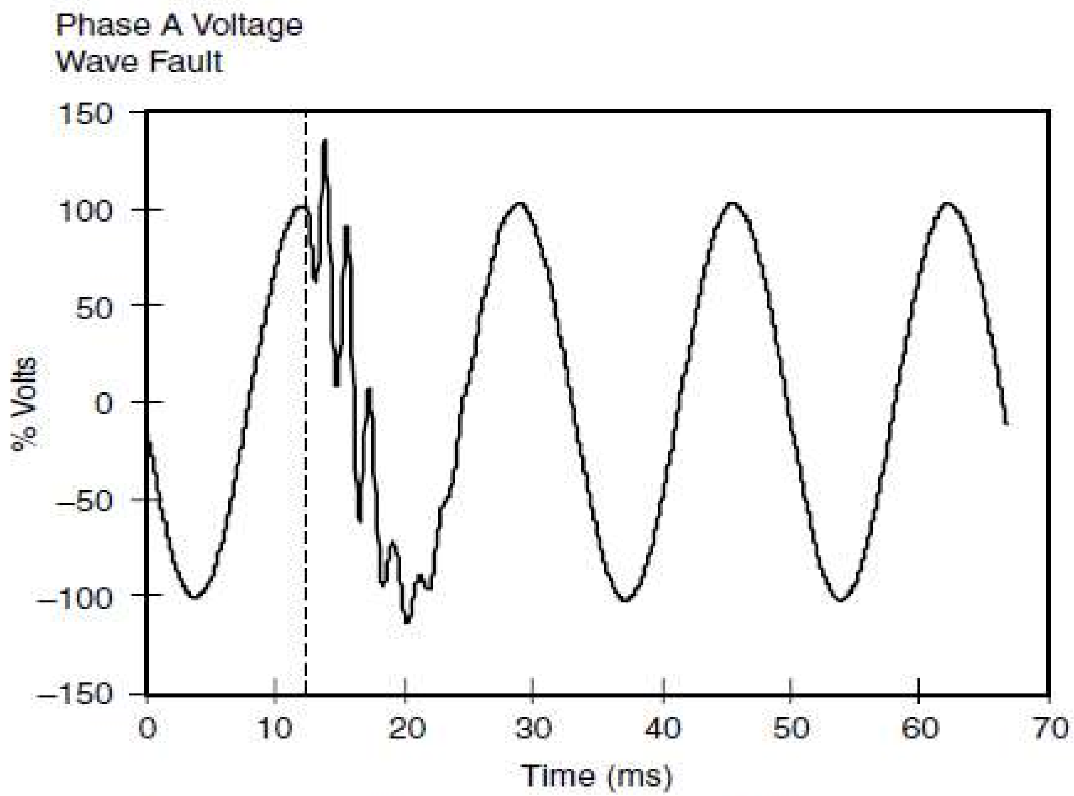
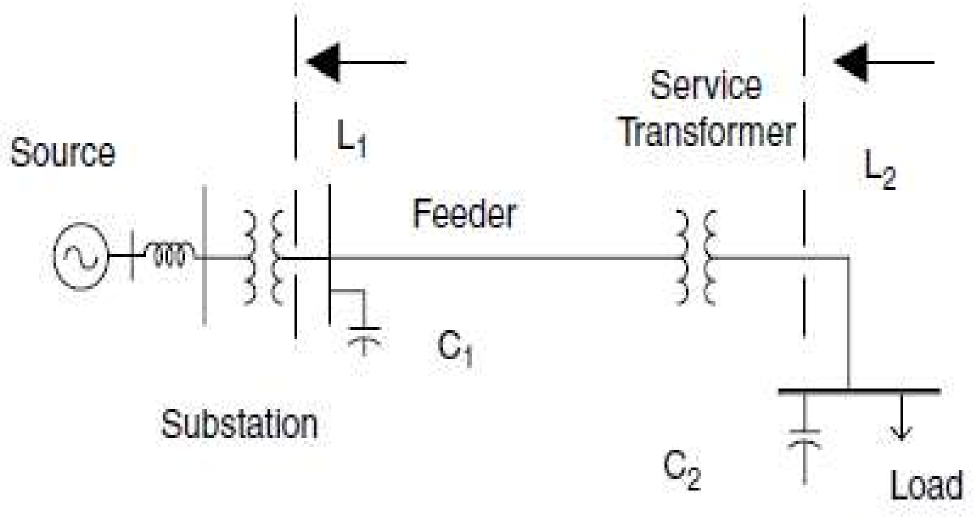


Figure 4.2 Typical utility capacitor-switching transient reaching 134 percent voltage, observed upline from the capacitor.

- the capacitor switch contacts close at a point near the system voltage peak.
- This is a common occurrence for many types of switches because the insulation across the switch contacts tends to break down when the voltage across the switch is at a maximum value.
- The voltage across the capacitor at this instant is zero. Since the capacitor voltage cannot change instantaneously, the system voltage at the capacitor location is briefly pulled down to zero and rises as the capacitor begins to charge toward the system voltage.
- Because the power system source is inductive, the capacitor voltage overshoots and rings at the natural frequency of the system.
- At the monitoring location shown, the initial change in voltage will not go completely to zero because of the impedance between the observation point and the switched capacitor.
- The overshoot will generate a transient between 1.0 and 2.0 pu depending on system damping
-

Magnification of capacitor-switching

- Magnification of utility capacitor-switching transients at the end user location occurs over a wide range of transformer and capacitor sizes.
- Resizing the customer’s power factor correction capacitors or step-down transformer is therefore usually not a practical solution
- Load side capacitors can magnify this transient overvoltage at the end-user bus for certain low-voltage capacitor and step-down transformer sizes.
- high-energy surge arresters can be applied to limit the transient voltage magnitude at the customer bus. Energy levels associated with the magnified transient will typically be about 1 kJ.
- the expected arrester energy for a range of low voltage capacitor sizes as shown in graph.
- the arresters can only limit the transient to the arrester protective level 1.8 times the normal peak voltage (1.8 pu). This may not be sufficient to protect sensitive electronic equipment that might only have a withstand capability of 1.75 pu.
- The voltage magnification transient can also be limited by converting the end user power factor corrections banks to harmonic filters



(a) Voltage magnification at customer capacitor due to energizing capacitor on utility system

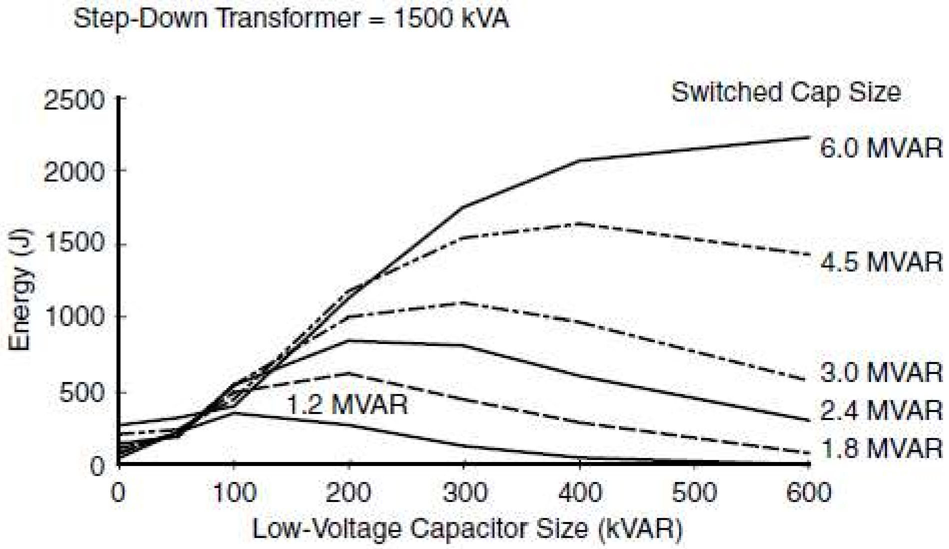


Figure 4.5 Arrester energy duty caused by magnified transient.

- **Lightning** is a potent source of impulsive transients.
- Figure illustrates some of the places where lightning can strike that results in lightning currents being conducted from the power system into loads.
- obvious conduction path occurs during a direct strike to a phase wire, either on the primary or the secondary side of the transformer
- This can generate very high over voltages, whether this is the most common way that lightning surges enter load facilities and cause damage. Very similar transient over voltages can be generated by lightning currents flowing along ground conductor paths.

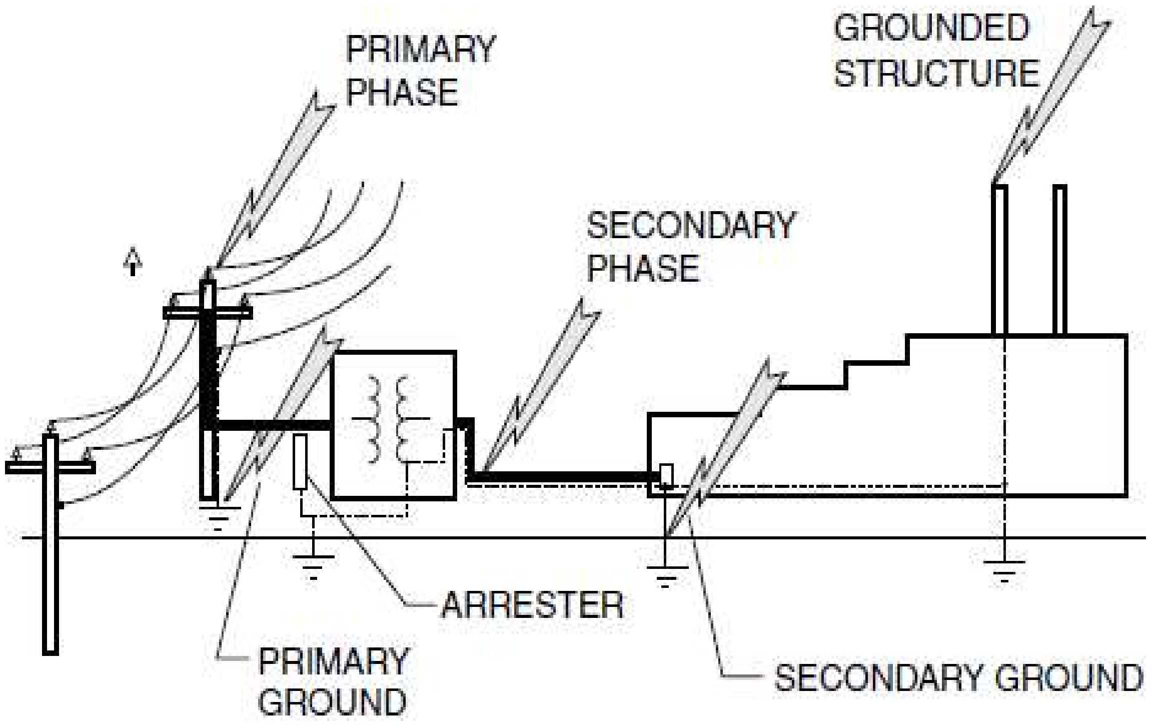


Figure 4.6 Lightning strike locations where lightning impulses will be conducted into load facilities.

- there can be numerous paths for lightning currents to enter the grounding system. Common ones, indicated by the dotted lines in Fig. include the primary ground, the secondary ground, and the structure of the load facilities. strikes to the primary phase are conducted to the ground circuits through the arresters on the service transformer.

- grounds are never perfect conductors, especially for impulses. While most of the surge current may eventually be dissipated into the ground connection closest to the strike, there will be substantial surge currents flowing in other connected ground conductors in the first few microseconds of the strike

- A direct strike to a phase conductor generally causes line flashover near the strike point it causes a fault with the accompanying voltage sags and interruptions. The lightning surge can be conducted a considerable distance along utility lines and cause multiple flashovers at pole and tower structures as it passes. The interception of the impulse from the phase wire is fairly straightforward if properly installed surge arresters are used

- Lightning does not have to actually strike a conductor to inject impulses into the power system. Lightning may simply strike near the line and induce an impulse by the collapse of the electric field.

- Lightning may also simply strike the ground near a facility causing the local ground reference to rise considerably This may force currents along grounded conductors into a remote ground, possibly passing near sensitive load apparatus.

- ***Ferro resonance***

- The term *Ferro resonance* refers to a special kind of resonance that involves capacitance and iron-core inductance.
- The most common condition in which it causes disturbances is when the magnetizing impedance of a transformer is placed in series with a system capacitor This happens when there is an open-phase conductor.
- Under controlled conditions, Ferro resonance can be exploited for useful purpose such as in a constant-voltage transformer Ferro resonance is different than resonance in linear system elements. In linear systems, resonance results in high sinusoidal voltages and currents of the resonant frequency. Linear-system resonance is the
- phenomenon behind the magnification of harmonics in power systems .
- Ferro resonance can also result in high voltages and currents, but the resulting waveforms are usually irregular and chaotic in shape.

- **Other switching transients**
- Line energization transients occur, as the term implies, when a switch is closed connecting a line to the power system.
- They generally involve higher-frequency content than capacitor energizing transients.
- The transients are a result of a combination of traveling-wave effects and the interaction of the line capacitance and the system equivalent source inductance.
- Traveling waves are caused by the distributed nature of the capacitance and inductance of the transmission or distribution line.

Line energizing transients typically result in rather benign overvoltages at distribution voltage levels

- To implement any kind of switching control for line energizing except for transmission lines operating at 345 kV and above.
- Line energizing transients usually die out in about 0.5 cycle.

- Devices for over voltage protection
- **surge suppressors**
- **isolation transformer**
- **Low-pass filters**
- **Low-impedance power conditioners**
- **Utility surge arresters**

surge suppressors

- Arresters and TVSS (transient voltage surge suppressor) devices protect equipment from transient over voltages by limiting the maximum voltage
- TVSSs are generally associated with devices used at the load equipment.
- A TVSS will sometimes have more surge-limiting elements than an arrester,
- The elements that make up these devices can be classified by two different modes of operation, *crowbar* and *clamping.*
- ***Crowbar*** *devices* are normally open devices that conduct **current during overvoltage transients**.
- **Once the device conducts, the line voltage will drop to nearly zero due to the short circuit imposed across the line.**
- These devices are usually manufactured **with a gap filled with air or a special gas**. The **gap arcs over when a sufficiently high overvoltage transient appears.**
- **Once the gap arcs over, usually power frequency current, or "follow current," will continue to flow in the gap until the next current zero**.
- Thus, **these devices have the disadvantage that the power frequency voltage drops to zero or to a very low value for at least one-half cycle. This will cause some loads to drop offline**

- ***Clamping devices*** for ac circuits are commonly nonlinear resistors (varistors) that conduct very low amounts of current until an overvoltage occurs.
- **Then they start to conduct heavily, and their impedance drops rapidly with increasing voltage.**
- These devices effectively conduct increasing amounts of current (and energy) to limit the voltage rise of a surge.
- **They have an advantage over gap-type devices in that the voltage is not reduced below the conduction level when they begin to conduct the surge current.**

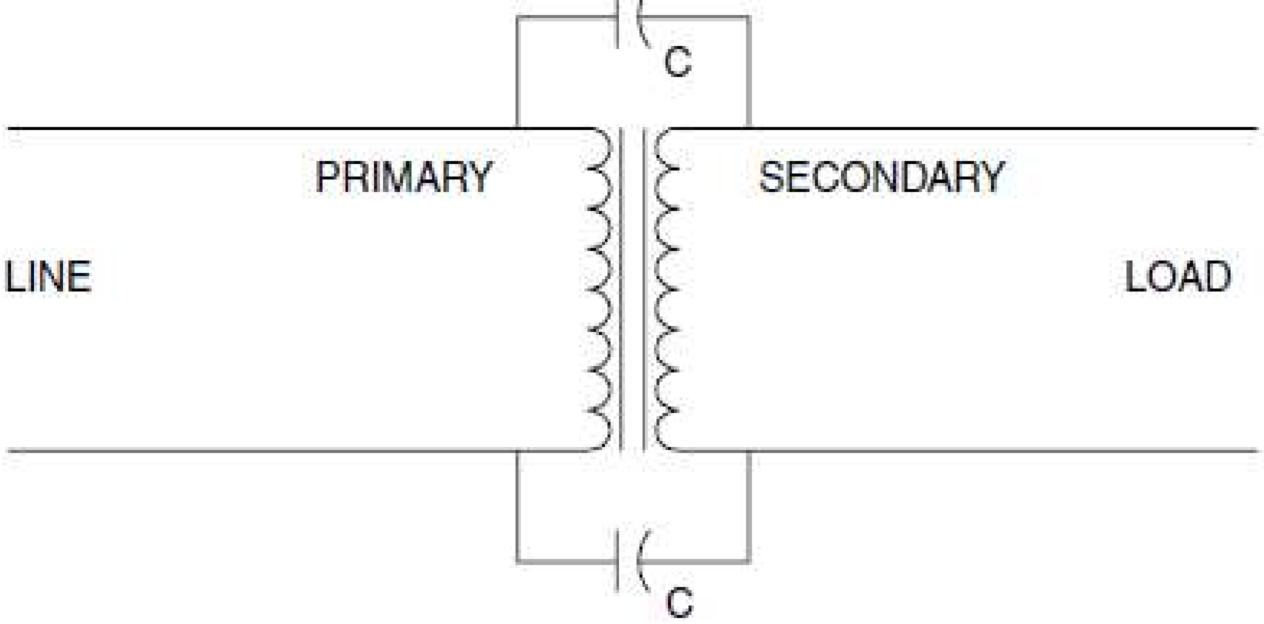


Figure 4.19 Isolation transformer.

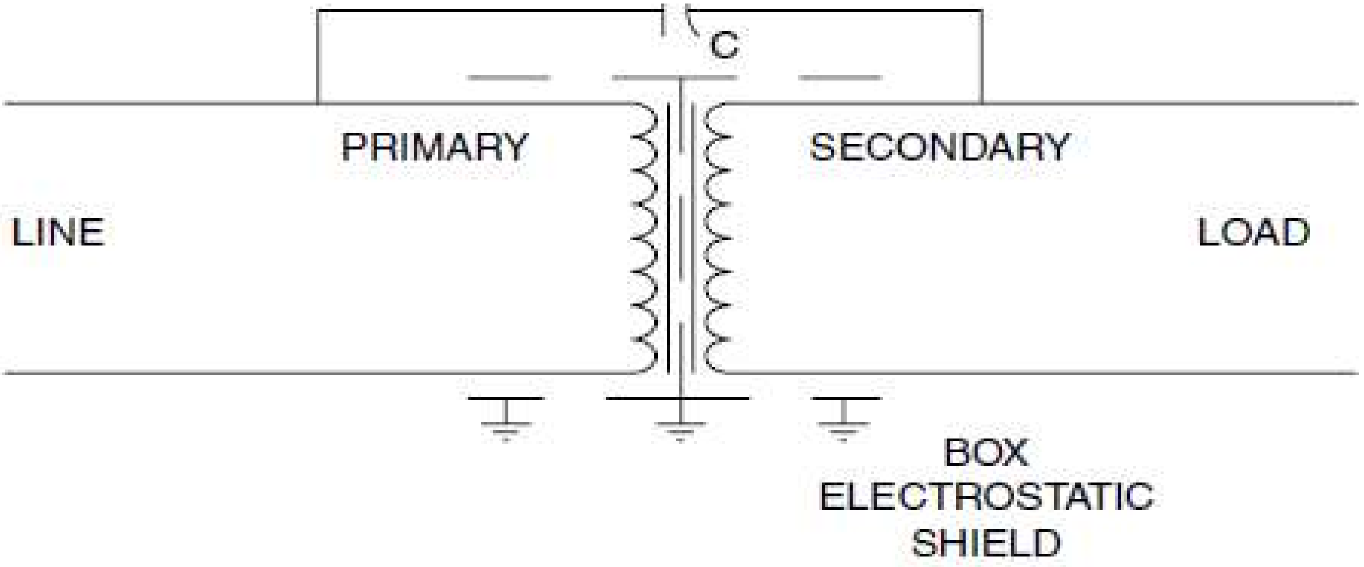


Figure 4.20 Isolation transformer with electrostatic shield.

- An **isolation transformer** used to **attenuate high-frequency noise and transients** as they attempt to pass from one side to the other. However, some common-mode and normal-mode noise can still reach the load.
- An electrostatic shield, is effective in **eliminating common-mode noise.** However, some **normal-mode noise** can still reach the load due to magnetic andcapacitive coupling.
- The chief characteristic of isolation transformers for **electrically isolating** the load from the system for transients is **their leakage inductance.**
- Therefore, **high-frequency noise and transients are kept from reaching the load, and any load-generated noise and transients are kept from reaching the rest of the power system.**
- Voltage notching due to power electronic switching is one example of a problem that can be limited to the load side by an isolation transformer.
- **Capacitor-switching** and **lightning transients** coming from the utility system can be attenuated, thereby preventing nuisance tripping of adjustable-speed drives and other equipment.
- isolation transformers is that they allow the user to define a **new ground reference, or *separately derived system***.
- This **new neutral-to-ground bond limits neutral-to-ground voltages at sensitive equipment**.

Low-pass filters

- **Low-pass filters** use the pi-circuit principle achieve even better protection for high-frequency transients. For general usage in electric circuits, low-pass filters are composed of series inductors and parallel capacitors.
- This ***LC* combination provides a low impedance path to ground for selected resonant frequencies**.
- **In surge protection usage, voltage clamping devices are added in parallel to the capacitors**

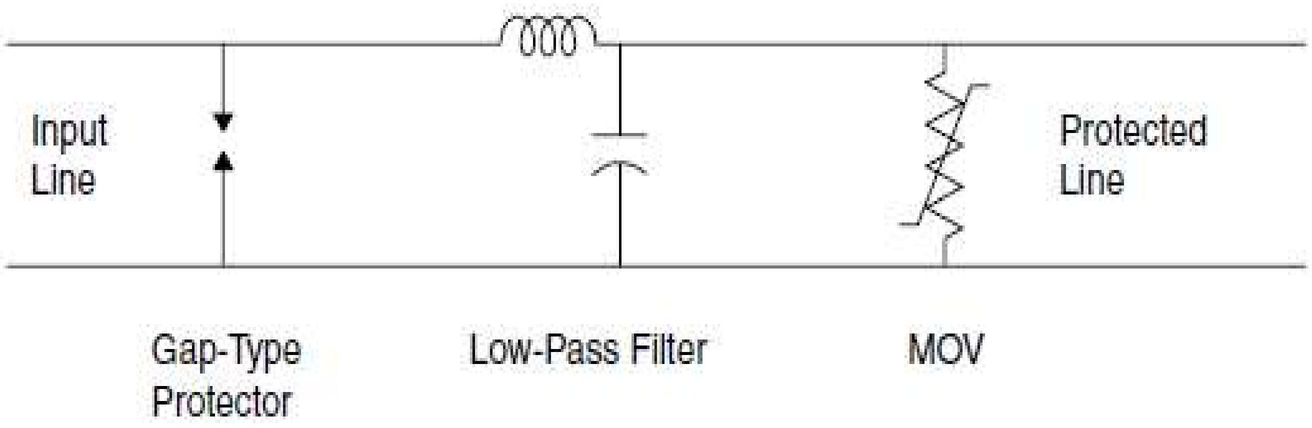


Figure 4.21 Hybrid transient protector.

- common hybrid protector that combines two **surge suppressors and a low-pass filter to provide maximum protection.**
- It uses a **gap-type** protector on the front end to handle **high-energy transients**.
- The low-pass filter limits transfer of **high-frequency transients.**
- The inductor helps block high-frequency transients and forces them into the first suppressor.
- The **capacitor limits the rate of rise**, while the **nonlinear resistor (MOV) clamps** the voltage magnitude at the protected equipment.

Low-impedance power conditioners

- Low-impedance power conditioners (LIPCs) are used primarily to interface with the switch-mode power supplies found in electronic equipment.
- **LIPCs differ from isolation transformers** in that these conditioners have **a much lower impedance** and **have a filter as part of their design** .
- The filter is on the output side and protects against high-frequency, source-side, common-mode, and normal-mode disturbances (i.e., noise and impulses).
- Note the new neutral-to-ground connection that can be made on the load side because of the existence
- of an isolation transformer.
- However, low- to medium-frequency transients (capacitor switching) can cause problems for LIPCs: The transient can be magnified by the output filter capacitor.

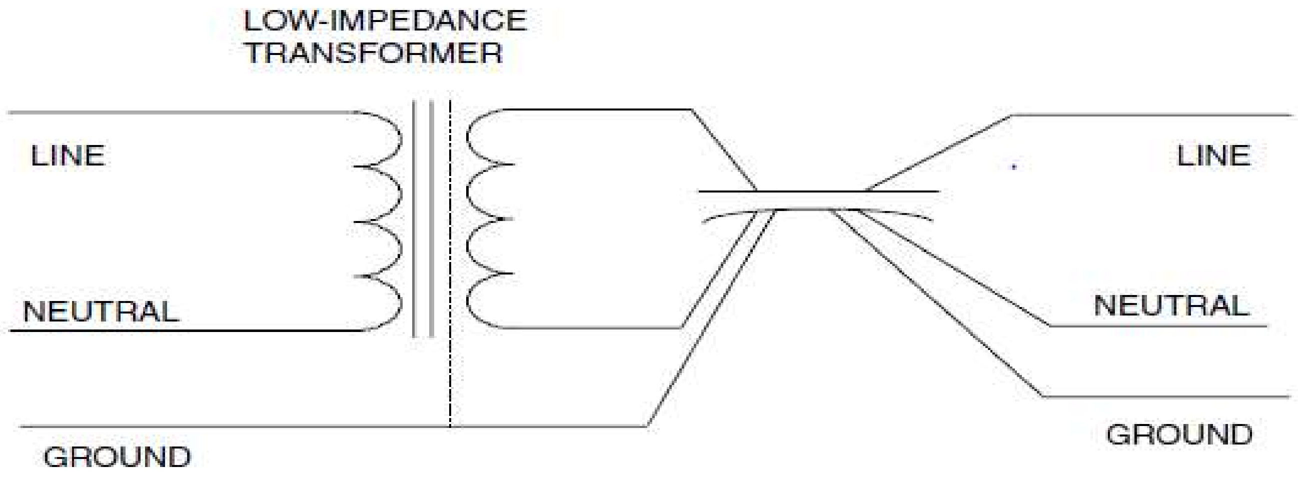


Figure 4.22 Low-impedance power conditioner.

- **Utility surge arresters**
- .

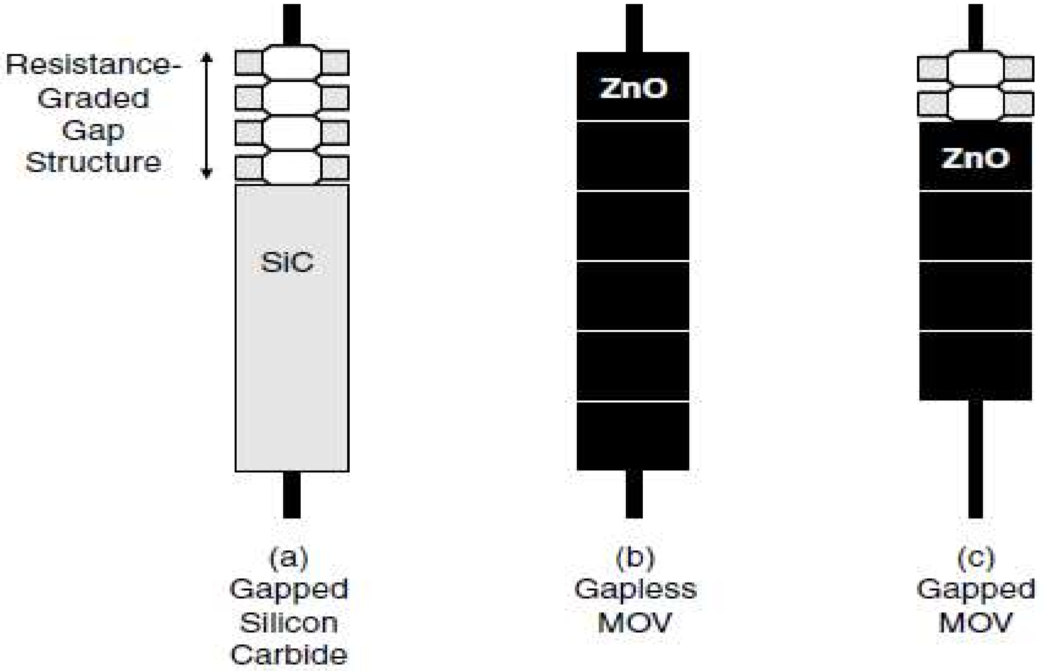


Figure 4.23 Three common utility surge arrester technologies.

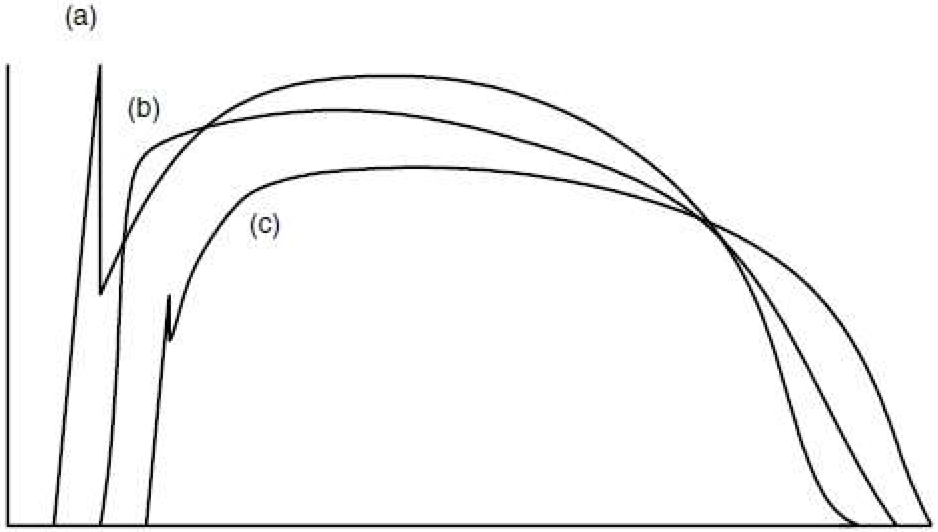


Figure 4.24 Comparative lightning wave discharge voltage characteristics for an 8×20 μs wave corresponding to the utility surge arrester technologies in Fig. 4.23.

- **Utility surge arresters**

- Originally, arresters were little more than spark gaps, which would result in a fault each time the gap sparked over.
- Also, the spark over transient injected a very steep fronted voltage wave into the apparatus being protected, which was blamed for many insulation failures.
- The addition of an SiC (silicon carbide) nonlinear resistance in series with a spark gap corrected some of these difficulties.
- **It allowed the spark gap to clear and reseal** without causing a fault and reduced the spark over transient to perhaps 50 percent of the total spark over voltage (Fig. 4.24*a*). However insulation failures were still blamed on this front-of-wave transient.
- **Also, there is substantial power-follow current after spark over, which heats the SiC material and erodes the gap structures, eventually leading to arrester failures or loss of protection**
- Gaps are necessary with the SiC because an economical SiC element giving the required discharge voltage is unable to withstand continuous system operating voltage.
- The development of MOV **(metal oxide varistor**) technology enabled the elimination of the gaps.
- This technology could withstand continuous system voltage without gaps and still provide a discharge voltage comparable to the SiC arresters
- The gapless MOV provided a somewhat better discharge characteristic without the objectionable spark over transient.
- The majority of utility distribution arresters manufactured today are of this design.
- The smaller number of MOV blocks yields a lightning-discharge voltage typically 20 to 30 percent less than a gapless MOV arrester.

• Principles of over voltage protection

The fundamental principles of overvoltage protection of load equipment's are as follows

1. Limit the voltage across sensitive insulation.

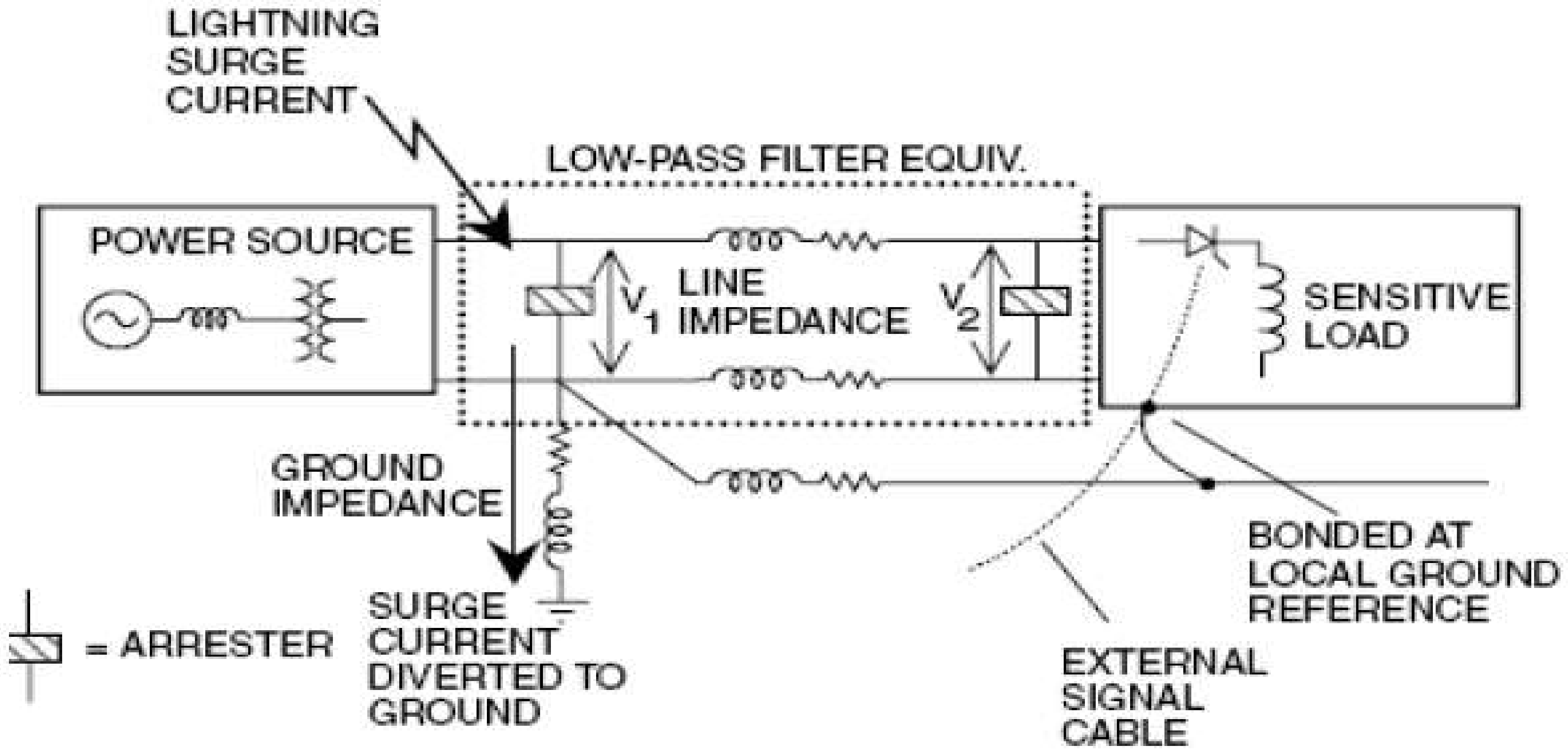
2. Divert the surge current away from the load.

3. Block the surge current from entering the load.

4. Bond grounds together at the equipment.

5. Reduce, or prevent, surge current from flowing between grounds.

6. Create a low-pass filter using limiting and blocking principles.



g. 3.7 Demonstrating the principles of overvoltage protection.

Utility capacitor bank switching transients

Switching timing

- Capacitor switching transients may be avoided if switching timing is observed and manipulated
- Peak time in industries starts with the beginning of the day and so utilities start switching coincides .
- As the timing of increase in load and capacitor switching coincides , it mostly causes shutdown of adjustable speed drives as observed by experts.
- This problem can be reduced in some cases by monitoring the switching time and Switching the Capacitors Few minutes before the start of load time.

Synchronous closing

This is new technology which controls capacitor switching transients by timing the closing of contacts to make system voltage almost equal to capacitor voltage when the contacts close .

As a result of this , the step change in voltage which occurs during capacitor switching is avoided.

Utility capacitor bank switching transients

Capacitor location

Capacitor bank located close to a sensitive protected equipment or close to higher transient over voltage location may be moved to another location in the circuit can eliminate some transient problems.

How ever change in capacitor bank location is not be an option always .

If a capacitor bank is located near a large load which needs reactive power .then moving the capacitor bank will eliminate its purpose of installation .

Reinsertion Resistors

- We can use resistor in the circuit .it will damp the first peak of capacitor transient .
- A typical arrangement involving pre insertion resistor include movable contacts which slides past the resistor contacts first then meets with the main contacts
- Further improvement pre insertion reactors . Which limit high frequency transient to a greater extent.

IEC 61000 Series:
Power Quality (PQ):

"The ability of a device, equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment "

IEEE 1159:2009,
IEEE 1100:2005

power quality (PQ):

The concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the supply system and other connected equipment.

several engineering organizations and standard bearers in several parts of the world are spending a large amount of resources to generate power quality standards.
Following is a list of power quality and related standards from two such organizations;
some of the standards listed are in existence at this time, while others are still
in process

Institute of Electrical and Electronic Engineers (IEEE)

International Electro technical Commission (IEC)

Institute of Electrical and Electronic Engineers (IEEE)

IEEE 644	Standard Procedure for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines
IEEE C63.12	Recommended Practice for Electromagnetic Compatibility Limits
IEEE 518	Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources
IEEE 519	Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
IEEE 1100	Recommended Practice for Powering and Grounding Sensitive Electronic Equipment
IEEE 1159	Recommended Practice for Monitoring Electric Power Quality
IEEE 141	Recommended Practice for Electric Power Distribution for Industrial Plants

IEEE 142 Recommended Practice for Grounding of Industrial and Commercial Power Systems

IEEE 241 Recommended Practice for Electric Power Systems in Commercial Buildings

IEEE 602 Recommended Practice for Electric Systems in Health Care Facilities

IEEE 902 Guide for Maintenance, Operation and Safety of Industrial and Commercial Power Systems

IEEE C57.110 Recommended Practice for Establishing Transformer Capability when Supplying Non sinusoidal Load

IEEE P1433 Power Quality Definitions

IEEE P1453 Voltage Flicker

IEEE P1564 Voltage Sag Indices

International Electro technical Commission (IEC)

IEC/TR3 61000- 2-1 Electromagnetic Compatibility — Environment

IEC/TR3 61000- 3-6 Electromagnetic Compatibility — Limits

IEC 61000- 4-7 Electromagnetic Compatibility — Testing and Measurement Techniques — General Guides on Harmonics and Interharmonics Measurements and Instrumentation

IEC 61642 Industrial a.c. Networks Affected by Harmonics — Application of Filters and Shunt Capacitors

IEC SC77A Low Frequency EMC Phenomena

IEC TC77/WG1 Terminology

IEC SC77A/WG1 Harmonics and Other Low Frequency Disturbances

Do follow the

- Feed back link
- Assignment link
- Leave the Class properly
- Once you completed those follow next class link

- Despite the situation don't stop yourself from learning
- Practice social distance stay home safe learn stay healthy .
- #Adityans #Stay Home #Stay Safe #Keep Learning
  #Qurantine Days #Online #Classes

THANK YOU
WE WILL CONTINUE IN NEXT CLASS

ADITYA COLLEGE OF ENGINEERING & TECHNOLOGY

Unit 3 Voltage Regulation & power factor improvement

By

PRABHA RANI.K

Dept of ELECTRICAL AND ELECTRONICS and Engineering

Aditya College of Engineering & Technology

Surampalem.

- A quick review on what we discussed in last class
- Today's Discussion on

Unit–III: Voltage Regulation and power factor improvement:

- Principles of regulating the voltage
- Device for voltage regulation
- Utility voltage regulator application
- Capacitor for voltage regulation
- End–user capacitor application
- Regulating utility voltage with distributed resources
- Flicker
- Power factor penalty
- Static VAR compensations for power factor improvement.

Principles of Regulating the Voltage

- The voltage drops too low under heavy load. Conversely, when the source voltage is boosted to overcome the impedance, there can be an overvoltage condition when the load drops too low.

- The corrective measures usually involve either compensating for the impedance *Z* or

- compensating for the voltage drop $IR + j\,I\,X$ caused by the impedance.

Too much of independence in power system

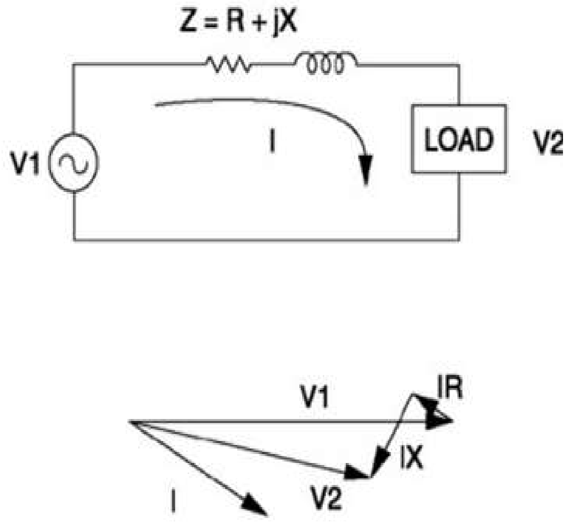
Power system is too weak for the load

Voltage drops too low

Overvoltage condition when load drops to low

Some common options for improving power system

voltage regulation,are



Principles of Regulating the Voltage

1. Add shunt capacitors to reduce the current *I* and shift it to be more in phase with the voltage.

2. Add voltage regulators, which boost the apparent *V*1.

3. Reconductor lines to a larger size to reduce the impedance *Z.*

4. Change substation or service transformers to larger sizes to reduce impedance *Z.*

5. Add some kind of dynamic reactive power (var) compensation, which serves the same purpose as capacitors for rapidly changing loads.

6. Add series capacitors to cancel the inductive impedance drop *IX*

Devices for Voltage Regulation

There are a variety of voltage regulation devices in use on utility and industrial power systems. We have divided these into three major classes:

1. Tap-changing transformer

- There are both mechanical and electronic tap-changing transformers.
- Tap-changing transformers are often autotransformer designs, although two- and three-winding transformers may also be equipped with tap changers.
- The mechanical devices are for the slower-changing loads, while the electronic ones can respond very quickly to voltage changes.

2. Isolation devices with separate voltage regulators

- Isolation devices include UPS systems, Ferro resonant (constant-voltage) transformers, and motor-generator sets. These are devices that essentially isolate the load from the power source by performing some sort of energy conversion.
- Therefore, the load side of the device can be separately regulated and can maintain constant voltage regardless of what is occurring at the power supply.
- The downside of using such devices is that they are costly, introduce more losses, and can cause harmonic distortion problems on the power supply system.

3. Impedance compensation devices, such as capacitors

- In power system compensating devices allows to maintain the voltage at constant level, which includes shunt & series Capacitors.
- The former helps in improving the voltage by compensating the inductive circuits. And later helps in reducing the voltage fluctuations or flickers .
- How ever these can be achieved by employing static Var compensator.

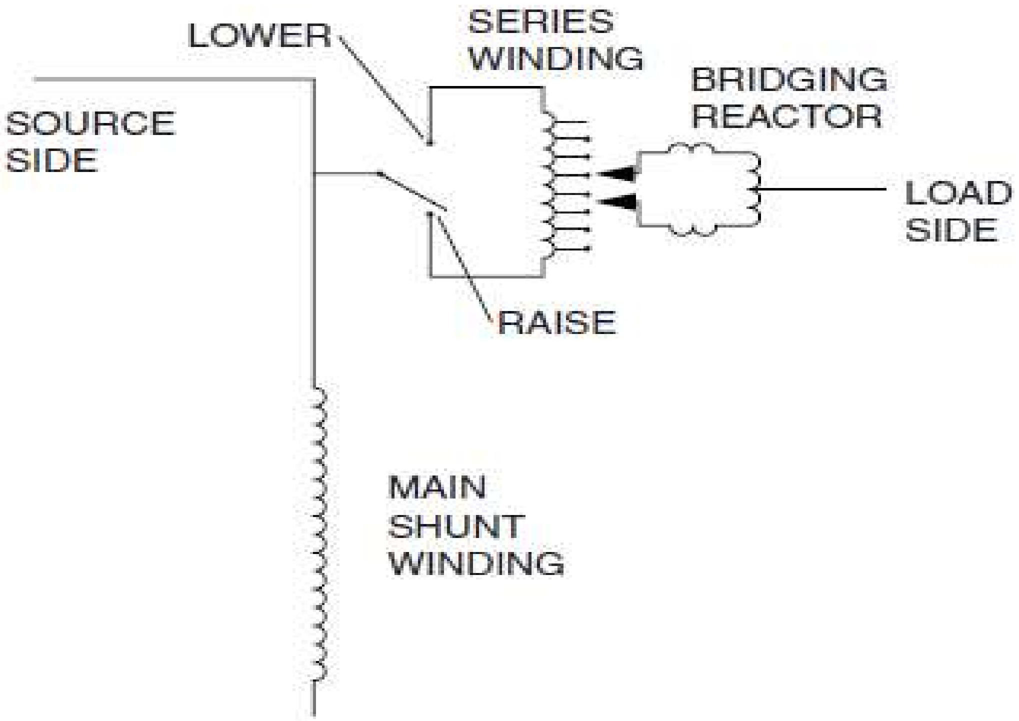


Figure 7.2 Schematic diagram of one type of utility voltage regulator commonly applied on distribution lines.

Utility step-voltage regulators.

- The voltage regulator are mainly employed to **boost the voltage on long feeders in order to avoid the slow change at end user .**
- The typical utility tap-changing regulator can regulate from -10 to +10 percent of the incoming line voltage in 32 steps of 5/8 percent.
- Distribution substation transformers commonly have three-phase load tap changers (LTCs) while line regulators installed out on the feeders are typically single-phase.
- When installed on a three-phase feeder, line regulators are generally installed in.
- there are also many installations of open delta regulator banks on lightly loaded three-phase feeders branches.

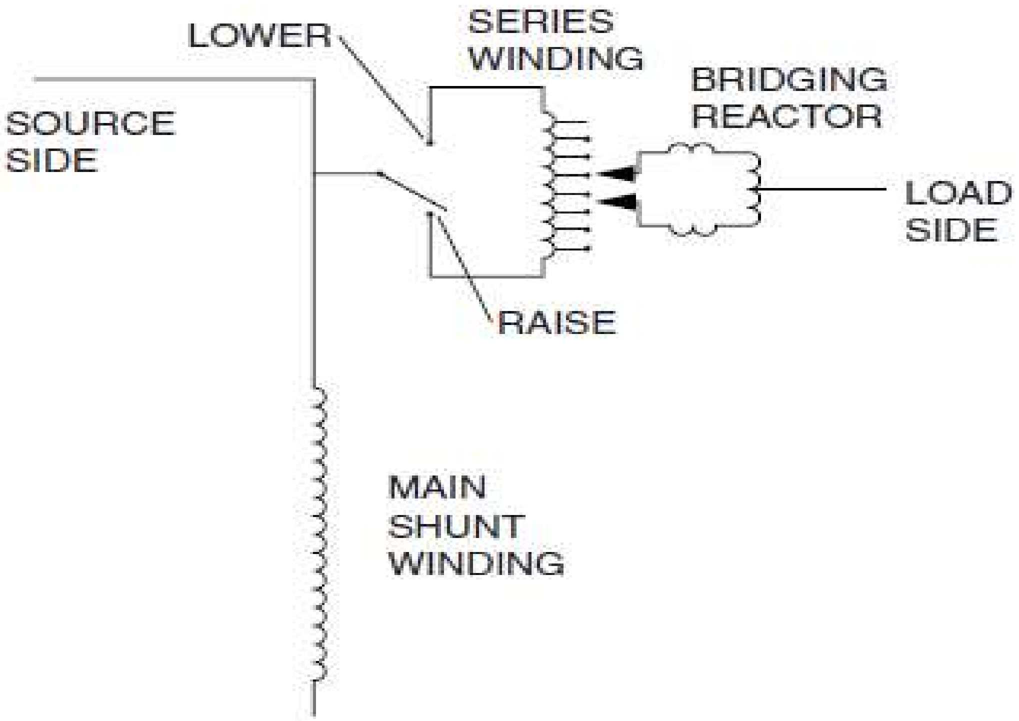


Figure 7.2 Schematic diagram of one type of utility voltage regulator commonly applied on distribution lines.

Utility step-voltage regulators.

- **A utility voltage regulator is a fairly complicated apparatus in order to achieve a durable and highly reliable tap-changing mechanism.**
- Utility line voltage regulators and substation (LTCs) load tap changers are relatively slow. The time delay when the voltage goes out of band is at least 15 s and is commonly 30 or 45 s.
- Their main application is boosting voltage on long feeders where the load is changing slowly over several minutes or hours. The voltage band typically ranges from 1.5 to 3.0 V on a 120-V base

Devices for voltage regulation

- **Ferro resonant transformers**
- **Electronic tap-switching regulators**
- **Magnetic synthesizers**
- **On-line UPS systems**
- **Motor-generator sets**
- **Static var compensators**

- **Ferro resonant transformers**

On the end-user side, Ferro resonant transformers are not only useful in protecting equipment from voltage sags but they can also be used to attain very good voltage regulation (±1 percent output).

- the steady-state input/output characteristics of a 120-VA Ferro resonant transformer with a 15-VA load as shown below
- As the input voltage is reduced down to 30 V, the output voltage stays constant.

- If the input voltage is reduced further, the output voltage begins to collapse.

- as the input voltage is reduced, the current drawn by the Ferro resonant transformer increases substantially from 0.4 to 2 A. Thus, Ferro resonant transformers tend to be loss and inefficient.

- **Ferro resonant transformers**

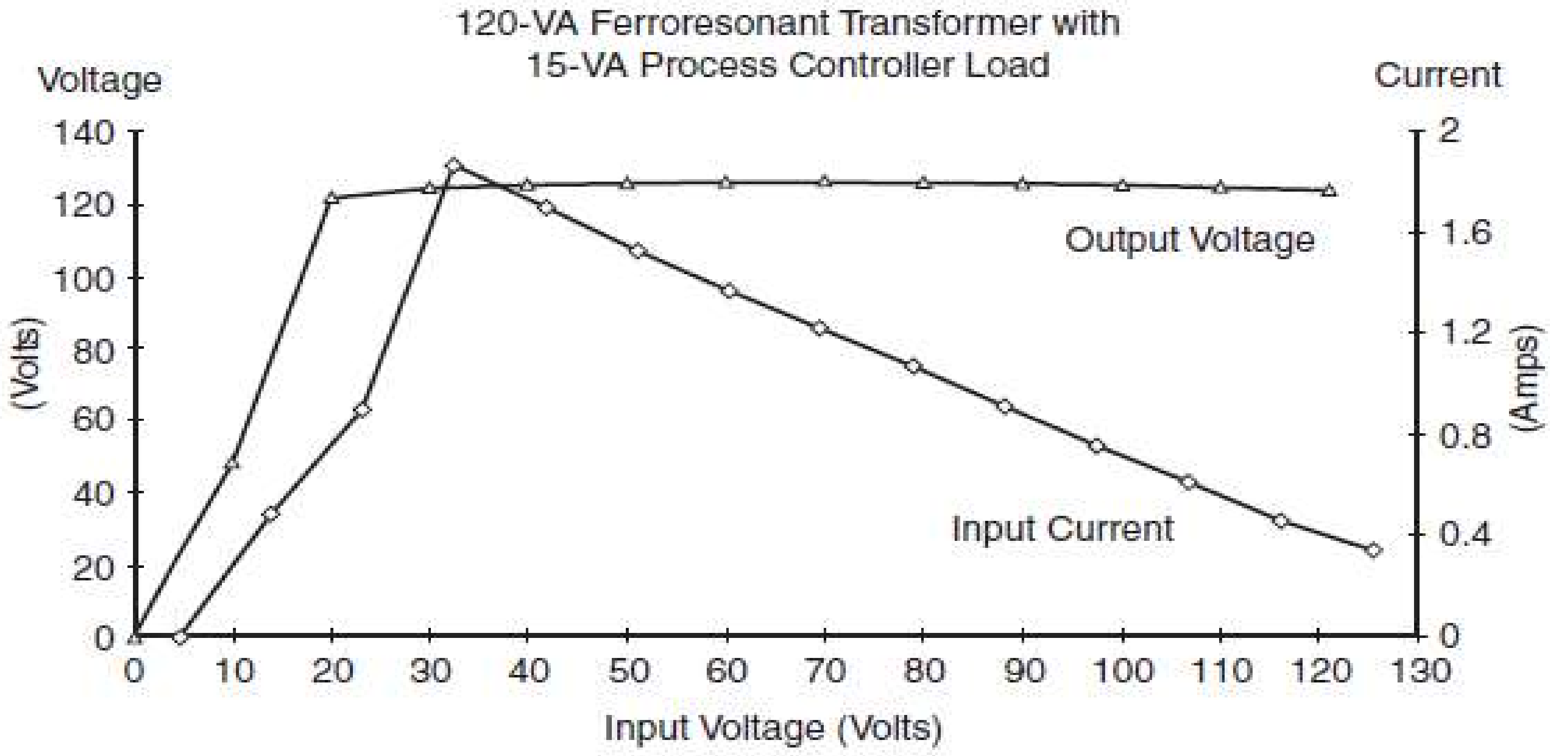


Figure 7.3 Ferroresonant transformer steady-state characteristics.

- **Electronic tap-switching regulators**

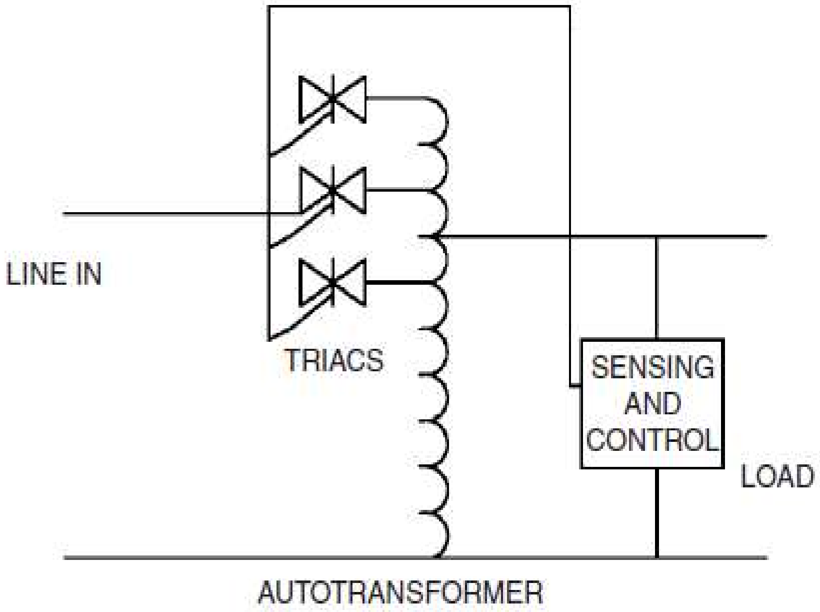


Figure 7.4 Electronic tap-switching regulator.

Electronic tap-switching regulators can also be used to regulate voltage.

They are more efficient than Ferro resonant transformers and use SCRs or triacs to quickly change taps, and hence voltage.

Tap switching regulators have a very fast response time of a half cycle and are popular for medium-power applications.

- **Magnetic synthesizers**

- **(**a usually computerized electronic apparatus for the production and control of sound (as for producing music)

Magnetic synthesizers, although intended for short-duration voltage sags can also be used for steady-state voltage regulation.
One manufacturer, for example, states that for input voltages of ±40 percent, the output voltage will remain within ±5 percent at full load.

Motor-generator sets

- Motor-generator sets are also used for voltage regulation.

- They completely decouple the load from the electric power system, shielding the load from electrical transients.

- Voltage regulation is provided by the generator control.

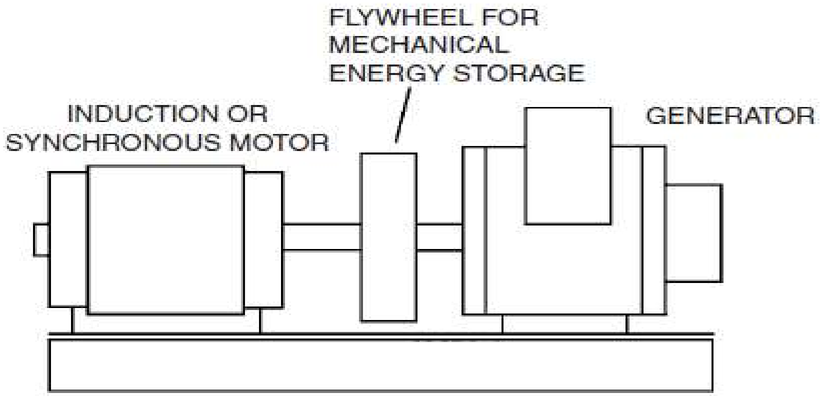


Figure 7.5 Motor-generator set.

- **Motor-generator sets**

- The major drawback of motor-generator sets is their response time to large load changes.
- Motor-generator sets can take several seconds to bring the voltage back up to the required level, making this device too slow for voltage regulation of certain loads, especially rapidly varying loads.
- Motor-generator sets can also be used to provide “ride through” from input voltage variations, especially voltage sags, by storing energy in a flywheel.

- **Static var compensators**
  - Static var compensators can be applied to either utility systems or industrial systems.
  - They help regulate the voltage by responding very quickly to supply or consume reactive power.
  - This acts with the system impedance to either raise or lower the voltage on a cycle-by-cycle basis.

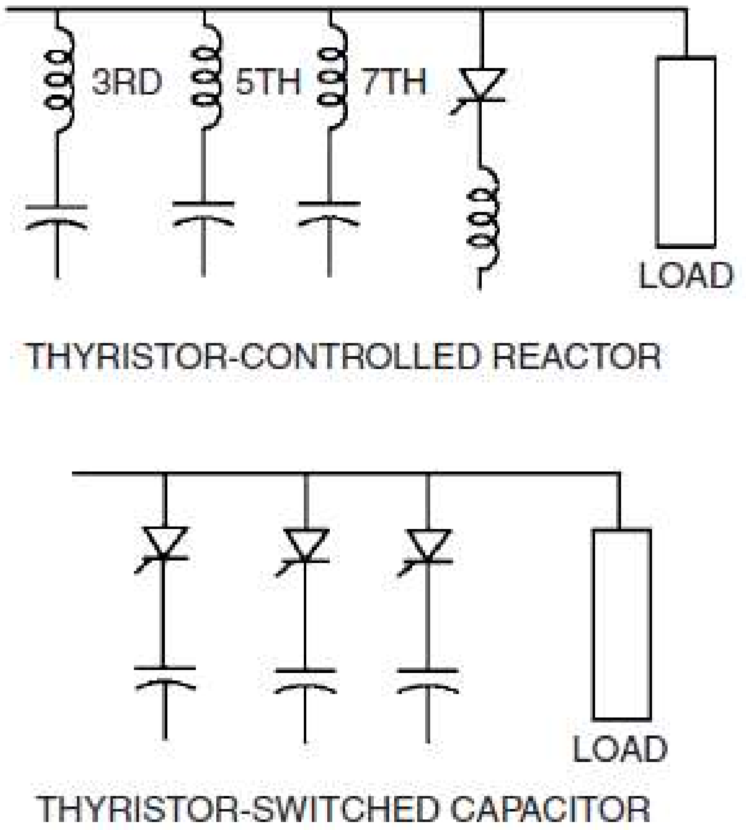


Figure 7.6 Common static var compensator configurations.

- **Static var compensators**

- There are two main types of static var compensators in common usage,

- The thyristor-controlled reactor (TCR) scheme is probably the most common. It employs a fixed capacitor bank to provide leading reactive power and a thyristor-controlled inductance that is gated on in various amounts to cancel all or part of the capacitance.

- The capacitors are frequently configured as filters to clean up the harmonic distortion caused by the thyristors. The thyristor-switched capacitor operates by switching multiple steps of capacitors quickly to match the load requirements as closely as possible.

- The capacitors are generally gated fully on so there are no harmonics

in the currents. The switching point is controlled so that there are no switching transients.

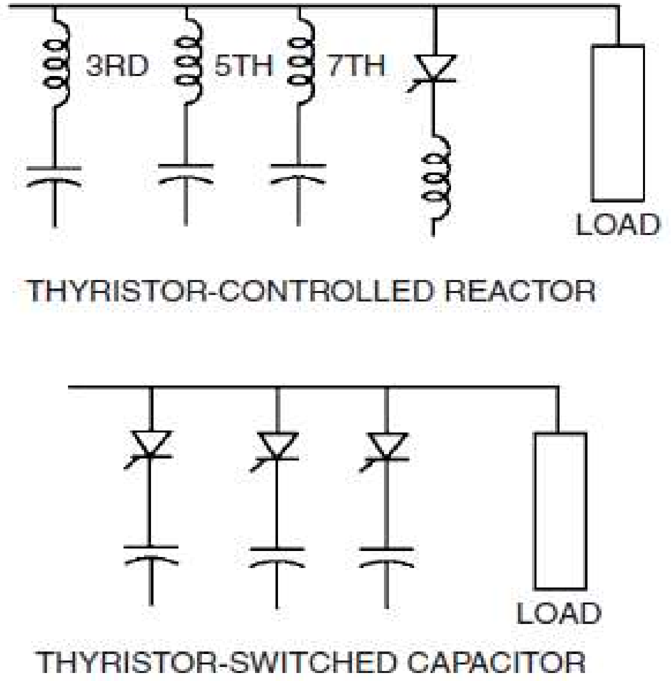


Figure 7.6 Common static var compensator configurations.

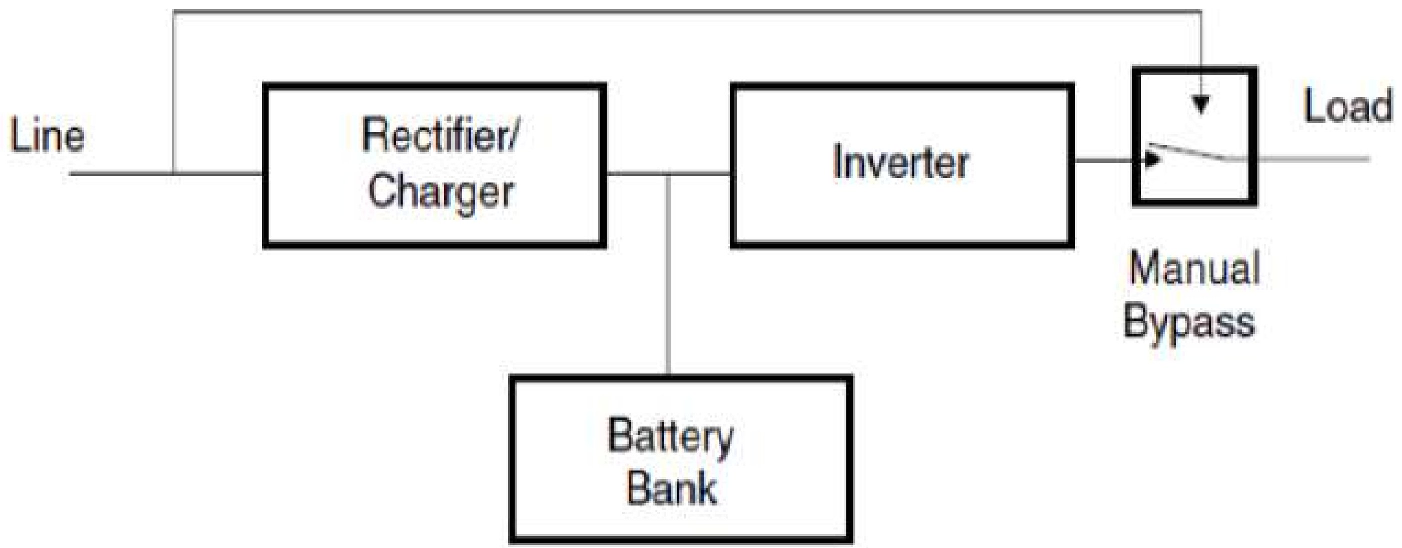
On-line UPS systems

- On-line UPS systems intended for protection against sags and brief interruptions can also be used for voltage regulation provided the source voltage stays sufficiently high to keep the batteries charged.

- This is a common solution for small, critical computer or electronic control loads in an industrial environment that has large, fluctuating loads causing the voltage to vary.

On-line UPS

The following figure shows a typical configuration of an on-line UPS.



[Fig.2.9 on-line UPS]

- In this design, the load is always fed through the UPS.

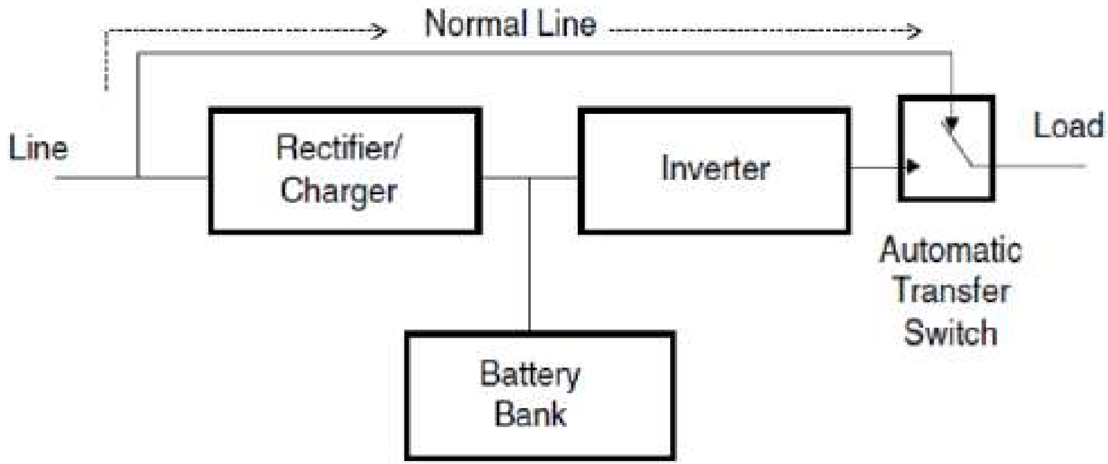
- The incoming ac power is rectified into dc power, which charges a bank of batteries. This dc power is then inverted back into ac power, to feed the load. If the in coming ac power fails, the inverter is fed from the batteries and continues to supply the load.

- In addition to providing ride-through for power outages, an on-line UPS provides very high isolation of the critical load from all power line disturbances. However, the on-line operation increases the losses and may be unnecessary for protection of many loads.

Standby UPS

- It is referred as offline, since the normal line power is used to power the equipment until a disturbance is detected and a switch transfers the load to the battery backed inverter.
- The transfer time from the normal source to the battery-backed inverter is important.
- A standby power supply does not typically provide any transient protection or voltage regulation as does an on-line UPS.

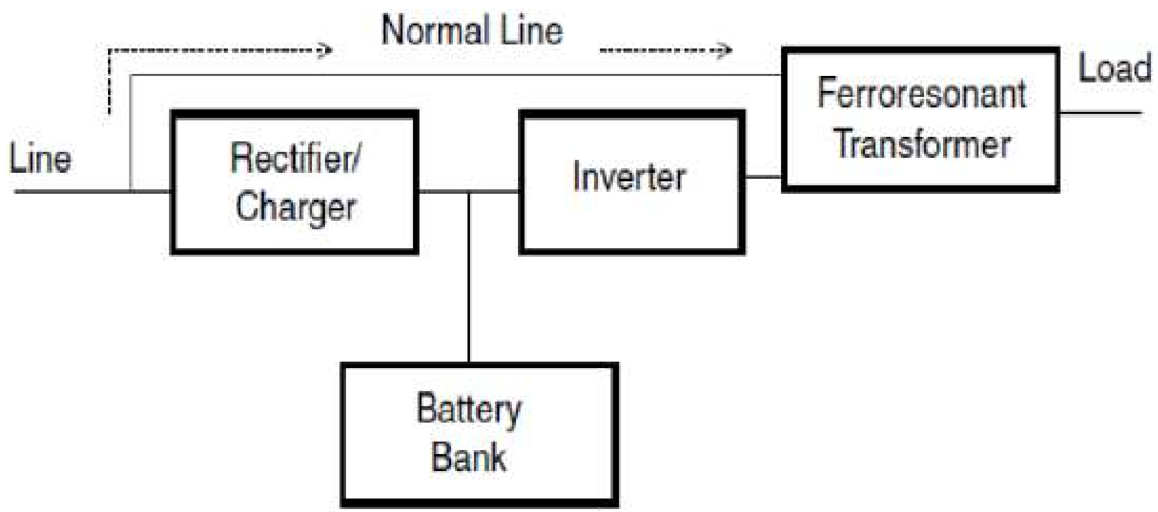
The following figure shows the configuration of a standby UPS.



[Fig.2.10 standby UPS]

The hybrid utilizes a voltage regulator on the UPS output to provide regulation to the load and momentary ride-through when the transfer from normal to UPS supply is made

The following figure shows the configuration of a hybrid UPS.



[Fig.2,11 hybrid UPS]

- **Capacitor for voltage regulation**

Capacitors may be used for voltage regulation on the power system in either the shunt or series configuration

Long-Duration Voltage Variations

Long-Duration Voltage Variations 307

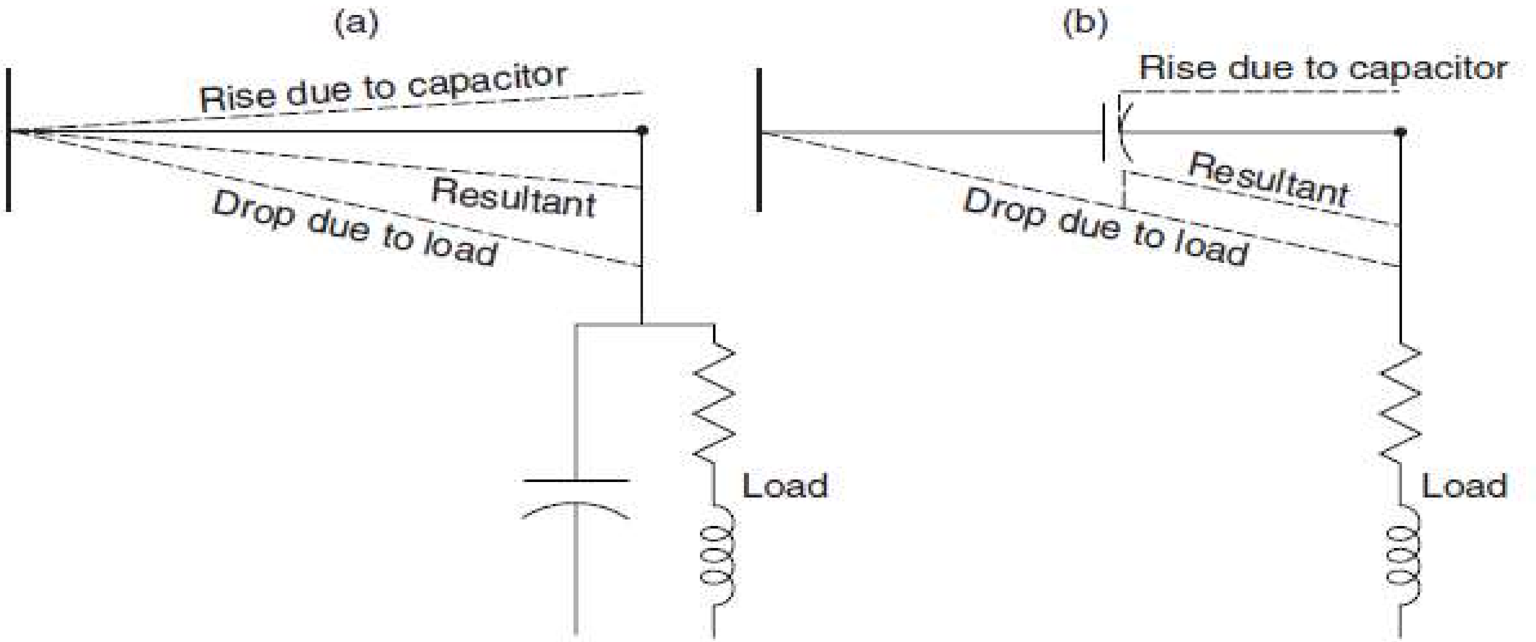


Figure 7.10 Feeder voltage rise due to shunt (*a*) and series (*b*) capacitors.

Shunt capacitors

- the presence of a shunt capacitor at the end of a feeder results in a gradual change in voltage along the feeder.

- Ideally, the percent voltage rise at the capacitor

$$\%\Delta V = \frac{100\,(V_{\text{with cap}} - V_{\text{no cap}})}{V_{\text{with cap}}}$$

- How ever with shunt capacitors, percent voltage rise is essentially independent of load.

- Therefore, automatic switching is often employed in order to deliver the desired regulation at high loads, but prevent excessive voltage at low loads.

- Switching may result in transient over voltages inside customer facilities,

Series capacitors

- Unlike the shunt capacitor, a capacitor connected in series with the feeder results in a voltage rise at the end of the feeder that varies directly with load current.
- Voltage rise is zero at no load and maximum at full load.
- Thus, series capacitors do not need to be switched in response to changes in load. Moreover, a series capacitor will require far smaller kV and kvar ratings than a shunt capacitor delivering equivalent regulation.
- But series capacitors have several disadvantages.

Firstly, they cannot provide reactive compensation for feeder loads and do not significantly reduce system losses.

Series capacitors can only release additional system capacity if it is limited by excessive feeder voltage drop.

Shunt capacitors, on the other hand, are effective when system capacity is limited by high feeder current as well.

- Secondly, series capacitors cannot tolerate fault current. This would result in a catastrophic overvoltage and must be prevented by bypassing the capacitor through an automatic switch.

- An arrester must also be connected across the capacitor to divert current until the switch closes

- These include resonance and/or hunting with synchronous and induction motors, and Ferro resonance with transformers.
- Because of these concerns, the application of series capacitors on distribution systems is very limited.

- One area where they have proved to be advantageous is where feeder reactance must be minimized, e.g., to reduce flicker.

Power Factor Penalty

- $P = V \; I \; COS \; \phi$
- FOR CONSTANT POWER AND SUPPLY VOLTAGE
- $I \propto \frac{1}{cos\phi}$
- I increases
- power factor decreases
- For same current lower power factor current drawing will be high
- I ↑↑
- $I^2R\ powerloss$ ↑↑
- ɧ efficiency ↓↓
- I ↑↑ Size of conductor increases
- Which ultimately results in voltage drop in transformer, busbars ,
- This leads to poor voltage regulation.
- Handiling capacity of power system ↓↓

- Power Factor penalty

- For Example consider a simple method in which power factor is less than 0.95 the demand will be adjusted by the following

- Adjusted demand = $\frac{0.95}{Actual\ power\ factor} * $ Actual Demand

- Let
- Actual demand = 800KW
- $Actual\ power\ factor$ = 0.8
- Demand charge = $10/KW

- Then Adjusted demand = $\frac{0.95}{0.8}$ *800
  = 950kw

- Power factor penalty = (Adjusted demand –Actual demand)*Demand charge
  = (950-800)*10
  = $1500/month

End-User Capacitor Application

The reasons that an end user might decide to apply power factor correction capacitors are to

■ Reduce electric utility bill

■ Reduce I^2R losses and, therefore, heating in lines and transformers

■ Increase the voltage at the load, increasing production and/or the efficiency of the operation

■ Reduce current in the lines and transformers, allowing additional load to be served without building new circuits

The primary motivation is generally economics to eliminate utility power factor penalties, but there are technical benefits related to power quality as well.

There can be power quality problems as a result of adding capacitors.

The most common are harmonics problems. While power factor correction capacitors are not harmonic sources, they can interact with the system to accentuate the harmonics that are already there

Location for power factor correction capacitors

- The benefits realized by installing power factor correction capacitors include the reduction of reactive power flow on the system.
- Therefore for best results, power factor correction should be located as close to the load as possible
- However, this may not be the most economical solution or even the best engineering solution, due to the interaction of harmonics and capacitors.

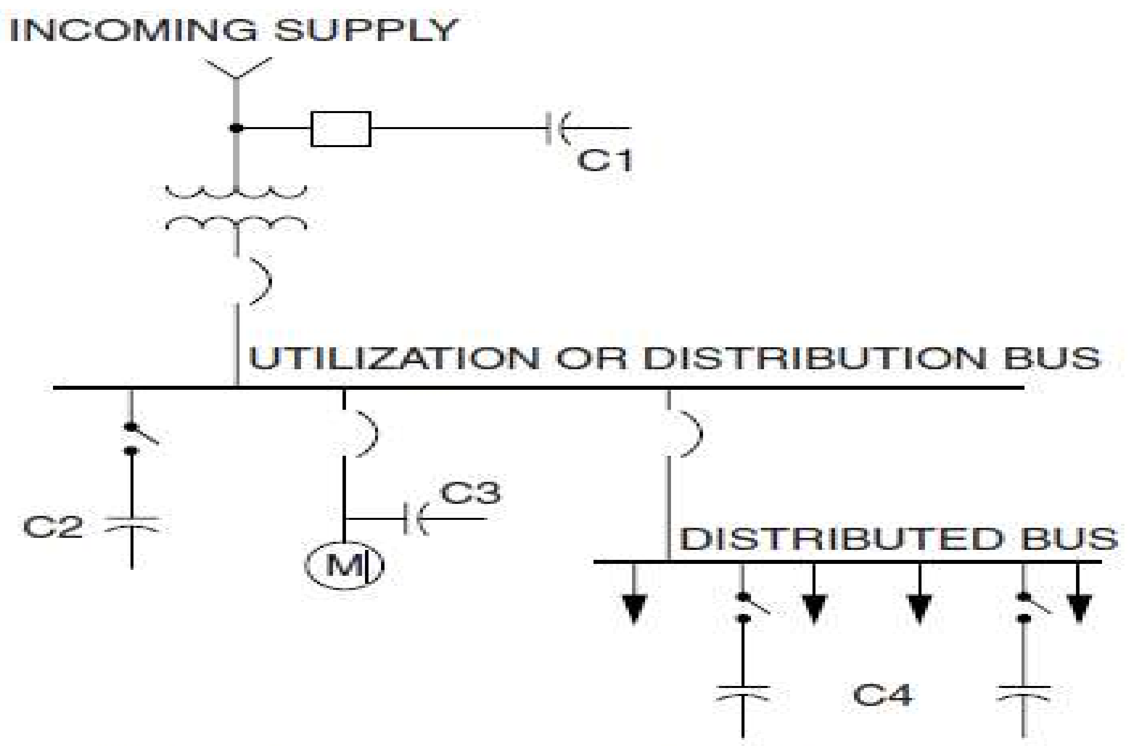


Figure 7.11 Location of power factor correction.

- C3 Near load . Its location is meant for power factor improvement
- C4 Near distribution sub station.
- C2 on L.V side of supply transformer.
- C2 and C3 both are beneficial for automatic switching purpose.

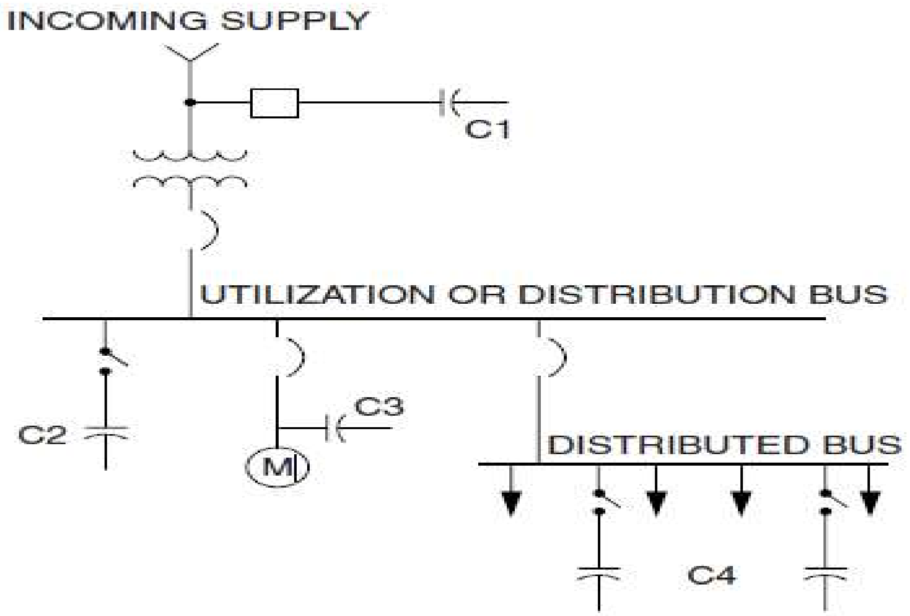


Figure 7.11 Location of power factor correction.

- C 1 on H.V side of supply transformer. It is beneficial for entire power system .

- The order of preference is from C1 to c4 and the best possible location is at C1 (near load)

Regulating Utility Voltage with Distributed Resources

- when the load approaches the system capacity limits.

- The movement toward utility deregulation in recent years has created renewed interest in distributed resources, and many of the issues related to power quality are addressed

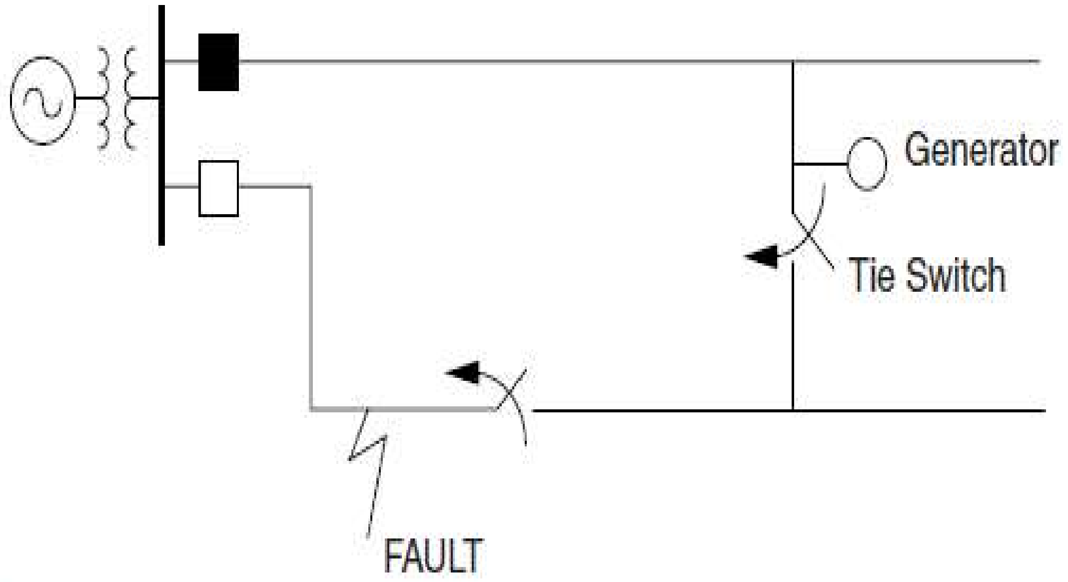


Figure 7.13 Using a generator to support restoration of service to the unfaulted portion of a feeder.

- Most of the utility-owned installations have been located in utility distribution substations. This offers load relief for the substation and transmission facilities, but contributes little else to the quality of power for the distribution feeder.
- Now, many distribution engineers are considering the benefits of moving the devices out onto the feeder to gain additional system capacity, loss reduction, improved reliability, and voltage regulation
- These generators will often be owned by end users, but could be contracted to operate for utility system benefits as well.
- While this option may be too expensive to consider for voltage regulation alone, it is a useful side effect of dispersed sources justified on the basis of deferment of capital expansion.

- Utilities usually have sectionalizing switches installed so that portions of a distribution feeder can be served from different feeders or substations during emergencies.
- If the fault occurs at the time of peak load, it may be impossible to pick up any more load from other feeders in the normal manner simply by closing a switch.
- However, a generator located near the switch tie point can potentially provide enough power to support the additional load at a satisfactory voltage.
- If the generator is of sufficient size, it could be employed to help regulate the voltage.
- One advantage of using a generator to regulate the voltage is that its controls respond much faster and more smoothly than discrete tap changing devices like regulators and LTCs.
- Direct transfer trip is generally required to ensure that the generator disconnects from the system when certain utility breakers operate.

- Although the DG no longer attempts to regulate the voltage, it is still useful for voltage regulation purposes during constrained loading conditions by displacing some active and reactive power.
- Alternatively, customer-owned DG may be exploited simply by operating off-grid and supporting part or all of the customer's load off-line.
- This avoids interconnection issues and provides some assistance to voltage regulation by reducing the load.
- The controls of distributed sources must be carefully coordinated with existing line regulators and substation LTCs.
- Reverse power flow can sometimes fool voltage regulators into moving the tap changer in the wrong direction.
- Also, it is possible for the generator to cause regulators to change taps constantly, causing early failure of the tap-changing mechanism.
- Fortunately, some regulator manufacturers have anticipated these problems and now provide sophisticated microcomputer- based regulator controls that are able to compensate

Flicker*

- The term flicker is sometimes considered synonymous with voltage fluctuations, voltage flicker, light flicker, or lamp flicker.

- The phenomenon being referred to can be defined as a fluctuation in system voltage that can result in observable changes (flickering) in light output.

- Because flicker is mostly a problem when the human eye observes it, it is considered to be a problem of perception.

- The system is too weak to support the load. Also, some of the solutions are the same as for the slow-changing voltage regulation problems.

- The voltage variations resulting from flicker are often within the normal service voltage range, but the changes are sufficiently rapid to be irritating to certain end users.

- The phenomenon being referred to can be defined as a fluctuation in system voltage that can result in observable changes (flickering) in light output

- Flicker can be separated into two types: cyclic and noncyclic. Cyclic flicker is a result of periodic voltage fluctuations on the system, while noncyclic is a result of occasional voltage fluctuations.

Flicker*

- By using a percentage, the flicker signal is independent of peak, peak-to-peak, rms, line-to-neutral, etc. Typically, percent voltage modulation is expressed by

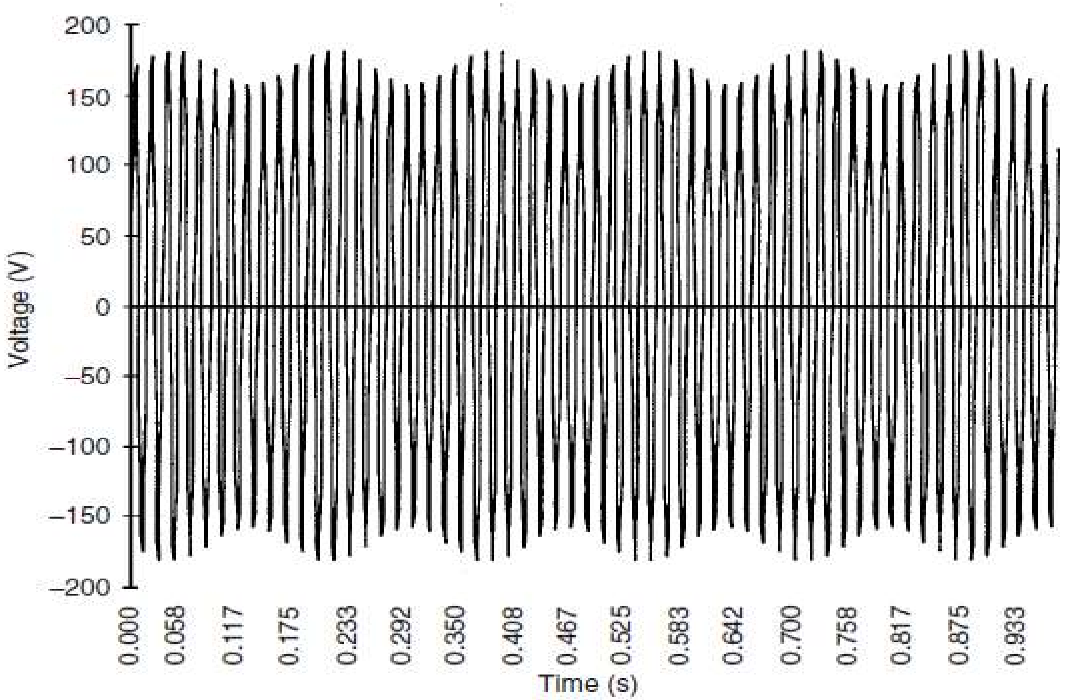


Figure 7.15 Example flicker waveform.

$$\text{Percent voltage modulation} = \frac{V_{max} - V_{min}}{V_0} \times 100\%$$

where V_{max} = maximum value of modulated signal

V_{min} = minimum value of modulated signal

V_0 = average value of normal operating voltage

Sources of flicker

Whether the resulting voltage fluctuations cause observable or objectionable flicker is dependent upon the following parameters:

- Size (VA) of potential flicker-producing source
- System impedance (stiffness of utility)
- Frequency of resulting voltage fluctuations

- Large induction machines undergoing start-up or widely varying load torque changes are also known to produce voltage fluctuations on systems
- In certain circumstances, superimposed inter harmonics in the supply voltage can lead to oscillating luminous flux and cause flicker

- **Mitigation techniques**

- Mitigation alternatives include static capacitors, power electronic-based switching devices, and increasing system capacity.

- The particular method chosen is based upon many factors such as the type of load causing the flicker, the capacity of the system supplying the load, and cost of mitigation technique.

- Flicker is usually the result of a varying load that is large relative to the system short-circuit capacity.

- One obvious way to remove flicker from the system would be to increase the system capacity sufficiently to decrease the relative impact of the flicker-producing load.

- Upgrading the system could include any of the following:

- reconductoring, replacing

- existing transformers with higher kVA ratings, or increasing the operating voltage.

- Motor modifications are also an available option to reduce the amount of flicker produced during motor starting and load variations.
- The motor can be rewound (changing the motor class) such that the speed-torque curves are modified. Unfortunately, in some cases this could result in a lower running efficiency.
- Flywheel energy systems can also reduce the amount of current drawn by motors by delivering the mechanical energy required to compensate for load torque variations.
- Series capacitors can also be used to reduce the effect of flicker on an existing system

Tap-Changing Transformers

- One important method is to use tap changing
- transformer and is commonly employed where main transformer is necessary.
- In this method, a number of tapping's are provided on the secondary of the transformer.
- The voltage drop in the line is supplied by changing the secondary e.m.f. of the transformer through the adjustment of its number of turns
- **(*i*) Off load tap-changing transformer**
- ***ii*) On-load tap-changing transformer.**

(*i*) Off load tap-changing transformer

- A number of tapping's have been provided on the secondary.
- As the position of the tap is varied, the effective number of secondary turns is varied and hence the output voltage of the secondary can be changed.
- when the movable arm makes contact with stud 1, the secondary voltage is minimum and
- when with stud 5, it is maximum.
- During the period of light load, the voltage across the primary is not much below the alternator voltage and the movable arm is placed on stud 1.
- When the load increases, the voltage across the primary drops, but the secondary voltage can be kept at the previous value by placing the movable arm on to a higher stud.
- Whenever a tapping is to be changed in this type of transformer, the load is kept off and hence the name off load tap-changing transformer

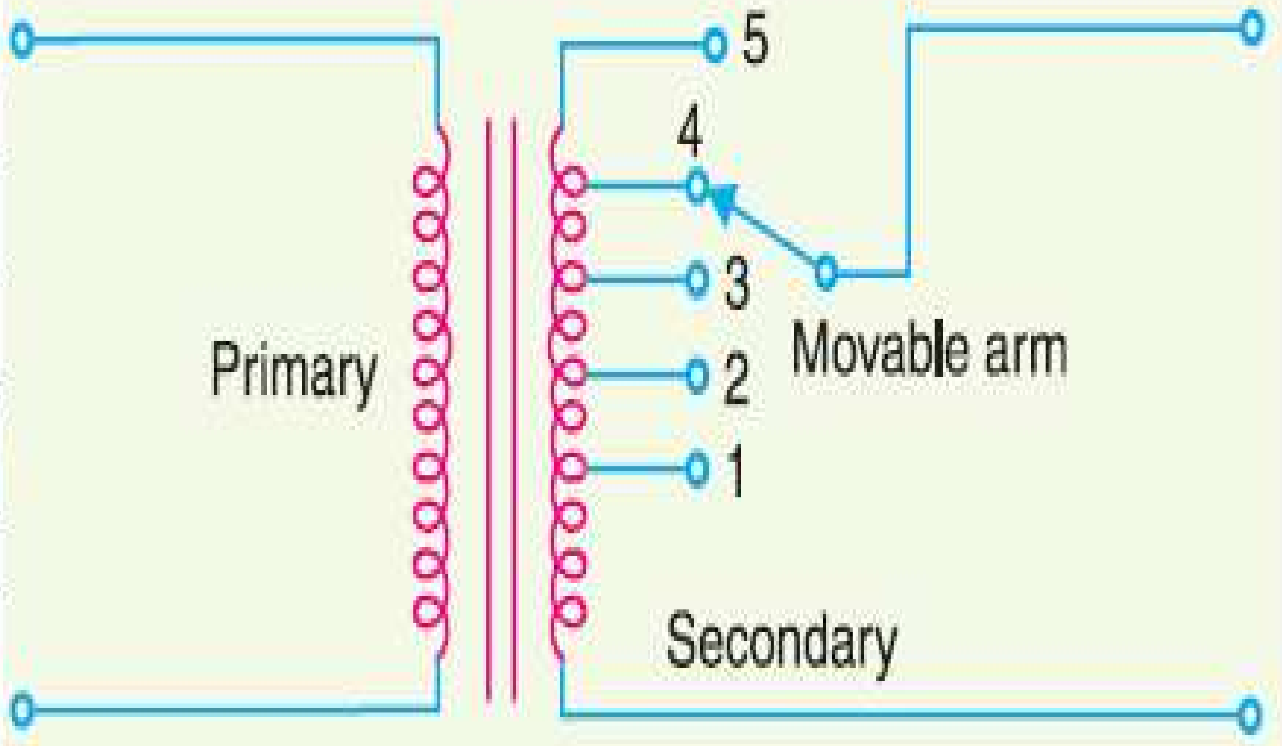


Fig. 15.4

- The principal disadvantage of the circuit arrangement
- It cannot be used for tap-changing on load.
- Suppose for a moment that tapping is changed from position 1 to position2 when the transformer is supplying load. If contact with stud 1 is broken before contact with stud 2 is made, there is break in the circuit and arcing results.
- On the other hand, if contact with stud 2 is made before contact with stud 1 is broken, the coils connected between these two tapping's are short circuited and carry damaging heavy currents. For this reason, the above circuit arrangement cannot be used for tap-changing on load.

(*ii*) On-load tap-changing transformer

- In supply system, tap-changing has normally to be performed on load so that there is no interruption to supply.
- . The secondary consists of two equal parallel windings which have similar tapping's 1*a* ...... 5*a* and 1*b* .... 5*b*.
- In the normal working conditions, switches *a*, *b* and tapping's with the same number remain

closed and each secondary winding carries one-half of the total current.

- the secondary voltage will be maximum when switches *a*, *b* and 5*a*, 5*b* are closed. However, the secondary voltage will be minimum when switches *a*, *b* and 1*a*, 1*b* are closed.

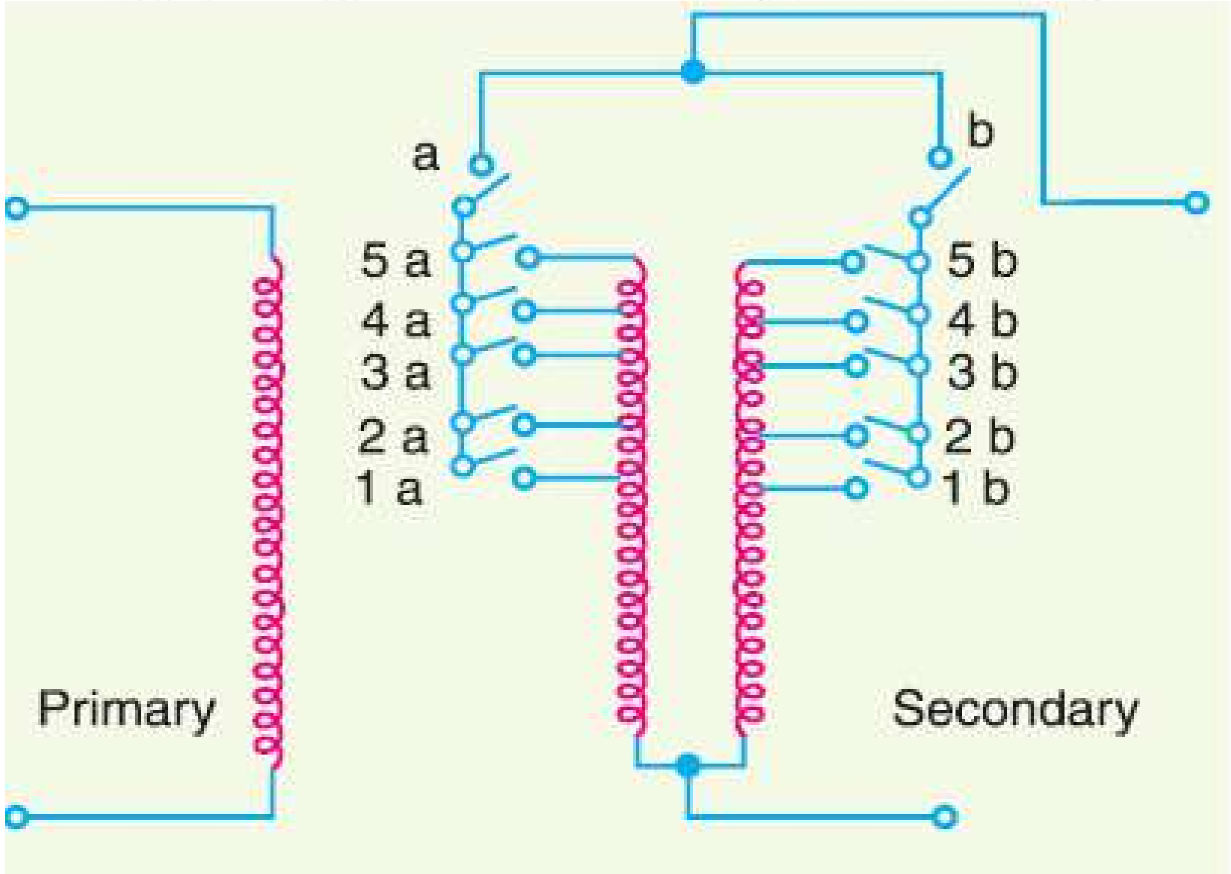


Fig. 15.5

- Suppose that the transformer is working with tapping position at 4*a*, 4*b* and it is desired to alter its position to 5*a*, 5*b*.

For this purpose, one of the switches *a* and *b*, say *a*, is opened. This takes the secondary winding controlled by switch *a* out of the circuit.

Now, the secondary winding controlled

- by switch *b* carries the total current which is twice its rated capacity. Then the tapping on the disconnected

winding is changed to 5*a* and switch *a* is closed.

After this, switch *b* is opened to disconnect its winding, tapping position on this winding is changed to 5*b* and then switch *b* is closed.

In this way, tapping position is changed without interrupting the supply.

This method has the following disadvantages

- **(*i*)** During switching, the impedance of transformer is increased and there will be a voltage surge.
- **(*ii*)** There are twice as many tappings as the voltage steps

Auto-Transformer Tap-changing

- A mid-tapped auto-transformer or reactor is used.
- One of the lines is connected to its mid-tapping.
- One end, say *a* of this transformer is connected to a series of switches across the odd tapping's and the other end *b* is connected to switches across even tapping's.
- A short-circuiting switch *S* is connected across the auto-transformer and remains in the closed position under normal operation.
- In the normal operation, there is *no inductive voltage drop across the auto-transformer.

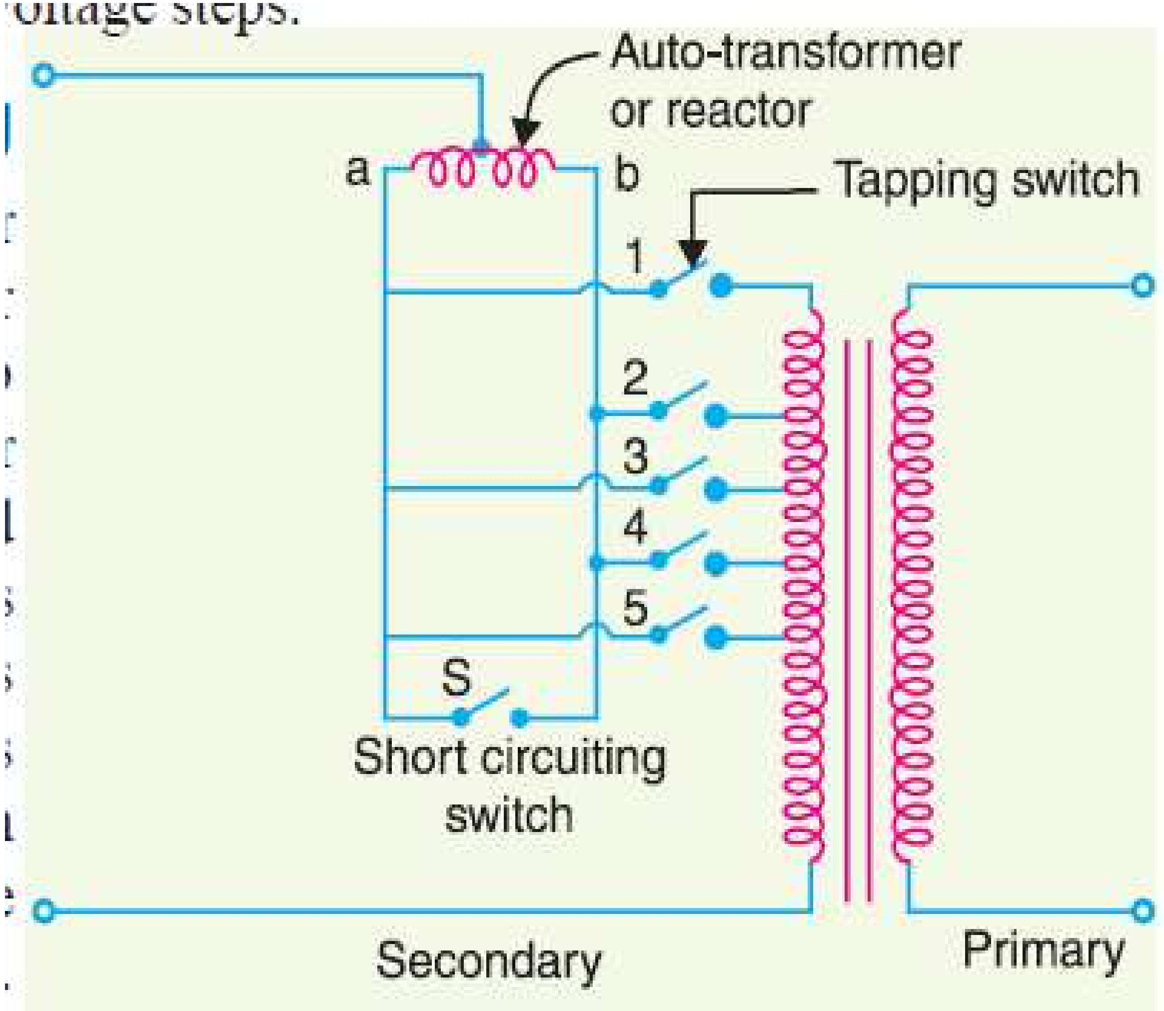


Fig. 15.6

Referring to Fig.

- it is clear that with switch 5 closed, minimum secondary turns are in the circuit and hence the output voltage will be the lowest.
- On the other hand, the output voltage will be maximum when switch 1 is closed.
- Suppose now it is desired to alter the tapping point from position 5 to position 4 in order to raise the output voltage.
- For this purpose, short-circuiting switch *S* is opened, switch 4 is closed, then switch 5 is opened and finally short-circuiting switch is closed.
- In this way, tapping can be changed without interrupting the supply.

It is worthwhile to describe the electrical phenomenon occurring during the tap changing.

- When the short-circuiting switch is opened, the load current flows through one-half of the reactor coil so that there is a voltage drop across the reactor.
- When switch 4 is closed, the turns between points 4 and 5 are connected through the whole reactor winding.
- A circulating current flows through this local circuit but it is limited to a low value due to high reactance of the reactor

Static VAR compensations for power factor improvement

.

- The compensators which doesn't have any rotating parts will come under static var compensators
- It consists of capacitor inductor and capacitive banks
- The primary objective of svc is to compensate reactive power and to improve Power factor
- It injects reactive current into the system at the midpoint of transmission inter connection
- It observe or supplies reactive Power to maintain desire Power factor and to regulate voltage.
- Reactive Power is required for various Purposes.
- Leading reactive Power is required to regulate the voltage at the end of long transmission lines and to improve Power factor
- Lagging reactive Power is required to compensate the voltage rise at the end of transmission line caused by capacitive Charging currents

Static VAR compensations for power factor improvement

- Let Q_C be the reactive Power charging by the Capacitor and Q_L be the reactive Power absorption by the inductor then

The net reactive Power injected into the bus will be

$Q = Q_C - Q_L$

Q is controlled by varying Q_L

During heavy loads

$Q_L > Q_C$

During light loads

$Q_C > Q_L$

SVC in its simple form is connected as thyistor controlled reactor (TCR) and thyristor Switched capacitor (TSC)

Static VAR compensations for power factor improvement

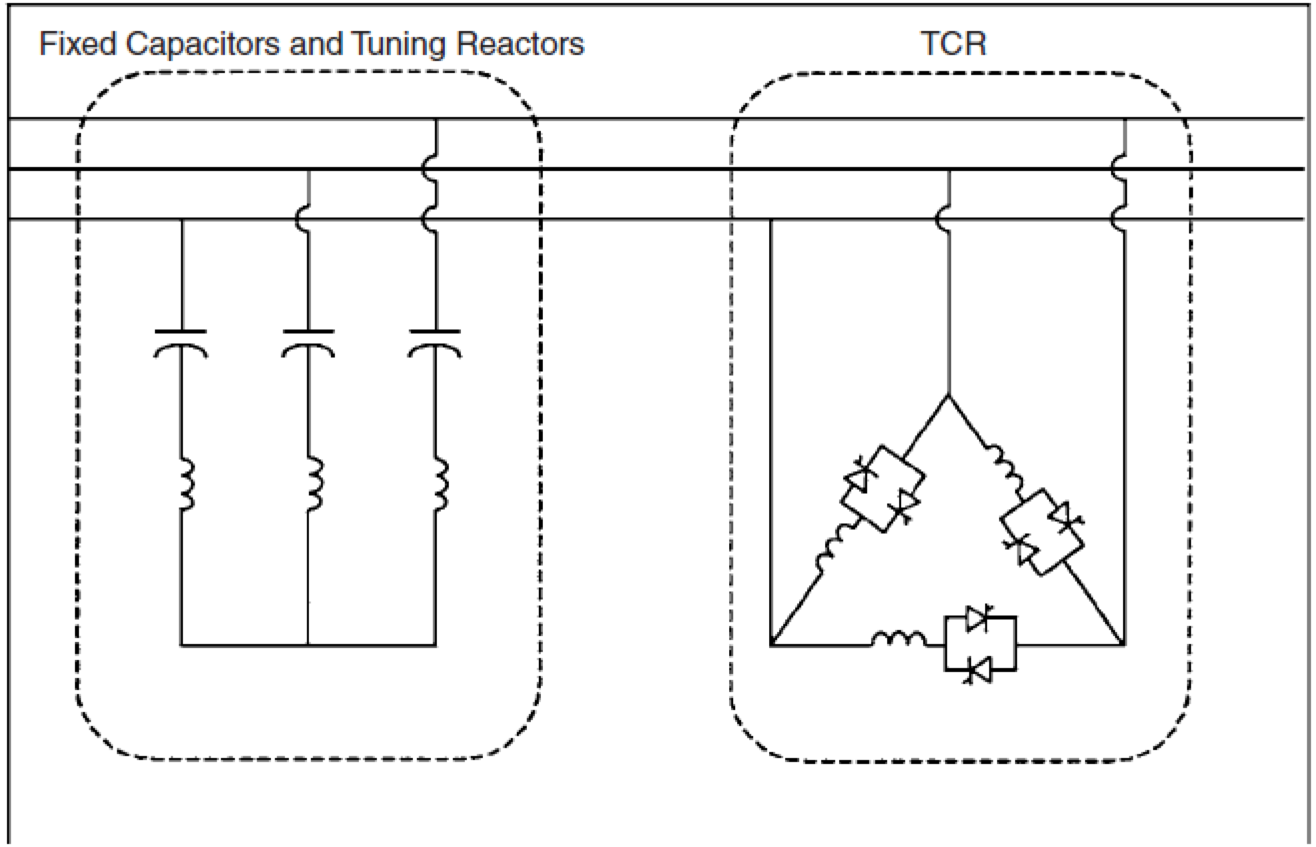
.

thyistor controlled reactor (TCR) and thyristor Switched capacitor (TSC)

- A TCR is thyristor controlled inductor, connected in shunt with line in which thyristor valve is controlled by partial conduction . In order to continuously vary the effective reactance of line

- A TSC is thyristor controlled capacitor. A thyristor switched capacitor is one which is connected in shunt with the line and the thyristor valve operated by full or zero conduction such that the effective reactance of the line is varied in a step wise manner.

Static VAR compensations for power factor improvement



Static VAR compensations for power factor improvement

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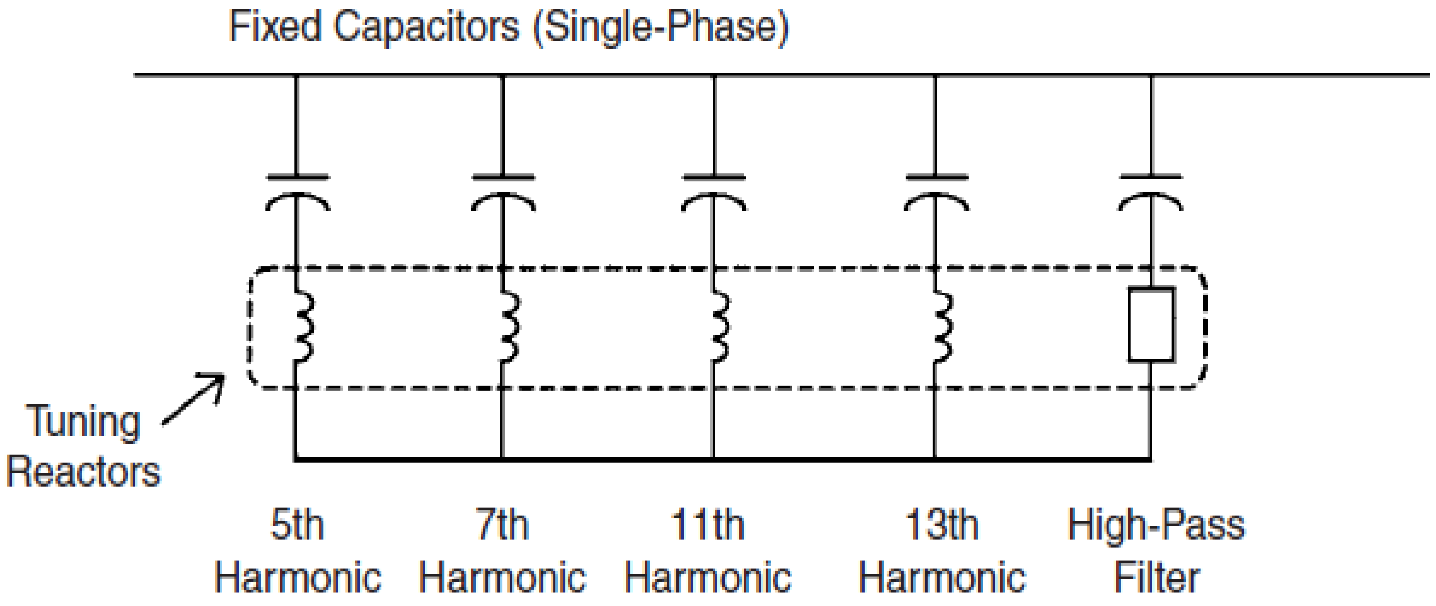

Static VAR compensations for power factor improvement

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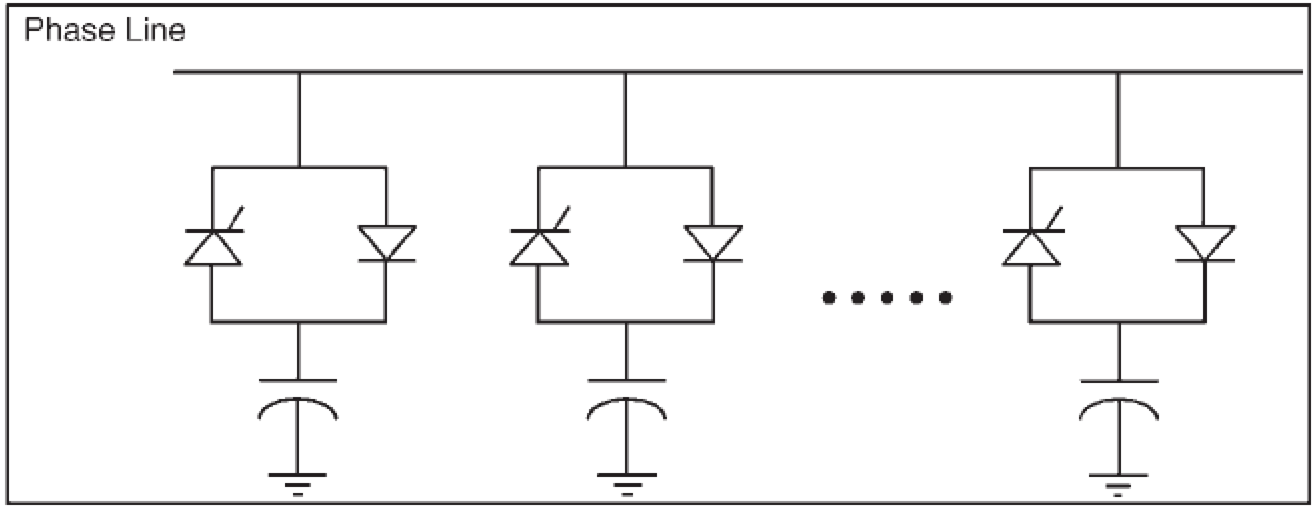

Figure 7.19 Typical TSC configuration.

Do follow the

- Feed back link
- Assignment link
- Leave the Class properly
- Once you completed those follow next class link

- Despite the situation don't stop yourself from learning
- Practice social distance stay home safe learn stay healthy .
- #Adityans #Stay Home #Stay Safe #Keep Learning
  #Qurantine Days #Online #Classes

THANK YOU
WE WILL CONTINUE IN NEXT CLASS

ADITYA COLLEGE OF ENGINEERING & TECHNOLOGY

Unit– IV: Harmonic distortion and solutions

By

PRABHA RANI.K

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Aditya College of Engineering & Technology

Surampalem.

- A quick review on what we discussed in last class
- Today's Discussion on

Unit– IV: Harmonic distortion and solutions

- Voltage distortion vs. Current distortion
- Harmonics vs. Transients
- Harmonic indices
- Sources of harmonics
- Effect of harmonic distortion
- Impact of capacitors, transformers,
- motors and meters
- Point of common coupling
- Passive and active filtering
- Numerical problems.

- **Harmonic distortion** is the change in waveforms of supply sinusoidal voltage .
- In other words harmonic distortion is production of harmonic frequencies by an electronic system when signal is applied at an input.
- Two types of harmonic distortion

- Even order harmonic distortion

- If the frequencies are even multiples of fundamental frequency ,then such harmonic frequencies are called even order harmonics

- Odd order harmonic distortion

- If the frequencies are odd multiples of fundamental frequency ,then such harmonic frequencies are called even order harmonics

- Voltage distortion vs. Current distortion

Voltage distortion	Current distortion
Harmonic Voltages are two great	Harmonic currents are two great
Non linear loads are sources of harmonic currents which leads to voltage distortion	Non linear loads are sources of harmonic currents
The effect of voltage distortion on a distribution system is minimum and is maximum at load buses	The effect of current distortion on load is minimum and serious in distribution system
The voltage distortion is dependent on current and impedance	Current distortions are independent

Harmonic indices

Harmonic indices are measures of effective value of Waveforms .these can be applied to either voltage or current waveforms. Generally the harmonic indices are classified

- Total harmonic distortion (THD)
- Total demand distortion (TDD)

It is defined as the ratio of the root mean square of the harmonic content to the root mean square value of fundamental component .it is abbreviated as THD which is widely employed to describe power quality issues in transmission and distribution systems. Mathematically it is given as

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

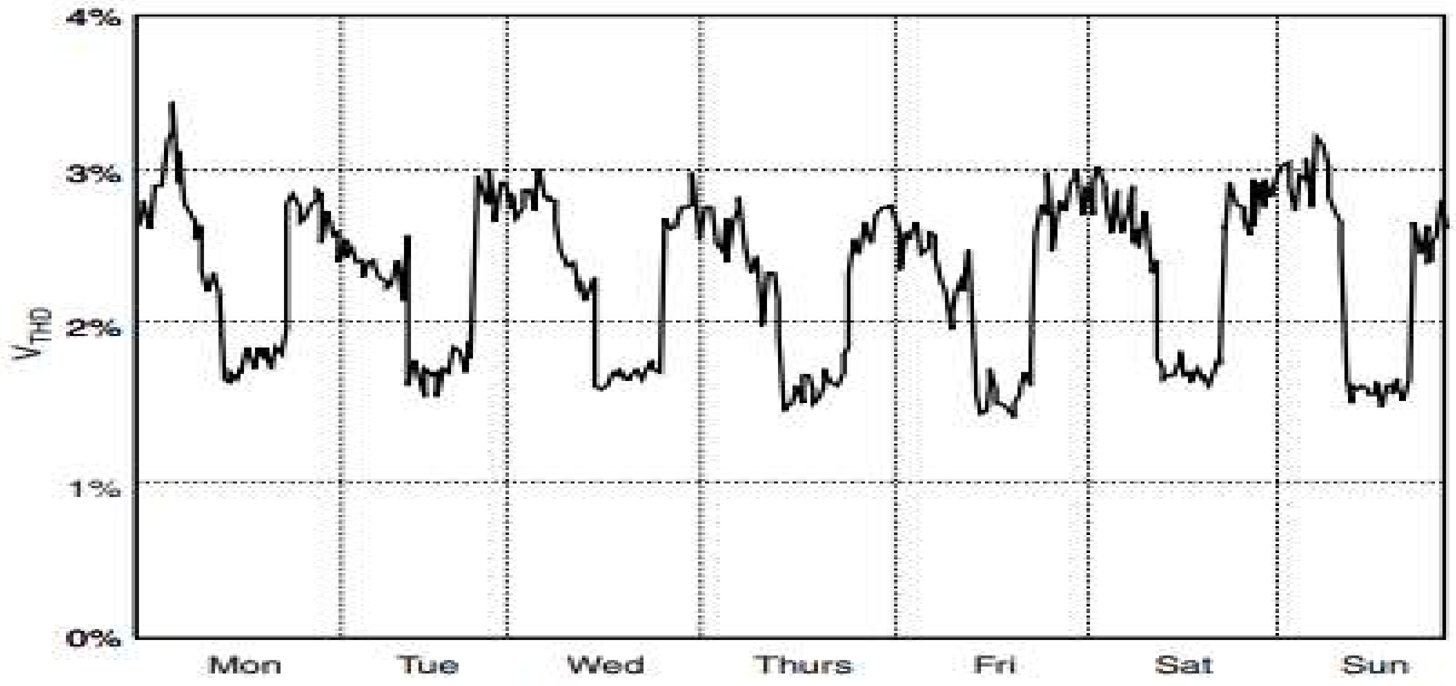
Mh= Harmonic content r.m.s Value

M1= Fundamental quantity

Total harmonic distortion (THD) provides the information regarding losses ,caused by the flow of current through conductor .

The index of THD is used to describe the Voltage harmonic distortion . How ever for better result THD should be measured at least for a period of one week.

The variation of harmonic distortions caused by voltage over a period of week



Total demand distortion (TDD)

Total demand distortion is defined as the ratio of the root mean square of the harmonic current to the root mean square value of rated or maximum demand fundamental current which is expressed as a percent . It is abrivated as TDD.

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

Ih= Harmonic current

IL= maximum demand of Fundamental current

- Harmonics vs. Transients

Harmonics	Transients
It is steady state calculation	It is time based calculation of response of the system to an event
Harmonic analysis is used to determine the steady state limits of voltage and current	It is used to determine the event of Particular equipment
Harmonics are integer multiple of fundamental frequencies .	Transients are not integer multiples of fundamental frequencies .
The frequencies will be harmonics	The frequencies will be natural frequencies
The wave form distortion is continuous	The wave form distortion is not continuous
They are associated with continuous operation of load	They are associated with changes in the system like Switching of capacitor banks.
Harmonics are broadly classified as	Transients are broadly classified as
Quasi stationary, Fluctuating, Rapidly changing	Switching surge, impulse spikes

- Sources of harmonics

- Single phase Power supplies
- Fluorescent lighting
- Adjustable Speed drives for HVAC
- Three phase Power converters
- Arcing devices
- Saturable devices

Single phase Power supplies

- Advances in semiconductor device technology have fueled a revolution in power electronics over the past decade, and there is every indication that this trend will continue.
- Equipment includes adjustable-speed motor drives, electronic power supplies, dc motor drives, battery chargers, electronic ballasts, and many other rectifier and inverter applications
- DC power for modern electronic and microprocessor-based office equipment is commonly derived from single-phase full-wave diode bridge rectifiers.

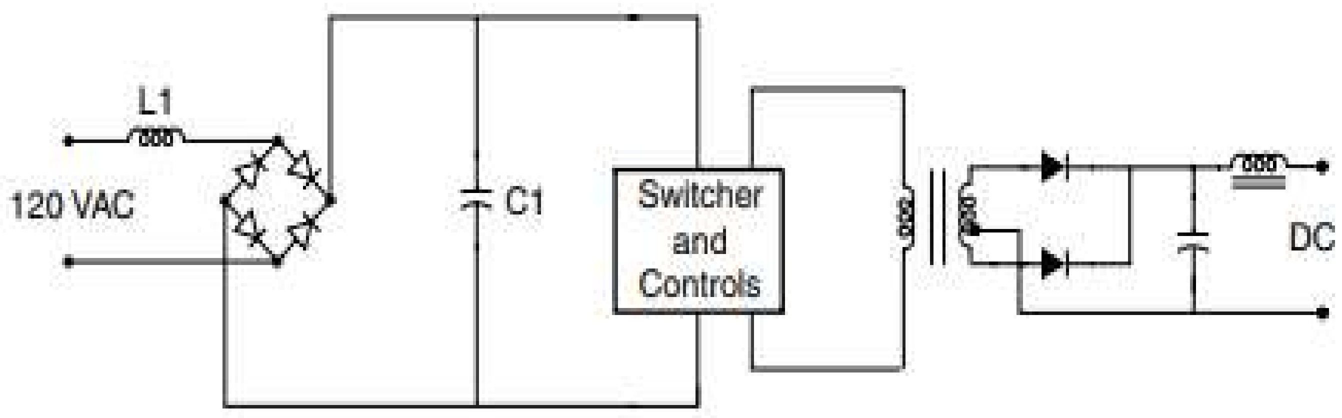


Figure 5.10 Switch-mode power supply.

There are two common types of single-phase power supplies.

- Older technologies use ac-side voltage control methods, such as transformers, to reduce voltages to the level required for the dc bus.

- The inductance of the transformer provides a beneficial side effect by smoothing the input current waveform, reducing harmonic content

- Newer-technology switch-mode power supplies use dc-to-dc conversion techniques to achieve a smooth dc output with small, lightweight components.

- The input diode bridge is directly connected to the ac line, eliminating the transformer. This results in a coarsely regulated dc voltage on the capacitor. This direct current is then converted back to alternating current at a very high frequency by the switcher and subsequently rectified again.

- The key advantages are the light weight, compact size, efficient operation, and lack of need for a transformer. Switch-mode power supplies can usually tolerate large variations in input voltage
- The increasing application of switch-mode power supplies causes concern for overloading of neutral conductors, Which is because of additive nature of third harmonic currents in neutral to three phase system.
- There is also a concern for transformer overheating due to a combination of harmonic content of the current, stray flux, and high neutral currents

- Fluorescent lighting
- In Power systems distortions are due to non linear loads at the end-user.

- Lighting typically accounts for 40 to 60 percent of a commercial building load.

- According to the 1995 Commercial Buildings Energy Consumption study conducted by the U.S. Energy Information Administration, fluorescent lighting was used on 77 percent of commercial floor spaces, while only 14 percent of the spaces used incandescent lighting.1 Fluorescent lights are a popular choice for energy savings.

- Fluorescent lights are discharge lamps; thus they require a ballast to provide a high initial voltage to initiate the discharge for the electric current to flow between two electrodes in the fluorescent tube.

- There are two types of ballasts, magnetic and electronic.
- A standard magnetic ballast is simply made up of an iron-core transformer with a capacitor encased in an insulating material.
- A single magnetic ballast can drive one or two fluorescent lamps, and it operates at the line fundamental frequency, i.e., 50 or 60 Hz. The iron-core magnetic ballast contributes additional heat losses, which makes it inefficient compared to an electronic ballast

- An electronic ballast employs a switch-mode–type power supply to convert the incoming fundamental frequency voltage to a much higher frequency voltage typically in the range of 25 to 40 kHz.

- This high frequency has two advantages.
- First, a small inductor is sufficient to limit the arc current.
- Second, the high frequency eliminates or greatly reduces the 100- or 120-Hz flicker associated with an iron-core magnetic ballast. A single electronic ballast typically can drive up to four fluorescent lamps.

- standard magnetic ballasts are usually rather benign sources of additional harmonics themselves since the main harmonic distortion comes from the behavior of the arc.

- The current THD is a moderate 15 percent. As a comparison, electronic ballasts, which employ switch-mode power supplies, can produce 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. Electronic ballasts typically produce current THDs in the range of between 10 % to 32%

- Adjustable Speed drives for HVAC

- Common applications of adjustable-speed drives (ASDs) in commercial loads can be found in elevator motors and in pumps and fans in HVAC systems.
- An ASD consists of an electronic power converter that converts ac voltage and frequency into variable voltage and frequency. The 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.

Three-phase power converters

Three-phase electronic power converters differ from single-phase converters mainly because they do not generate third-harmonic currents. This is a great advantage because the third-harmonic current is the largest component of harmonics.

The input to the PWM drive is generally designed like a three-phase version of the switch-mode power supply in computers. The rectifier feeds directly from the ac bus to a large capacitor on the dc bus.

With little intentional inductance, the capacitor is charged in very short pulses, creating the distinctive “rabbit ear” ac-side current waveform with very high distortion.

Whereas the switch-mode power supplies are generally for very small loads, PWM drives are now being applied for loads up to 500 horsepower (hp). This is a justifiable cause for concern from power engineers.

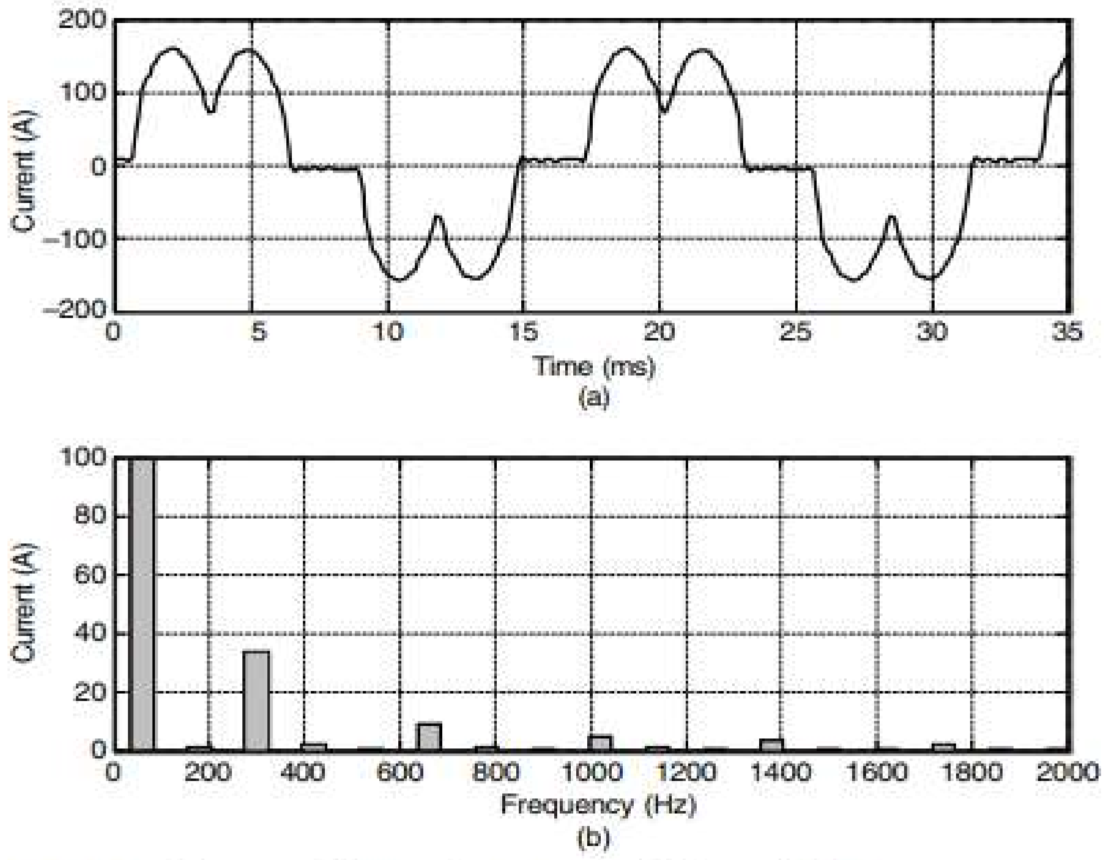


Figure 5.14 Current and harmonic spectrum for CSI-type ASD.

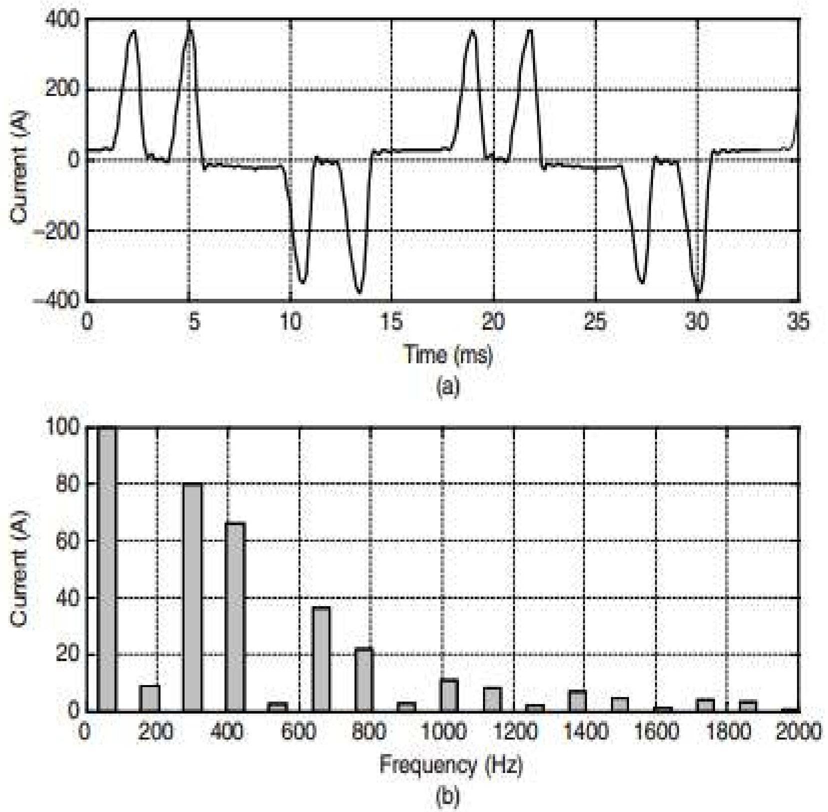


Figure 5.15 Current and harmonic spectrum for PWM-type ASD.

- Arcing devices
- arc is basically a voltage clamp in series with a reactance that limits current to a reasonable value
- 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.
- Three phase arcing devices can be arranged to cancel the triple harmonics through the transformer connection.
- Arcing devices includes arc furnaces, arc welders, and discharge-type lighting (fluorescent, sodium vapor, mercury vapor) with magnetic ballasts

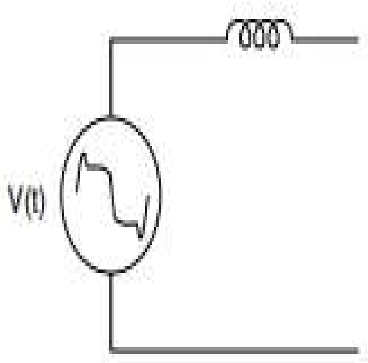


Figure 5.20 Equivalent circuit for an arcing device.

• Saturable devices

- Saturable devices   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 normally operate just below the “knee” point of the magnetizing saturation characteristic.
- The operating flux density of a transformer is selected based on a complicated optimization of steel cost, no-load losses, noise, and numerous other factors.
- 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 current.

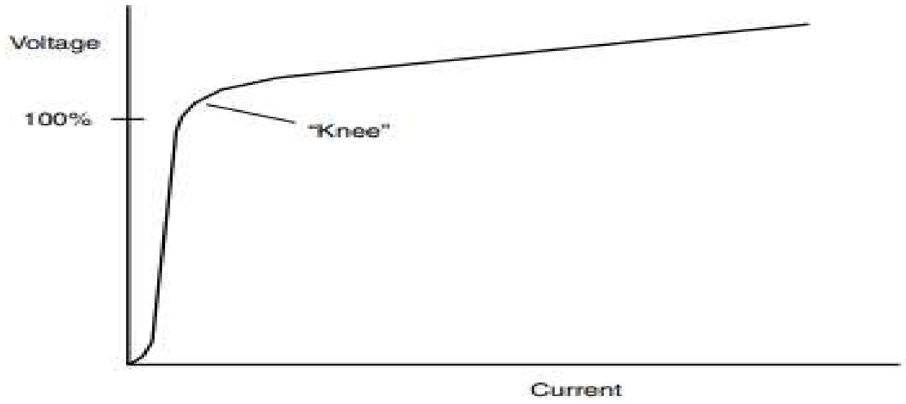


Figure 5.21 Transformer magnetizing characteristic.

- Impact of Harmonics capacitors, transformers, motors and meters

- Capacitors
- In electrical Power systems Capacitors are usually used as power factor correction devices from commercial and industrial loads to distribution and transmission systems.
- The combination of harmonica and capacitor will cause more severe Power quality condition called harmonic resonance.
- Due increase in harmonics the overall life of capacitor gets shortened.
- Resonance Provides higher voltages and currents in capacitor.
- The capacitor bank act as a sink for higher harmonic currents which results in over load and causes the failure of the bank.
- Harmonic voltage increase dielectric loss in capacitor.

Transformers

- Transformers are designed to deliver the required power to the connected loads with minimum losses at fundamental frequency. Harmonic distortion of the current, in particular, as well as of the voltage will contribute significantly to additional heating.
- To design a transformer to accommodate higher frequencies, designers make different design choices such as using continuously transposed cable instead of solid conductor and putting in more cooling ducts.

There are three effects that result in increased transformer heating when the load current includes harmonic components:

1. RMS current.

If the transformer is sized only for the kVA requirements of the load, harmonic currents may result in the transformer rms current being higher than its capacity. The increased total rms current results in increased conductor losses.

2.Eddy current losses.

These are induced currents in a transformer caused by the magnetic fluxes. These induced currents flow in the windings, in the core, and in other conducting bodies subjected to the magnetic field of the transformer and cause additional heating. This component of the transformer losses increases with the square of the frequency of the current causing the eddy currents. Therefore, this becomes a very important component of transformer losses for harmonic heating.

3.Core losses.

The increase in core losses in the presence of harmonics will be dependent on the effect of the harmonics on the applied voltage and the design of the transformer core. Increasing the voltage distortion may increase the eddy currents in the core laminations. The net impact that this will have depends on the thickness of the core laminations and the quality of the core steel. The increase in these losses due to harmonics is generally not as critical as theprevious two.

The load loss P_{LL} can be considered to have two components: I^2R loss and eddy current loss P_{EC}:

$$P_{LL} = I^2R + P_{EC} W$$

The I^2R loss is directly proportional to the rms value of the current. However, the eddy current is proportional to the square of the current and frequency, which is defined by

$$P_{EC} = K_{EC} \times I^2 \times h^2$$

where K_{EC} is the proportionality constant.

The per-unit full-load loss under harmonic current conditions is given by

$$P_{LL} = \sum I_h^2 + (\sum I_h^2 \times h^2)\, P_{EC-R}$$

Where P EC-R is the eddy current loss factor under rated conditions.

The *K* factor3 commonly found in power quality literature concerning transformer derating can be defined solely in terms of the harmonic
currents as follows:

$$K = \frac{\sum (I_h^2 \times h^2)}{\sum I_h^2}$$

Then, in terms of the *K* factor, the rms of the distorted current is derived to be

$$\sqrt{\sum I_h^2} = \sqrt{\frac{1 + P_{EC-R}}{1 + K \times P_{EC-R}}} \quad \text{(pu)}$$

where P_{EC-R} = eddy current loss factor
h = harmonic number
I_h = harmonic current

Thus, the transformer derating can be estimated by knowing the perunit eddy current loss factor. This factor can be determined by

1. Obtaining the factor from the transformer designer
2. Using transformer test data and the procedure in ANSI/IEEE Standard C57.110
3. Typical values based on transformer type and size

Impact on motors and generators

- Motors can be significantly impacted by the harmonic voltage distortion.
- Harmonic voltage distortion at the motor terminals is translated into harmonic fluxes within the motor.
- Harmonic fluxes do not contribute significantly to motor torque, but rotate at a frequency different than the rotor synchronous frequency, basically inducing high-frequency currents in the rotor.
- The effect on motors is similar to that of negative-sequence currents at fundamental frequency: The additional fluxes do little more than induce additional losses.
- Decreased efficiency along with heating, vibration, and high-pitched noises are indicators of harmonic voltage distortion.
- At harmonic frequencies, motors can usually be represented by the blocked rotor reactance connected across the line. The lower-order harmonic voltage components, for which the magnitudes are larger and the apparent motor impedance lower, are usually the most important for motors.

- Motors appear to be in parallel with the power system impedance with respect to the harmonic current flow and generally shift the system resonance higher by causing the net inductance to decrease.

- Whether this is detrimental to the system depends on the location of the system resonance prior to energizing the motor.
- Motors also may contribute to the damping of some of the harmonic components depending on the *X*/*R* ratio of the blocked rotor circuit.
- In systems with many smaller-sized motors, which have a low *X*/*R* ratio, this could help attenuate harmonic resonance.

Impact on energy and demand metering

- Harmonic currents from nonlinear loads can impact the accuracy of watt-hour and demand meters adversely.
- Traditional watt-hour meters are based on the induction motor principle.
- The rotor element or the rotating disk inside the meter revolves at a speed proportional to the power flow.
- This disk in turn drives a series of gears that move dials on a register.
- Conventional magnetic disk watt hour meters tend to have a negative error at harmonic frequencies.
- That is, they register low for power at harmonic frequencies if they are properly calibrated for fundamental frequency.
- This error increases with increasing frequency.
- In general, nonlinear loads tend to inject harmonic power back onto the supply system and linear loads absorb harmonic power due to the distortion in the voltage.

$$P_{\text{measured}} = P_1 - a_3P_3 - a_5P_5 - a_7P_7 - \cdots$$

- where $a3$, $a5$, and $a7$ are multiplying factors (1.0) that represent the inaccuracy of the meter at harmonic frequency.
- The measured power is a little greater than that actually used in the load because the meter does not subtract off quite all the harmonic powers.
- However, these powers simply go to feed the line and transformer losses, and some would argue that they should not be subtracted at all.
- That is, the customer injecting the harmonic currents should pay something additional for the increased losses in the power delivery system.
- In the case of the linear load, the measured power is

$$P_{measured} = P_1 + a_3 P_3 + a_5 P_5 + a_7 P_7 + \cdots$$

Fundamentals of Harmonics 219

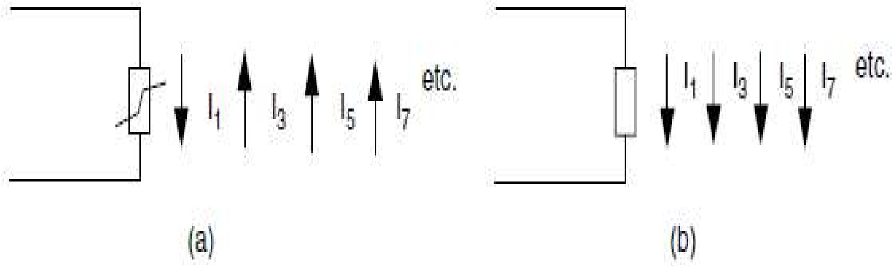
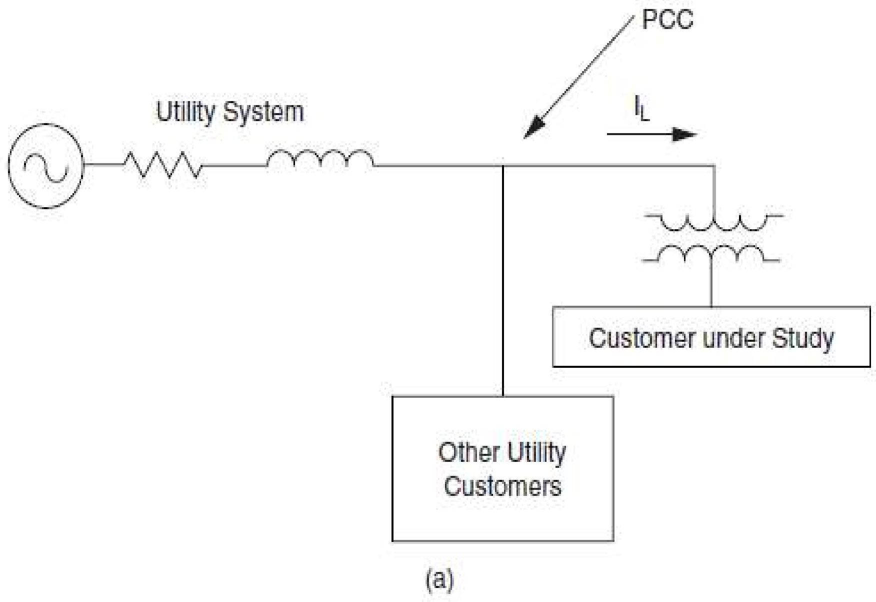


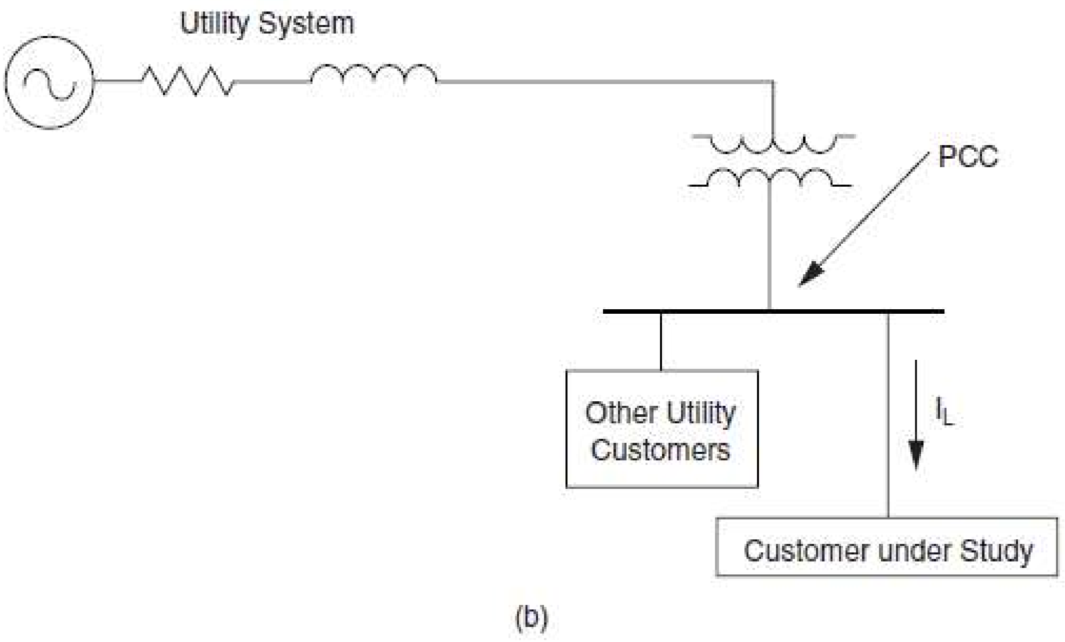
Figure 5.37 Nominal direction of harmonic currents in (*a*) nonlinear load and (*b*) linear load (voltage is distorted).

- Point of common coupling



PCC selection depends on where multiple customers are served.
(*a*) PCC at the transformer primary where multiple customers are served.

- 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



PCC at the transformer secondary where multiple customers are served

- when the primary of the transformer is the PCC, current measurements for verification can still be performed at the transformer secondary.
- The measurement results should be referred to the transformer high side by the turns ratio of the transformer, and the effect of transformer connection on the zero-sequence components must be taken into account.
- For instance, a delta-wye connected transformer will not allow zero-sequence current components to flow from the secondary to the primary system. These secondary components will be trapped in the primary delta winding.
- Therefore, zero-sequence componentsmeasured on the secondary side would not be included in the evaluation for a PCC on the primary side.

- Passive and active filtering

- **Passive filters** are inductance, capacitance, and resistance elements configured and tuned to control harmonics.

- They are commonly used and are relatively inexpensive compared with other means for eliminating harmonic distortion. However, they have the disadvantage of potentially interacting adversely with the power system, and it is important to check all possible system interactions when they are designed.

- They are employed either to shunt the harmonic currents off the line or to block their flow between parts of the system by tuning the elements to create a resonance at a selected frequency.

Shunt passive filters.

- The most common type of passive filter is the single-tuned “notch” filter.
- This is the most economical type and is frequently sufficient for the application.
- The notch filter is series-tuned to present a low impedance to a particular harmonic current and is connected in shunt with the power system.
- Thus, harmonic currents are diverted from their normal flow path on the line through the filter.
- 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.
- Passive filters should always be placed on a bus where the short-circuit reactance *X*SC can be expected to remain constant.
- While the notch frequency will remain fixed, the parallel resonance will move with system impedance.
- filters must be designed with the capacity of the bus in mind.
- The temptation is to size the current-carrying capability based solely on the load that is producing the harmonic.

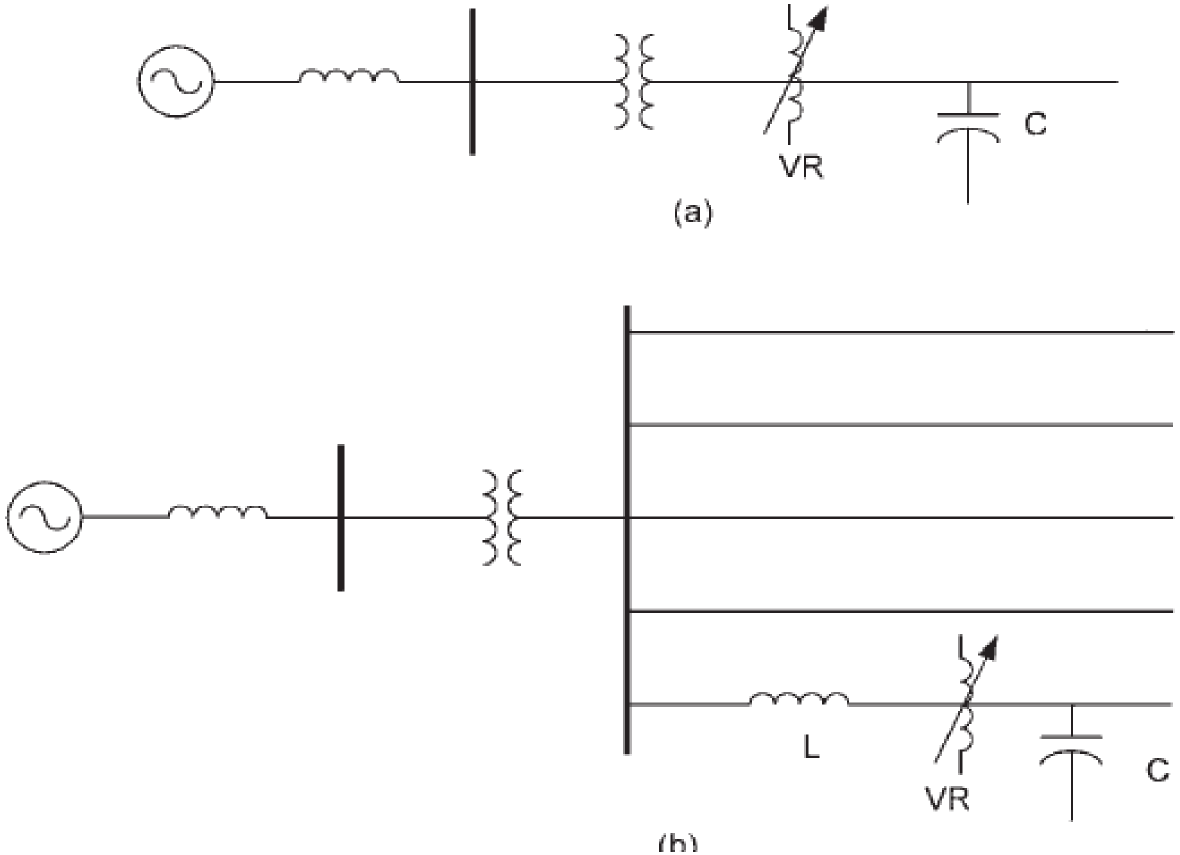
Series passive filters.

Unlike a notch filter which is connected in shunt with the power system, a series passive filter is connected in series with the load.

- The inductance and capacitance are connected in parallel and are tuned to provide a high impedance at a selected harmonic frequency.
- The high impedance then blocks the flow of harmonic currents at the tuned frequency only.
- At fundamental frequency, the filter would be designed to yield a low impedance, thereby allowing the fundamental current to follow with only minor additional impedance and losses.
- Series filters are used to block a single harmonic current (such as the third harmonic) and are especially useful in a single-phase circuit.
- The use of the series filters is limited in blocking multiple harmonic currents.

- Each harmonic current requires a series filter tuned to that harmonic.

- This arrangement can create significant losses at the fundamental frequency. Furthermore, like other series components in power systems, a series filter must be designed to carry a full rated load current and must have an overcurrent protection scheme. Thus, series filters are much less commonly applied than shunt filters.



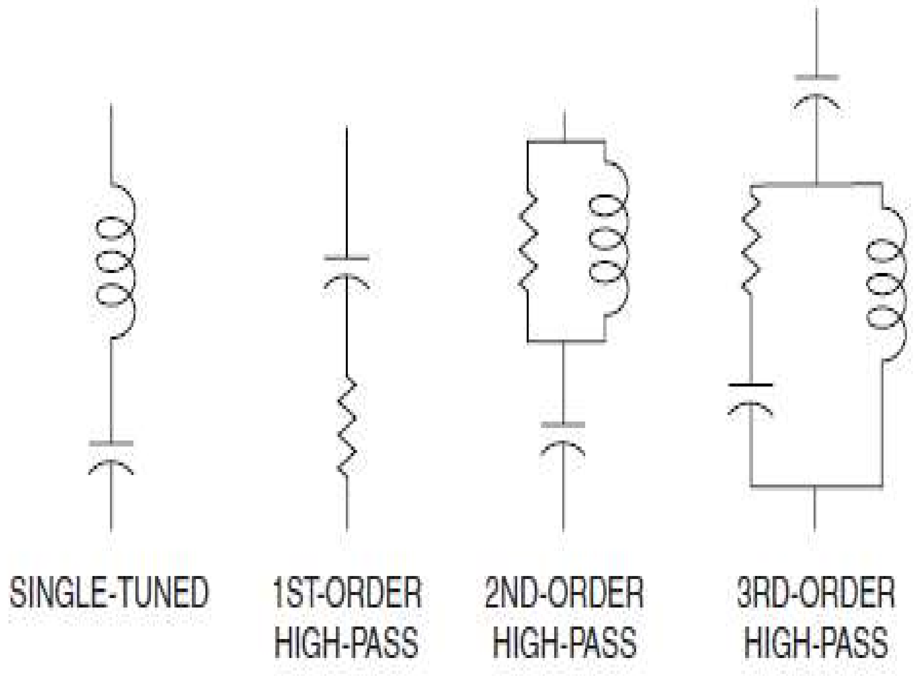


Figure 6.12 Common passive filter configurations.

Active filters

Active filters are relatively new types of devices for eliminating harmonics.

- They are based on sophisticated power electronics and are much more expensive than passive filters. However, they have the distinct advantage that they do not resonate with the system.

- Active filters can work independently of the system impedance characteristics.

- Thus, they can be used in very difficult circumstances where passive filters cannot operate successfully because of parallel resonance problems.
- They can also address more than one harmonic at a time and combat other power quality problems such as flicker.
- They are particularly useful for large, distorting loads fed from relatively weak points on the power system.

- The basic idea is to replace the portion of the sine wave that is missing in the current in a nonlinear load.

- An electronic control monitors the line voltage and/or current, switching the power electronics very precisely to track the load current or voltage and force it to be sinusoidal.

there are two fundamental approaches:

- one that uses an inductor to store current to be injected into the system at the appropriate instant and one that uses a capacitor.
- Therefore, while the load current is distorted to the extent demanded by the nonlinear load, the current seen by the system is much more sinusoidal.
- Active filters can typically be programmed to correct for the power factor as well as harmonics.

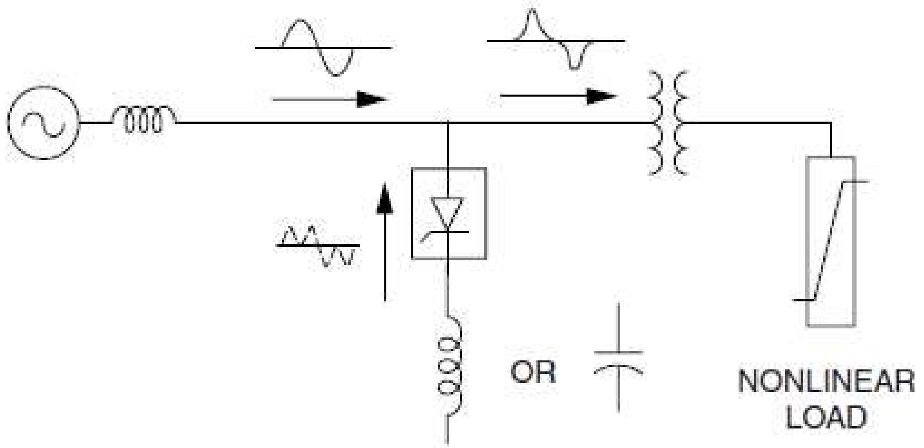


Figure 6.25 Application of an active filter at a load.

Harmonic Filter Design:

1. Select a tuned frequency for the filter.
2. Compute capacitor bank size and the resonant frequency.
3. Compute filter reactor size.
4. Evaluate filter duty requirements.
5. Computation of fundamental duty requirements.
6. Computation of harmonic duty requirements.
7. Evaluate total rms current and peak voltage requirements.
8. Evaluate capacitor rating limits.
9. Evaluate filter frequency response.
10. Evaluate the effect of filter parameter variations within specified tolerance.

Do follow the

- Feed back link
- Assignment link
- Leave the Class properly
- Once you completed those follow next class link

- Despite the situation don't stop yourself from learning
- Practice social distance stay home safe learn stay healthy .
- #Adityans #Stay Home #Stay Safe #Keep Learning
  #Qurantine Days #Online #Classes

THANK YOU
WE WILL CONTINUE IN NEXT CLASS

ADITYA COLLEGE OF ENGINEERING & TECHNOLOGY

Unit–V :Monitoring and Instrumentation

By

PRABHA RANI.K

Dept of ELECTRICAL AND ELECTRONICS and Engineering

Aditya College of Engineering & Technology

Surampalem.

- A quick review on what we discussed in last class
- Today's Discussion on

Unit–VI :Monitoring and Instrumentation

- Power quality monitoring and considerations
- Historical perspective of PQ measuring instruments
- PQ measurement equipment
- Assessment of PQ measuring data
- Application of intelligent systems
- PQ monitoring standards

Power quality monitoring and considerations

.

- Power quality monitoring is the process of gathering, analyzing, and interpreting raw measurement data into useful information.
- The process of gathering data is usually carried out by continuous measurement of voltage and current over an extended period.

MONITORING CONSIDERATION

The monitoring objectives often determine the choice of monitoring equipment, triggering thresholds, methods for data acquisition and storage, and analysis and interpretation requirements.

Several common objectives of power quality monitoring are summarized here

Monitoring to characterize specific problems

Monitoring as part of an enhanced power quality service

Monitoring as part of predictive or just-in-time maintenance

Monitoring as part of a facility site survey

Monitoring to characterize specific problems

- Many power quality service departments or plant managers solve problems by performing short-term monitoring at specific customer sites or at difficult loads
- This is a reactive mode of power quality monitoring, but it frequently identifies the cause of equipment incompatibility, which is the first step to a solution.

Monitoring as part of an enhanced power quality service

- Many power producers are currently considering additional services to offer customers.
- One of these services would be to offer differentiated levels of power quality to match the needs of specific customers.
- A provider and customer can together achieve this goal by modifying the power system or by installing equipment within the customer‘s premises.

Monitoring as part of an enhanced power quality service

- Many power producers are currently considering additional services to offer customers.
- One of these services would be to offer differentiated levels of power quality to match the needs of specific customers.
- A provider and customer can together achieve this goal by modifying the power system or by installing equipment within the customer‘s premises.
- In either case, monitoring becomes essential to establish the bench marks for the differentiated service and to verify that the utility achieves contracted levels of power quality.

Monitoring as part of predictive or just-in-time maintenance

- Power quality data gathered over time can be analyzed to provide information relating to specific equipment performance
- Equipment maintenance can be quickly ordered to avoid catastrophic failure, thus preventing major power quality disturbances which ultimately will impact overall powerquality performance
- The monitoring program must be designed based on the appropriate objectives, and it must make the information available in a convenient form and in a timely manner(i.e. Immediately).
- The most comprehensive monitoring approach will be a permanently installed monitoring system with automatic collection of information about steady-state power quality conditions and energy use as well as disturbances

Monitoring as part of a facility site survey

- Site surveys are performed to evaluate concerns for power quality and equipment performance throughout a facility.
- The survey will include inspection of wiring and grounding concerns, equipment connections, and the voltage and current characteristics throughout the facility
- The initial site survey should be designed to obtain as much information as possible about the customer facility.

1. Nature of the problems (data loss, nuisance trips, component failures, control system malfunctions, etc.)

2. Characteristics of the sensitive equipment experiencing problems (equipment design information or at least application guide information)

3. The times at which problems occur

4. Coincident problems or known operations (e.g., capacitor switching) that occur at the same time

5. Possible sources of power quality variations within the facility (motor starting, capacitor switching, power electronic equipment operation, arcing equipment, etc.)

6. Existing power conditioning equipment being used

7. Electrical system data (one-line diagrams, transformer sizes and impedances, load information, capacitor information, câble data, etc.)

Determining what to monitor

- The range of conditions that must be characterized creates challenges both in terms of the monitoring equipment performance specifications and in the data-collection requirements

- The priorities for monitoring should be determined based on the objectives of the effort.

- Projects to benchmark system performance should involve a reasonably complete monitoring effort.

- Projects designed to evaluate compliance with IEEE Standard 519-1992 for harmonic distortion levels may only require steady-state monitoring of harmonic levels.

- Other projects focused on specific industrial problems may only require monitoring of rms variations, such as voltage sags.

Choosing monitoring locations

monitoring may be prohibitively expensive and there are challenges in data management, analysis, and interpretation.
Fortunately, taking measurements from all possible locations is usually not necessary since measurements taken from several strategic locations can be used to determine characteristics of the overall system.

Thus, it is very important that the monitoring locations be selected carefully based on the monitoring objectives.

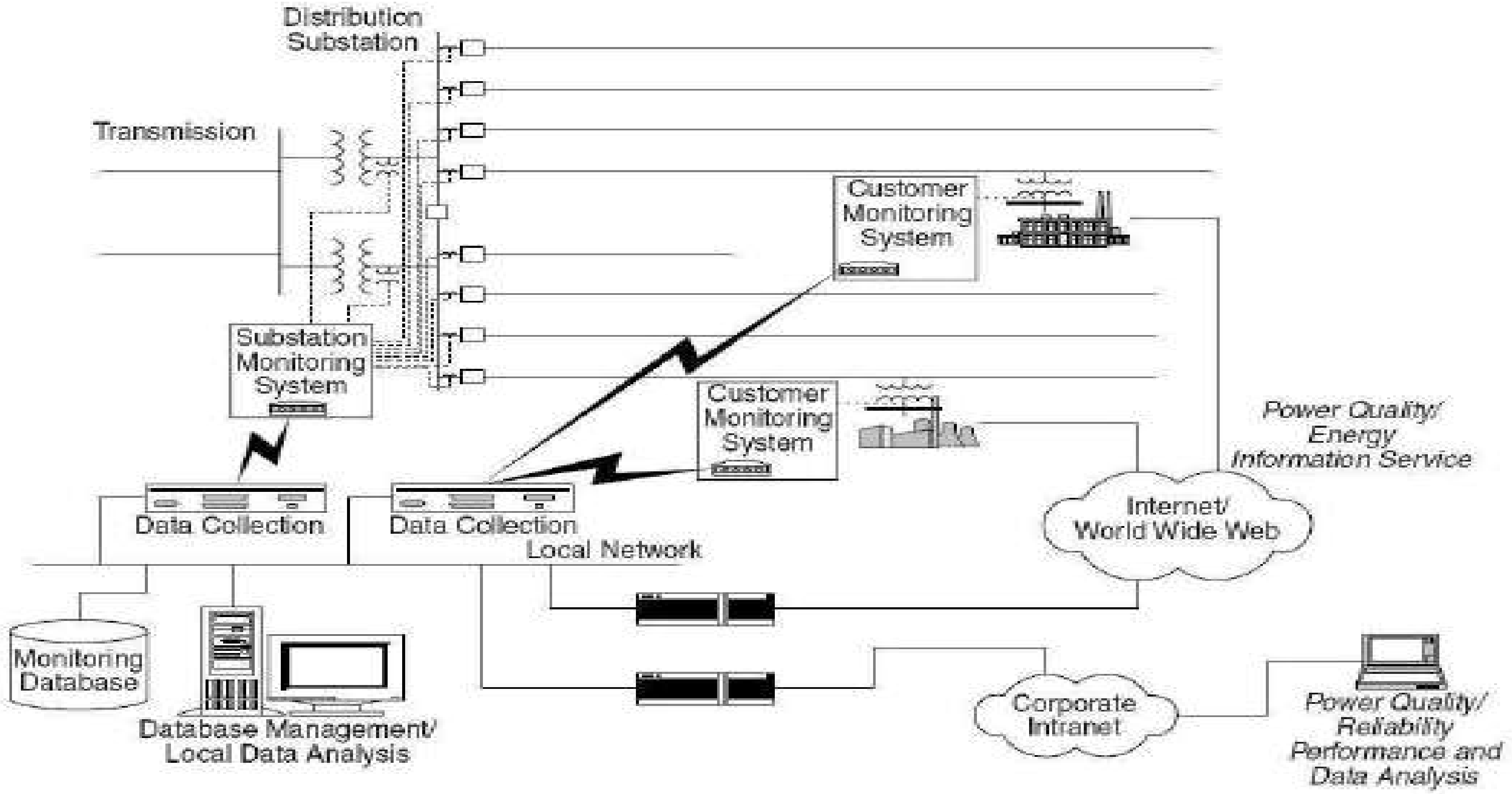


Figure 5.1 Illustration of system power quality monitoring concept with monitoring at the substation and selected customer locations.

Options for permanent power quality monitoring equipment

Digital fault recorders (DFRs) DFR will typically trigger on fault events and record the voltage and current waveforms that characterize the event. This makes them valuable for characterizing rms disturbances, such as voltage sags, during power system faults.

Smart relays and other IEDs

Many types of substation equipment may have the capability to be an intelligent electronic device (IED) with monitoring capability.

Voltage recorders

Typically, the voltage recorder provides a trend that gives the maximum, minimum, and average voltage within a specified window.

In-plant power monitors.

Capabilities usually include wave shape capture for evaluation of harmonic distortion levels, voltage profiles for steady-state rms variations, and triggered wave shape captures for voltage sag conditions.

- Historical perspective of PQ measuring instruments

- Significant development on power quality devices was not made until the 1960s when Martzloff developed a surge counter that could capture a voltage waveform of lightning strikes

- By the mid-1960s, limitations of power quality devices relating to the trigger mechanism and the preset frequency response were well understood.

- In the mid-1970s when Dranetz Engineering Laboratories (now Dranetz-BMI) introduced the Series 606 power line disturbance analyser.

- This was a microprocessor based monitor-analyzer first manufactured in 1975, and many units are still in service.

- Second-generation power quality instruments debuted in the mid- 1980s. This generation of power quality monitors generally featured full graphic display and digital memory to view and store captured power quality events, including both transients and steady-state events.

- By the mid-1990s, the third-generation power quality instruments emerged. The development of the third-generation power monitors was inspired in part by the EPRI DPQ project. This generation of monitors was more appropriate as part of a complete power quality monitoring system, and the software systems to collect and manage the data were also developed.

1. Managing the large volume of raw measurement data that must be collected, analyzed, and archived becomes a serious challenge as the number of monitoring points grows.

2. The data volume collected at each monitoring point can strain communication mechanisms employed to move that data from monitor to analysis point.

3. As understanding of system performance grows through the feedback provided by the monitoring data, detailed views of certain events, such as normal capacitor switching, become less valuable and would be of more use in a summary or condensed form.

4. The real value of any monitoring system lies in its ability to generate information rather than in collecting and storing volumes of detailed raw data.

- PQ measurement equipment

Types of instruments

Although instruments have been developed that measure a wide variety of disturbances, a number of different instruments may be used, depending on the phenomena being investigated. Basic categories of instruments that may be applicable include

■ Wiring and grounding test devices

■ Multimeters

■ Oscilloscopes

■ Disturbance analyzers

■ Harmonic analyzers and spectrum analyzers

■ Combination disturbance and harmonic analyzers

■ Flicker meters

■ Energy monitors

Besides these instruments, which measure steady-state signals or disturbances on the power system directly, there are other instruments that can be used to help solve power quality problems by measuring ambient conditions:

1. Infrared meters can be very valuable in detecting loose connections and overheating conductors. An annual procedure of checking the system in this manner can help prevent power quality problems due to arcing, bad connections, and overloaded conductors.

2. Noise problems related to electromagnetic radiation may require measurement of field strengths in the vicinity of affected equipment. Magnetic gauss meters are used to measure magnetic field strengths for inductive coupling concerns. Electric field meters can measure the strength of electric fields for electrostatic coupling concerns.

3. Static electricity meters are special-purpose devices used to measure static electricity in the vicinity of sensitive equipment. Electrostatic discharge (ESD) can be an important cause of power quality problems in some types of electronic equipment.

Regardless of the type of instrumentation needed for a particular test, there are a number of important factors that should be considered when selecting the instrument.
Some of the more important factors include

- Number of channels (voltage and/or current)
- Temperature specifications of the instrument
- Ruggedness of the instrument
- Input voltage range (e.g., 0 to 600 V)
- Power requirements
- Ability to measure three-phase voltages
- Input isolation (isolation between input channels and from each input to ground)
- Ability to measure currents
- Housing of the instrument (portable, rack-mount, etc.)
- Ease of use (user interface, graphics capability, etc.)
- Documentation
- Communication capability (modem, network interface)

Wiring and grounding testers:

- Many power quality problems reported by end users are caused by problems with wiring and/or grounding within the facility.
- These problems can be identified by visual inspection of wiring, connections, and panel boxes and also with special test devices for detecting wiring and grounding problems.
- Important capabilities for a wiring and grounding test device include
- Detection of isolated ground shorts and neutral-ground bonds
- Ground impedance and neutral impedance measurement or indication
- Detection of open grounds, open neutrals, or open hot wires
- Detection of hot/neutral reversals or neutral/ground reversals

After initial tests of wiring integrity, it may also be necessary to make quick checks of the voltage and/or current levels within a facility.
Overloading of circuits, under voltage and overvoltage problems, and unbalances between circuits can be detected in this manner.

These measurements just require a simple multi meter. Signals used to check

For these include

- Phase-to-ground voltages
- Phase-to-neutral voltages
- Neutral-to-ground voltages
- Phase-to-phase voltages (three-phase system)
- Phase currents

Neutral currents

The most important factor to consider when selecting and using a multimeter is the method of calculation used in the meter.

calculate the rms value. The three most common methods are

1. Peak method.

Assuming the signal to be a sinusoid, the meter reads the peak of the signal and divides the result by 1.414 (square root of 2) to obtain the rms.

2. Averaging method.

The meter determines the average value of a rectified signal. For a clean sinusoidal signal (signal containing only one frequency), this average value is related to the rms value by a constant.

3. True rms.

The rms value of a signal is a measure of the heating that will result if the voltage is impressed across a resistive load. One method of detecting the true rms Value is to actually use a thermal detector to measure a heating value. More modern digital meters use a digital calculation of the rms value by squaring the signal on a sample by-sample basis, averaging over the period, and then taking the square root of the result.

Disturbance analysers

- They typicallycan measure a wide variety of system disturbances from very short duration transient voltages to long-duration outages or under voltages.
- Thresholds can be set and the instruments left unattended to record disturbances over a period of time

There are basically two categories of these devices:

1. Conventional analyzers that summarize events with specific information such as overvoltage and under voltage magnitudes, sags and surge magnitude and duration, transient magnitude and duration, etc.

2. Graphics-based analyzers that save and print the actual waveform along with the descriptive information which would be generated by one of the conventional analyzers

Spectrum analyzers and harmonic analyzers

Harmonic analyzers have several capabilities. They capture harmonic waveforms and display them on a screen.
They calculate the K factor to de rate transformers and the total harmonic distortion (THD) in percent of the fundamental.

They also measure the corresponding frequency spectrum, i.e., the harmonic frequency associated with the current and voltage up to the fiftieth harmonic.

They display the harmonic frequency on a bar graph or as the signal‘s numerical values.

harmonic measurement requirements will demand an instrument that is designed for spectral analysis or harmonic analysis.

Important capabilities for useful harmonic measurements include Capability to measure both voltage and current simultaneously so that harmonic power flow information can be obtained.

- Capability to measure both magnitude and phase angle of individual harmonic Components (also needed for power flow calculations).

- Synchronization and a sampling rate fast enough to obtain accurate measurement of harmonic components up to at least the 37th harmonic (this requirement is a combination of a high sampling rate and a sampling interval based on the 60-Hz fundamental).

- Capability to characterize the statistical nature of harmonic distortion levels (harmonics levels change with changing load conditions and changing system conditions).

There are basically three categories of instruments to consider for harmonic analysis:

Simple meters.

General-purpose spectrum analyzers.

Special-purpose power system harmonic analyzers.

Simple meters.

It may sometimes be necessary to make a quick check of harmonic levels at a problem location.

These devices generally use microprocessor-based circuitry to perform the necessary calculations to determine individual harmonics up to the 50th harmonic, as well as the rms, the THD, and the telephone influence factor (TIF).

Some of these devices can calculate harmonic powers (magnitudes and angles) and can upload stored waveforms and calculated data to a personal computer

General-purpose spectrum analyzers..

They are general signal analysis instruments.

The advantage of these instruments is that they have very powerful capabilities for a reasonable price since they are designed for a broader market than just power system applications.

The disadvantage is that they are not designed specifically for sampling power frequency waveforms and, therefore, must be used carefully to assure accurate harmonic analysis

Special-purpose power system harmonic analyzers.

Besides the general purpose spectrum analyzers just described, there are also a number of instruments and devices that have been designed specifically for power system harmonic analysis.

These are based on the FFT with sampling rates specifically designed for determining harmonic components in power signals.

They can generally be left in the field and include communications capability for remote monitoring.

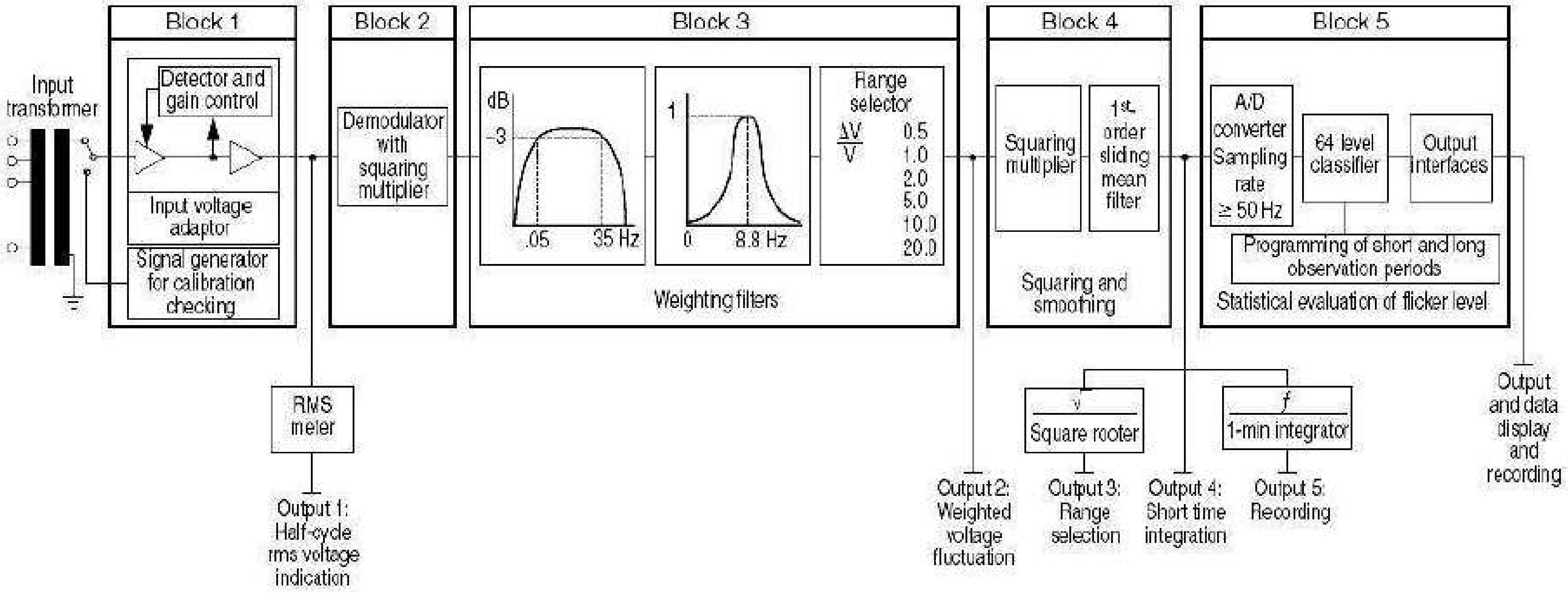


Figure 5.5 Diagram of the IEC flicker meter.

A flicker meter is essentially a device that demodulates the flicker signal, weights it according to established flicker curves, and performs statistical analysis on the processed data

- Generally, these meters can be divided up into three sections.
- In the first section the input waveform is demodulated, thus removing the carrier signal.
- As a result of the demodulator, a dc offset and higher-frequency terms (sidebands) are produced.
- The second section removes these unwanted terms using filters, thus leaving only the modulating (flicker) signal remaining.
- The second section also consists of filters that weight the modulating signal according to the particular meter specifications.
- The last section usually consists of a statistical analysis of the measured flicker

Block 1

an input voltage adapter that scales the input half-cycle rms value to an internal reference level. This allows flicker measurements to be made based upon a percent ratio rather than be dependent upon the input carrier voltage level.

Block 2

simply a squaring demodulator that squares the input to separate the voltage fluctuation (modulating signal) from the main voltage signal (carrier signal), thus simulating the behavior of the incandescent lamp.

Block 3

consists of multiple filters that serve to filter out unwanted frequencies produced from the demodulator and also to weight the input signal according to the incandescent lamp eye-brain response. The basic transfer function for the weighting filter is

$$H(s) = \frac{k\omega_1 s}{s^2 + 2\lambda s + {\omega_1}^2} \cdot \frac{1 + s/\omega_2}{(1 + s/\omega_3)(1 + s/\omega_4)}$$

Block 4

consists of a squaring multiplier and sliding mean filter. The voltage signal is squared to simulate the nonlinear eye-brain response, while the sliding mean filter averages the signal to simulate the short-term storage effect of the brain. The output of this block is considered to be the instantaneous flicker level. A level of 1 on the output of this block corresponds to perceptible flicker.

Block 5

consists of a statistical analysis of the instantaneous flicker level. The output of block 4 is divided into suitable classes, thus creating a histogram. A probability density function is created based upon each class, and from this a cumulative distribution function can be formed.

- Flicker level evaluation can be divided into two categories, short term and long-term.
- Short-term evaluation of flicker severity PST is based upon an observation period of 10 min.
- This period is based upon assessing disturbances with a short duty cycle or those that produce continuous fluctuations. PST can be found using the equation

$$P_{ST} = \sqrt{0.0314P_{0.1} + 0.0525P_{1s} + 0.0657P_{3s} + 0.28P_{10s} + 0.08P_{50s}}$$

where the percentages P0.1, P1s, P3s, P10s, and P50s are the flicker levels that are exceeded 0.1, 1.0, 3.0, 10.0, and 50.0 percent of the time, respectively.

These values are taken from the cumulative distribution curve discussed previously. A PST of 1.0 on the output of block 5 represents the objectionable (or irritable) limit of flicker

For cases where the duty cycle is long or variable, such as in arc furnaces, or disturbances on the system that are caused by multiple loads operating simultaneously, the need for the long-term assessment of flicker severity arises.

Therefore, the long term flicker severity PLT is derived from PST using the equation

$$P_{\mathrm{LT}} = \sqrt[3]{\frac{\sum_{i=1}^{N} P_{\mathrm{ST}i}^{3}}{N}}$$

where N is the number of PST readings and is determined by the duty cycle of the flicker-producing load.

- Application of intelligent systems
- Many advanced power quality monitoring systems are equipped with either offline or on-line intelligent systems to evaluate disturbances and system conditions so as to make conclusions about the cause of the problem or even predict problems before they occur.
- The applications of intelligent systems or autonomous expert systems in monitoring instruments help engineers determine the system condition rapidly.
- This is especially important when restoring service following major disturbances.
- **Basic design of an expert system for monitoring applications**
- The development of an autonomous expert system calls for many approaches such as signal processing and rule-based techniques along with the knowledge discovery approach commonly known as data mining

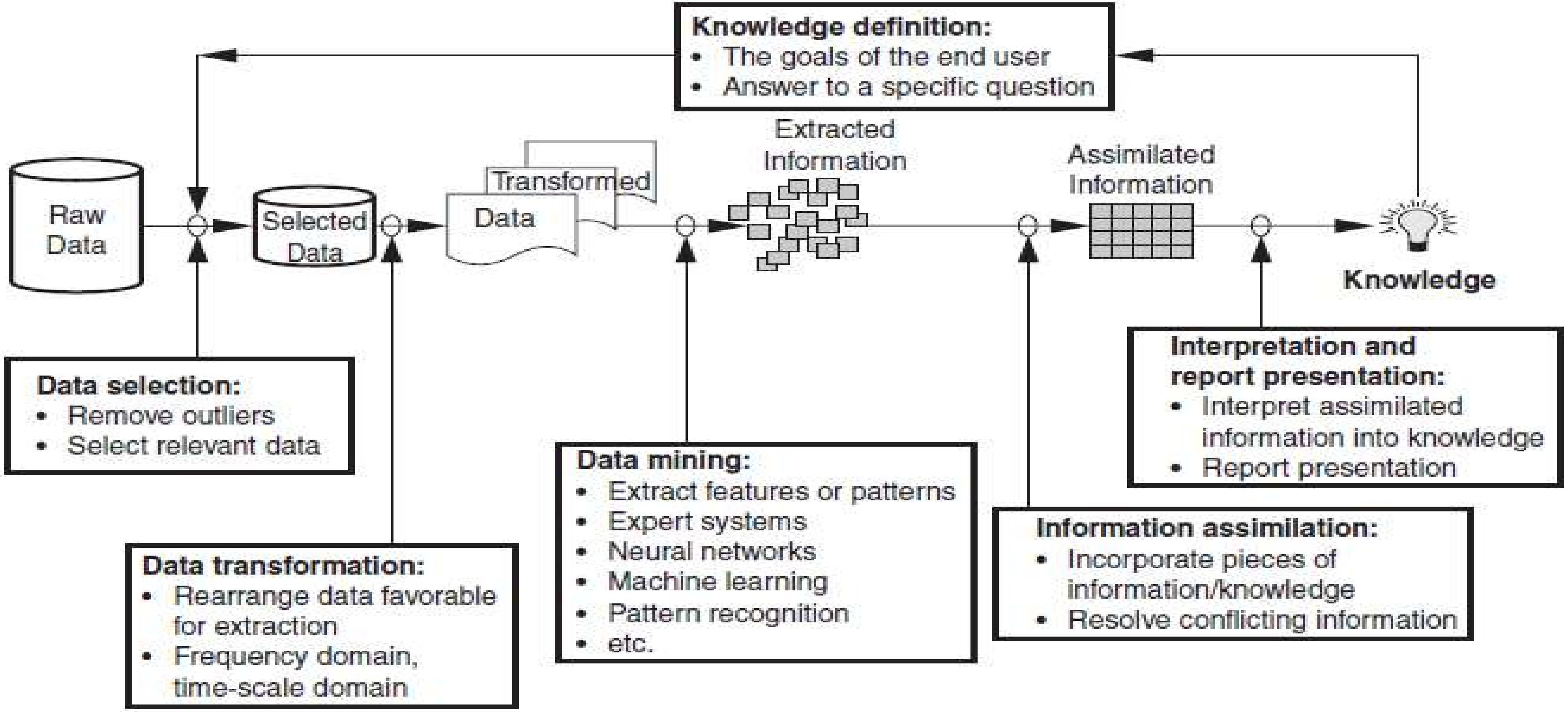


Figure 11.30 Process of turning raw data into answers or knowledge.

- The process of turning raw measurement data into knowledge involves data selection and preparation, information extraction from selected data, information assimilation, and report presentation.

- These steps are commonly known as knowledge discovery or data mining.

- The first step in the knowledge discovery is to select appropriate measurement quantities and disregard other types of measurement that do not provide relevant information.

- In addition, during the data selection process preliminary analyses are usually carried out to ensure the quality of the measurement. For example, an expert system module is developed to retrieve a specific answer, and it requires measurements of instantaneous three-phase voltage and current waveforms to be available

- The second step attempts to represent the data and project them onto domains in which a solution is more favorable to discover. Signal-processing techniques and power system analysis are applied.

- An example of this step is to transform data into another domain where the information might be located.

- The Fourier transform is performed to uncover frequency information for steady-state signals, the wavelet transform is performed to find the temporal and frequency information for transient signals, and other transforms may be performed as well.

- The last step in the chain is interpretation of knowledge and report presentation.

Example applications of expert systems

- **Voltage sag direction module,**
- **Radial fault locator module.**
- **Capacitor-switching operation inspection module**.
- **Lightning correlation module**.

There are many applications for the intelligent power quality monitoring concept.
Some of the more important applications are listed in this section.

- Energy and demand profiling with identification of opportunities for energy savings and demand reduction
- Harmonics evaluations to identify transformer loading concerns, sources of harmonics, problems indicating mis operation of equipment (such as converters), and resonance concerns associated with power factor correction
- Voltage sag impacts evaluation to identify sensitive equipment and possible opportunities for process ride-through improvement
- Power factor correction evaluation to identify proper operation of capacitor banks, switching concerns, resonance concerns, and optimizing performance to minimize electric bills
- Motor starting evaluation to identify switching problems, inrush current concerns, and protection device operation
- Short-circuit protection evaluation to evaluate proper operation of protective devices based on short-circuit current characteristics, time-current curves, et

Power Quality Monitoring Standards

IEC 61000-4-30: ***Testing and Measurement Techniques—Power Quality Measurement Methods***

IEEE 1159: Guide for power qualitymonitoring

- Class A performance is for measurements where very precise accuracy is required.
- Two instruments that comply with the requirements of class A should give the same results (within the specified levels of accuracy) for any of the types of power quality variations considered.
- These instruments could be appropriate for laboratories or for special applications where highly precise results are required.

- Class B performance still indicates that the recommended procedures for characterizing power quality variations are used but that the exact accuracy requirements may not be met.

- These instruments are appropriate for most system power quality monitoring (surveys, troubleshooting, characterizing performance, etc.).

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