CONTENTS

REE-081 : Introduction to Power Quality & FACTS

1
UNIT

Introduction

CONTENTS

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PART-1

Terms and Definitions of Transients, Long Duration Voltage Variations : Over Voltage, Under Voltage, and Sustained Interruptions.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.1. **What is power quality ? Discuss the parameters that define the quality of electrical power. Explain the term "Good Power Quality".**

AKTU 2014-15, Marks 05

Answer

A. Power quality :

1. Power quality is a measure of the electrical network or grid to provide "clean" and stable power. A characteristic of good electric power quality is the steady voltage supply where the frequency of the supply remains close the rated value.
2. "Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.

B. Parameter :

i. **Voltage :** The voltage must be sinusoidal, constant and within limits.
ii. **Current :** The current must be sinusoidal, constant and within limits.
iii. **Frequency :** The frequency must be constant and within limits.

C. Good power quality : If the voltage :

1. Has a constant sine wave shape with fundamental frequency only.
2. Is supplied at constant frequency.
3. Forms a symmetrical three-phase power system.
4. Has a constant RMS value and unchanged over time.
5. Is unaffected by load changes.
6. Is reliable, *i.e.*, energy available when required.

Que 1.2. **What would be the impact of "poor power quality" on system efficiency, reliability and operation?**

AKTU 2014-15, Marks 05

Answer

1. Poor power quality can negatively impact large industrial complexes, data centers, sensitive medical machinery, or impact small businesses and even households in a number of ways.
2. It can reduce the speed of production in businesses, it can damage sensitive equipment, and it can effect efficiency and increase costs.
3. Bad power quality also results in increased energy consumption which isn't good for either homeowners or business people.

Que 1.3. **What are the objectives of standardization of power quality phenomena ? State and explain important standard used to define and classify power quality disturbances.**

AKTU 2014-15, Marks 05

Answer

A. **Objectives of power quality :** Refer Q. 1.1, Page 1–2A, Unit-1.

B. **Standards for power quality disturbances :**

IEEE 644	Standard procedure for measurement of power frequency electric and magnetic fields from AC power lines
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 1159	Recommended practice for monitoring electric power quality
IEEE 141	Recommended practice for electric power distribution for industrial plants
IEEE 241	Recommended practice for electric power systems in commercial buildings
IEEE C57.110	Recommended practice for establishing transformer capability when supplying nonsinusoidal load.
IEEE P1453	Voltage flicker
IEEE P1564	Voltage sag indices

Que 1.4. **What are different types of electrical transients that occur in power system ?**

AKTU 2018-19, Marks 10

AKTU 2016-17, Marks 10

OR

What is transient disturbance ? How many types of transients are present ? Discuss each type by giving suitable examples.

AKTU 2014-15, Marks 05

Answer

A. **Transient disturbance :**

1. The term transient usually originates from electric circuit theory where it describes voltage and current variation from its present steady state to next steady state.
2. In the power system, the term transient is usually used in a different way. It denotes abrupt change in voltage and current for short duration.
3. Usually for duration less than the period of power system voltage and current signal (50-60 Hz).

B. **Transients can be classified into two categories :**

1. **Impulsive transient :**

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

b. Impulsive transients are normally characterized by their rise and decay times, which can also be revealed by their spectral content.

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

d. Current impulsive transient caused by lightning stroke shown in Fig. 1.4.1.

e. Impulsive have three categories spectral content :

i. Nanosecond – 5 ns rise

ii. Microsecond – 14 μs rise

iii. Millisecond – 0.1 ms rise

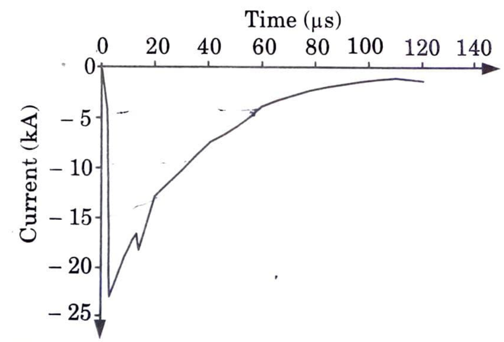


Fig. 1.4.1. Impulsive transient due to lighting stroke current.

2. **Oscillatory transient :**

a. 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 polarity values.

b. An oscillatory transient consists of a voltage or current whose instantaneous value changes polarity rapid. It is described by its spectral content, duration and magnitude.

c. Oscillatory transient current caused by back-to-back capacitor switching shown in Fig. 1.4.2.

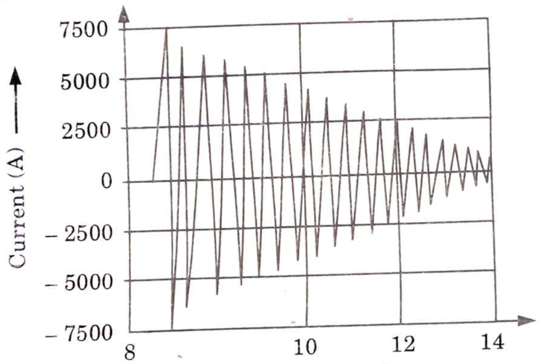


Fig. 1.4.2. Oscillatory transient caused due to back-to-back capacitor switching.

d. Medium frequency transient can also be the result of a system response to an impulsive transient.

e. Oscillatory have three categories :

i. Low frequency – < 5 kHz

ii. Medium frequency – 5 to 500 kHz

iii. High frequency – 0.5 to 5 MHz

Que 1.5. **Write a technical note on the following :**

i. CBEMA curves.

ii. IEEE 519 standard.

Answer

i. CBEMA curves.

1. One of the most frequently employed display of data to represent the power quality is the called CBEMA curve.

2. A portion of the curve adapted from IEEE Standard 446 that we typically use in our analysis of power quality monitoring results is shown in Fig. 1.5.1.

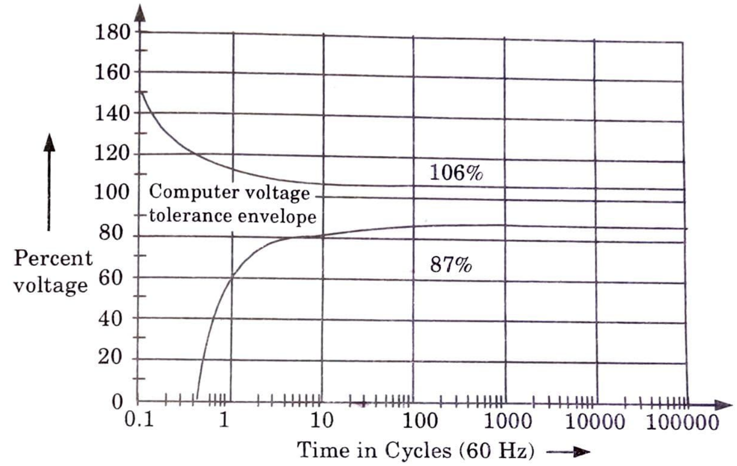


Fig. 1.5.1. A portion of the CBEMA curve commonly used as a design target for equipment and a format for reporting power quality variation data.

3. This curve was originally developed by CBEMA to describe the tolerance of mainframe computer equipment to the magnitude and duration of voltage variations on the power system.

4. While many modern computers have greater tolerance than this, the curve has become a standard design target for sensitive equipment to be applied on the power system and a common format for reporting power quality variation data.

5. The axes represent magnitude and duration of the event. Points below the envelope (in Fig. 1.5.2) are presumed to cause the load to drop out due to lack of energy.

6. Points above the envelope are presumed to cause other malfunctions such as insulation failure, overvoltage trip, and overexcitation.

ii. IEEE 519 standard :

1. IEEE 519 is intended to limit the negative impact of non-linear power system loads.

2. IEEE 519 provides a standard method to measure current harmonics and voltage harmonics and sets recommended guidelines for power system harmonics.

3. Current or voltage distortion levels as determined through simulation are compared with the recommended limit outline in IEEE standard 519–1992.

Que 1.6. **Explain long duration voltage variation with suitable example.**

AKTU 2017-18, Marks 10

OR

Define overvoltage and undervoltage. Also explain different causes of the overvoltage and undervoltage in power systems.

AKTU 2018-19, Marks 10

Answer

A. Overvoltage : An overvoltage is an increase in the rms AC voltage greater than 110 percent at the power frequency for duration longer than 1 min.

a. Cause of overvoltage :

1. Overvoltages are usually the result of load switching (e.g., switching OFF a large load or energizing a capacitor bank).
2. The overvoltages result because either the system is too weak for the desired voltage regulation or voltage controls are inadequate.
3. Incorrect tap settings on transformers can also result in system overvoltages.

B. Undervoltage : An undervoltage is a decrease in the rms AC voltage to less than 90 percent at the power frequency for duration longer than 1 min.

b. Cause of undervoltage :

1. Undervoltages are the result of switching events that are the opposite of the events that cause overvoltages.
2. A load switching ON or a capacitor bank switching OFF can cause an undervoltage until voltage regulation equipment on the system can bring the voltage back to within tolerances.

C. Sustained interruptions : When the supply voltage has been zero for a period of time in excess of 1 min, the long-duration voltage variation is also considered a sustained interruption.

PART-2

Short Duration Voltage Variations : Interruption, Sag, Swell, Voltage Imbalance, Notching DC Offset, Waveform Distortion, Voltage Fluctuation, Power Frequency Variations.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.7. **Define 'Interruption'. Give its causes.**

Answer

A. Interruption :

1. An interruption occurs when the supply voltage or load current decreases to less than 0.1 per unit for a period of time not exceeding 1 min.
2. The interruptions are measured by their duration since the voltage magnitude is always less than 10 % of nominal.
3. The duration of interruption due to a fault on the utility system is determined by the operating time of utility protective devices.
4. Instantaneous reclusion generally will limit the interruption caused by non-permanent fault to less than 30 cycles. Delayed reclosing of the protective device may cause a momentary or temporary interruption.

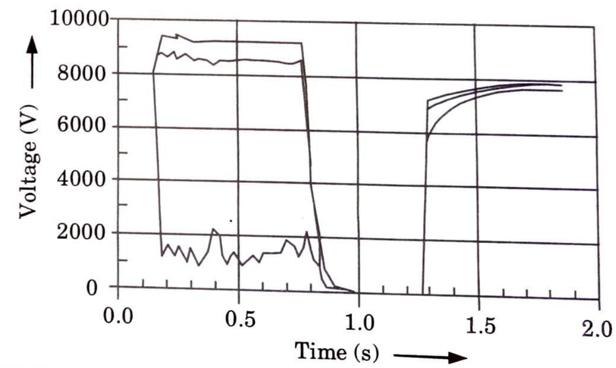


Fig. 1.7.1. Three-phase rms voltages for a **momentary interruption** due to a fault and subsequent recloser **operation.**

5. Fig. 1.7.1 shows a momentary interruption during which voltage on one phase sags to about 20 % for about 3 cycles and then drops to zero for about 1.8 sec until the recloser closes back.

B. Cause of interruption :

1. Power system faults
2. Equipment failure
3. Control malfunctions.

Que 1.8. **What are causes of interruptions ? How do short duration interruptions differ from sustained interruptions ? What is the importance of interruptions ?**

AKTU 2018-19, Marks 10

Answer

i. **Causes of interruptions :** Refer Q. 1.7, Page 1–7A, Unit-1.

ii. **Difference :**

Short duration interruption	Sustained interruption
Interruption of a few seconds is known as short duration interruption.	Interruption of more than a minute is known as sustained interruption.

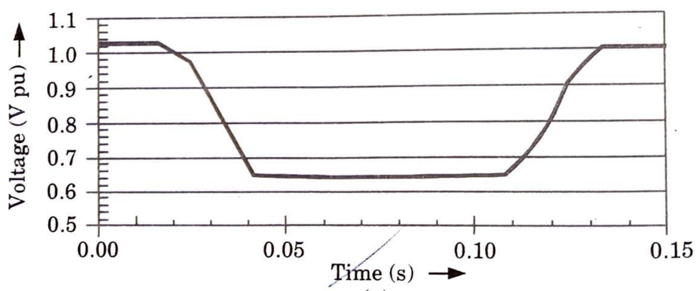
iii. **Importance :** Interruption may prevent accident as it cuts the supply for a while.

Que 1.9. **What is the meaning of voltage sag ? What are the causes of the voltage sag in a power system ?** **AKTU 2016-17, Marks 10**

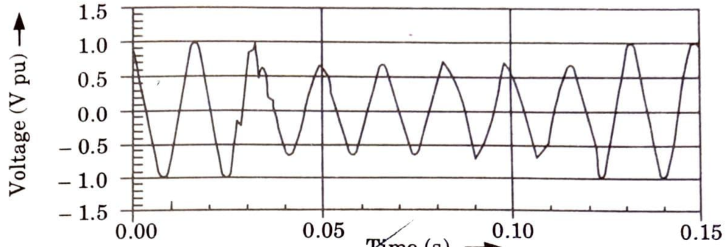
Answer

Voltage sag (Voltage drops) or Dips :

1. A sag is a decrease to between 0.1 and 0.9 per unit in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min.
2. The power quality community has used term sag a short-duration voltage decrease.
3. Voltage sags are usually associated with system faults but can also be caused by energization of heavy loads or starting of large motors.
4. Fig. 1.9.1(a) shows typical voltage sag that can be associated with a single line to ground (SLG) fault on another feeder from the same substation.
5. An induction motor will draw 6 to 10 times its full load current start up.
6. If current magnitude is large relative to that available for current in the system at that point the resulting voltage sag can be significant.



(a)



(b)

Fig. 1.9.1. Voltage sag caused by SLG, (a) RMS waveform voltage sag event, (b) voltage sag waveform.

Que 1.10. **How ferroresonant transformer can be used to handle voltage sag conditions ? Explain in detail.**

AKTU 2015-16, Marks 10

AKTU 2014-15, Marks 05

OR

With a typical ferro-resonant circuit diagram discuss, how a ferrous-resonant transformers handless voltages sag conditions.

AKTU 2018-19, Marks 10

Answer

Ferroresonant transformers :

1. Ferroresonant transformers, also called constant-voltage transformers (CVTs), can handle most voltage sag conditions.
2. CVTs are especially attractive for constant low-power loads.

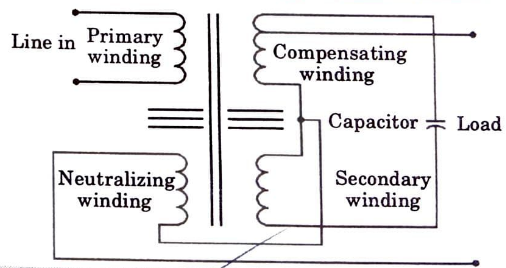


Fig. 1.10.1. Schematic of ferroresonant constant-voltage transformer.

3. Ferroresonant transformers are basically 1:1 transformers which are excited high on their saturation curves, thereby providing an output voltage which is not significantly affected by input voltage variations. A typical ferroresonant transformer schematic circuit diagram is shown in Fig. 1.10.1.

4. Fig. 1.10.2 shows the voltage sag ride-through improvement of a process controller fed from a 120-VA ferroresonant transformer. With the CVT, the process controller can ride through voltage sag down to 30 percent of nominal, as opposed to 82 percent without one.

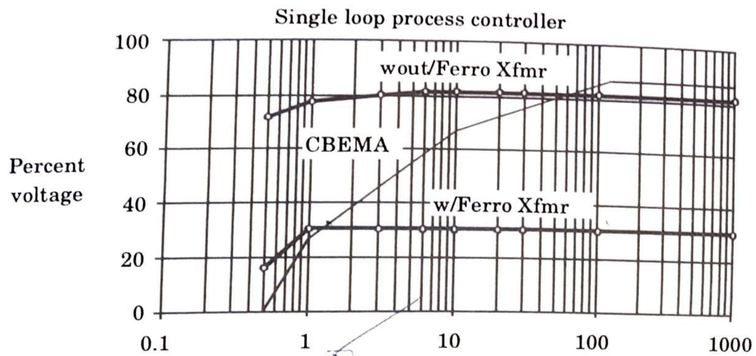


Fig. 1.10.2 Voltage sag improvement with ferroresonant transformer.

5. Ferroresonant transformers should be sized significantly larger than the load. Fig. 1.10.3 shows the allowable voltage sag as a percentage of nominal voltage (that will result in at least 90 percent voltage on the CVT output) versus ferroresonant transformer loading, as specified by one manufacturer.

6. At 25 percent of loading, the allowable voltage sag is 30 percent of nominal, which means that the CVT will output over 90 percent normal voltage as long as the input voltage is above 30 percent.

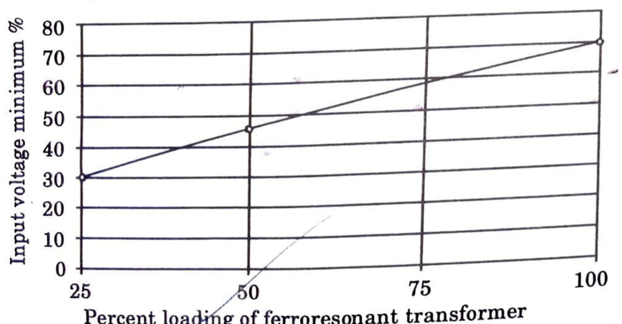


Fig. 1.10.3. Voltage sag versus ferroresonant transformer loading.

7. As the loading is increased, the corresponding ride-through capability is reduced, and when the ferroresonant transformer is overloaded (*e.g.*, 150 percent loading), the voltage will collapse to zero.

Que 1.11. **How voltage sags are caused by large motor starting ?**

AKTU 2014-15, Marks 05

Answer

1. Voltage sag produced by induction motor starting current is one of the main causes of sensitive equipment dropout.
2. An induction motor will draw six to ten times its full load current while starting. 6 to 10
3. This lagging current then causes a voltage drop across the impedance of the system.
4. Generally induction motors are balanced 3 phase loads, voltage sags due to their starting are symmetrical.
5. Each phase draws approximately the same inrush current. The magnitude of voltage sag depends on :
   a. Characteristics of the induction motor
   b. Strength of the system at the point where motor is connected.

Que 1.12. **Distinguish between voltage sag and undervoltage. Briefly discuss the techniques used for sag or dip mitigation.**

AKTU 2014-15, Marks 10

Answer

A. Difference between voltage sag and undervoltage :

S. No.	Voltage sag	Undervoltage
1.	**Definition :** A decrease in RMS voltage at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage.	**Definition :** An undervoltage is a decrease in the rms AC voltage to less than 90 percent at the power frequency for a duration longer than 1 min.
2.	**Cause :** i. Connection of heavy loads and start up of large motors. ii. Due to faults.	**Cause :** i. Poor system voltage regulation. ii. Load switched ON and power factor correction capacitor switched OFF.
3.	**Impact :** i. Tripping of sensitive equipment. ii. Resetting of control system.	**Impact :** Harmful for all equipment without back supply facilities.

B. Mitigation of voltage sag : There are many techniques used for mitigation of voltage sag :

a. Dynamic Voltage Restorer (DVR) :

1. The DVR is a series connected power electronic device used to inject voltage of required magnitude and frequency.

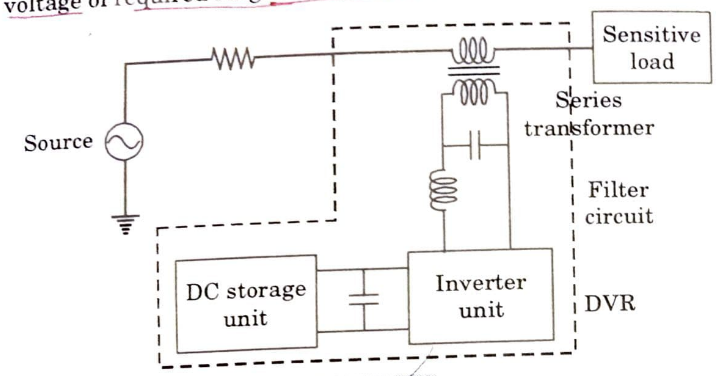


Fig. 1.12.1.

2. The nominal or rated voltage is compared with the voltage variation and the DVR injects the difference voltage that is required by the load.

b. DSTATCOM : DSTATCOM is a shunt connected device designed to regulate the voltage either by generating or absorbing the reactive power.

Basic structure :

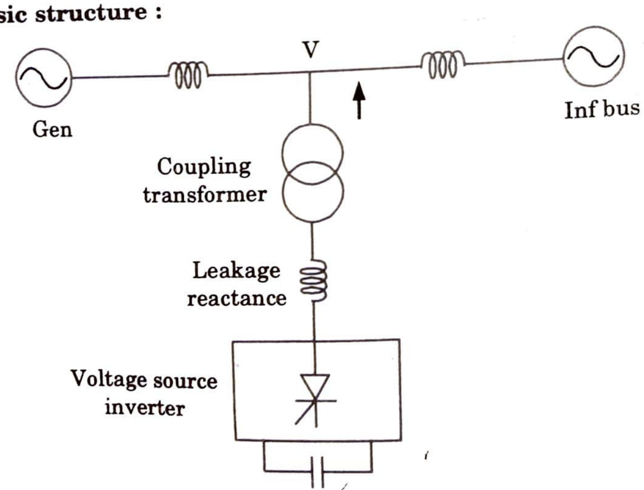


Fig. 1.12.2.

Operation of DSTATCOM : A DSTATCOM is capable of compensating either bus voltage or line current. It can operate in two modes based on the parameter which it regulates.

c. PWM switched auto-transformer : The auto-transformer is controlled by a PWM operated power electronic switch.

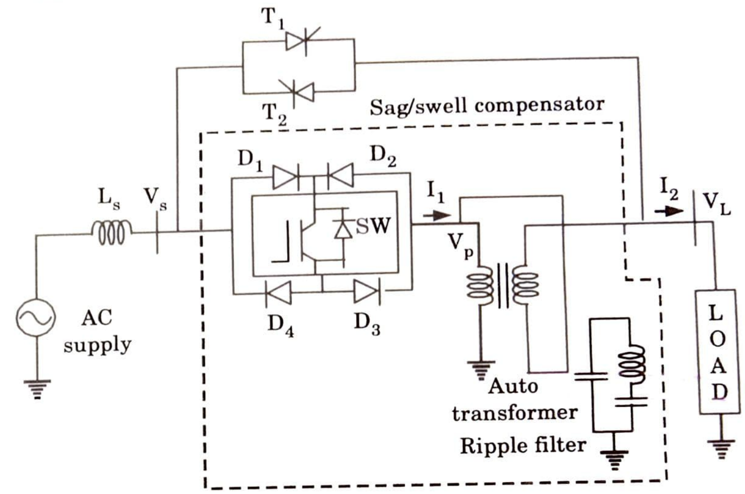


Fig. 1.12.3. Voltage sag mitigation scheme using auto transformer.

Que 1.13. **Explain the term voltage swell with suitable waveform.**

Answer

1. A swells is defined as an increase of between 1.1 and 1.8 per unit in rms voltage or current at the power frequency for duration from 0.5 cycle to 1 min.
2. As with sags, swells are usually associated with system fault conditions, but they are not as common as voltage sags.
3. A swells can occur is from the temporary voltage rise on the unfaulted phases during single line-to-ground (SLG) fault.
4. Swells can also caused by their switching OFF a large load or energizing a large capacitor bank.
5. Swells are characterized by their magnitude (rms value) and duration. The severity of a voltage swell during a fault condition is a function of the fault location, system impedance and grounding.
6. Fig. 1.13.1 illustrates a voltage swell caused by an SLG fault.

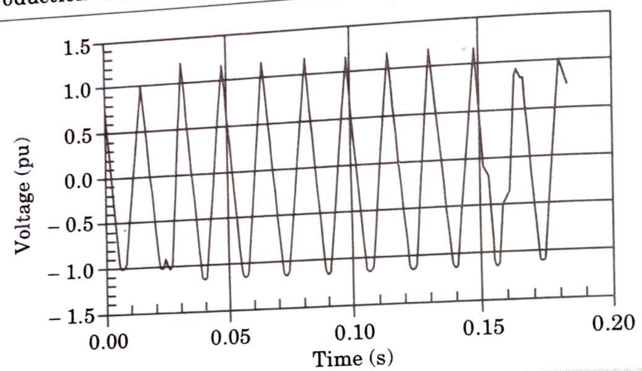


Fig. 1.13.1. Instantaneous voltage swell caused by an SLG fault.

Que 1.14. What is 'voltage imbalance' ?

Answer

1. Voltage imbalance is a condition in which the three-phase voltage differ in amplitudes or are displaced for their normal 120 degree phase relationship or both.
2. The ratio of the negative sequence or zero sequence voltage to the positive-sequence voltage in percent, known as voltage imbalance. Voltage imbalance also called voltage unbalance.
3. The primary source of voltage unbalance of is single-phase loads on a three-phase circuit.
4. Voltage unbalance can also be the result of blown fuses in one phase of a three-phase capacitor bank.

Que 1.15. Discuss the different types of waveform distortion.

AKTU 2016-17, Marks 10

OR

Explain the following types of waveform distortions :

A. DC offset
B. Interharmonic
C. Noise
D. Notching.

AKTU 2015-16, Marks 10

Answer

A. DC offset :

1. The presence of a DC voltage or current in an AC power system is termed DC offset. This can occur as the result of a geomagnetic disturbance or asymmetry of electronic power converters.

2. Direct current in AC networks can have a detrimental effect by biasing transformer cores so they saturate in normal operation.
3. This causes additional heating and loss of transformer life. Direct current may also cause the electrolytic erosion of grounding electrodes and other connectors.

B. Interharmonic :

1. Voltages or currents having frequency components that are not integer multiples of the frequency at which the supply system is designed to operate (e.g., 50 or 60 Hz) are called interharmonics.
2. They can appear as discrete frequencies or as a wideband spectrum.
3. Interharmonics can be found in networks of all voltage classes.
4. The main sources of interharmonic waveform distortion are static frequency converters, cycloconverters, induction furnaces, and arcing devices.
5. Power line carrier signals can also be considered as interharmonics.

C. Noise :

1. Noise is defined as unwanted electrical signals with broadband spectral content lower than 200 kHz superimposed upon the power system voltage or current in phase conductors, or found on neutral conductors or signal lines.
2. Noise in power systems can be caused by power electronic devices, control circuits, arcing equipment, loads with solid-state rectifiers, and switching power supplies.

D. Notching :

1. Notching is a periodic voltage disturbance caused by the normal operation of power electronic devices when current is commutated from one phase to another.
2. Since notching occurs continuously, it can be characterized through the harmonic spectrum of the affected voltage. However, it is generally treated as a special case.
3. The frequency components associated with notching can be quite high and may not be readily characterized with measurement equipment normally used for harmonic analysis.

Que 1.16. Distinguish between voltage flicker and voltage fluctuations. What are the main reasons of these problems ?

AKTU 2014-15, Marks 05

Answer

S. No.	Voltage fluctuations	Voltage flicker
1.	Voltage fluctuations are systematic variation of the voltage envelope or a series of random voltage changes the magnitude of which does not normally exceed the voltage range of 0.9 to 1.1 per unit.	The term flicker is derived from the impact of voltage fluctuation on lamps such that they are perceived by the human eye to flicker.
2.	Voltage fluctuation is an electromagnetic phenomenon.	Voltage flicker is an undesirable result of the voltage fluctuation in some load.

B. Reasons :

1. This is caused by an arc furnace, one of the most common causes of voltage fluctuations on utility transmission and distribution systems.
2. It can also be due to switching ON or OFF of heavy loads.

Que 1.17. **Write short note on**

i. Voltage imbalance
ii. Voltage fluctuations
iii. Power frequency variations.

AKTU 2018-19, Marks 10

Answer

i. **Voltage imbalance :** Refer Q. 1.14, Page 1–15A, Unit-1.

ii. **Voltage fluctuation :** Refer Q. 1.16, Page 1–16A, Unit-1.

iii. **Power frequency variations :**

1. Power frequency variations are defined as the deviation of the power system fundamental frequency from it specified nominal value (*e.g.*, 50 or 60 Hz).
2. The power system frequency is directly related to the rotational speed of the generators supplying the system. There are slight variations in frequency as the dynamic balance between load and generation changes.
3. The size of the frequency shift and its duration depends on the load characteristics and the response of the generation control system to load changes.

Que 1.18. **Explain the various types of power system disturbances and their impacts on power quality.**

AKTU 2015-16, Marks 10

Answer

A. **Power system disturbances :**

i. **Transients :** Refer Q. 1.4, Page 1–3A, Unit-1.

ii. **Interruption :** Refer Q. 1.7, Page 1–7A, Unit-1.

iii. **Voltage swell :** Refer Q. 1.13, Page 1–14A, Unit-1.

iv. **Voltage sag and undervoltage :** Refer Q. 1.12, Page 1–12A, Unit-1.

v. **Overvoltage :** Refer Q. 1.6, Page 1–6A, Unit-1.

vi. **Voltage fluctuations :** Refer Q. 1.16, Page 1–16A, Unit-1.

B. **Impact of power system disturbances :**

i. **Voltage sag and undervoltage :** Refer Q. 1.12, Page 1–12A, Unit-1.

ii. **Overvoltage :** Problems with equipment that requires constant steady-state voltage as overvoltage may damage or even burn the system.

iii. **Transients :**

1. Control system resetting
2. Damage to sensitive electronic components
3. Damage to insulation.

iv. **Voltage imbalance :**

1. Overheating in motors/generators
2. Interruption of 3-phase operation.

v. **Voltage fluctuation :**

1. Flicker in fluorescent lamps
2. Flicker in incandescent lamps.

Que 1.19. **State and explain different mitigation methods and operational measures to minimize the voltage disturbances of customer site.**

AKTU 2018-19, Marks 10

OR

What are the equipments needed to minimize the voltage disturbance ? Identify the location of these.

AKTU 2016-17, Marks 10

Answer

i. **Ferroresonant transformer :** Refer Q. 1.10, Page 1–10A, Unit-1.

ii. **Active series compensator :**

1. These are one of the new technologies using power electronic component that can boost the voltage by injecting a voltage in series with the remaining voltage during a voltage sag condition.

2. A one-line diagram illustrating the power electronics that are used to achieve the compensation is shown in Fig. 1.19.1.

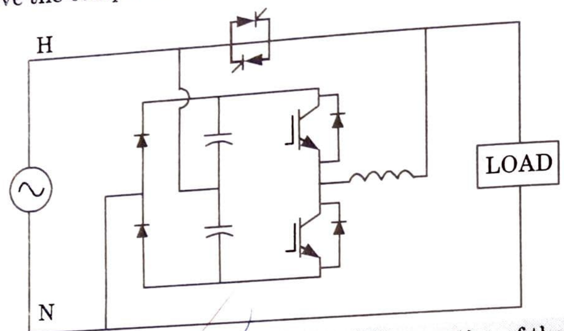


Fig. 1.19.1. Topology illustrating the operation of the active series compensator.

3. When a disturbance to the input voltage is detected, a fast switch opens and the power is supplied through the series-connected electronics.
4. This circuit adds or subtracts a voltage signal to the input voltage so that the output voltage remains within a specified tolerance during the disturbance.
5. The switch is very fast so that the disturbance seen by the load is less than a quarter cycle in duration. This is fast enough to avoid problems with almost all sensitive loads.
6. The circuit can provide voltage boosting of about 50 percent, which is sufficient for all voltage sag conditions.
7. They are available in size ranges from small single-phase devices (1 to 5 kVA) to very large devices that can be applied on the medium-voltage systems (2 MVA and larger).

iii. Magnetic synthesizers :

1. Magnetic synthesizers use a similar operating principle to CVTs except they are three-phase devices and take advantage of the three-phase magnetic to provide improved voltage sag support and regulation for three-phase loads.
2. They are applicable over a size range from about 15 to 200 kVA and are typically applied for process loads of larger computer systems where voltage sags or steady-state voltage variations are important issues.
3. A block diagram of the process is shown in Fig. 1.19.2. Energy transfer and line isolation are accomplished through the use of non-linear chokes. This eliminates problems such as line noise.

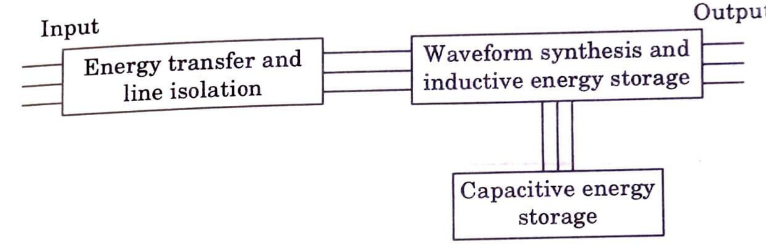


Fig. 1.19.2. Block diagram of magnetic synthesizer.

4. The waveform energy is stored in the saturated transformers and capacitors as current and voltage.

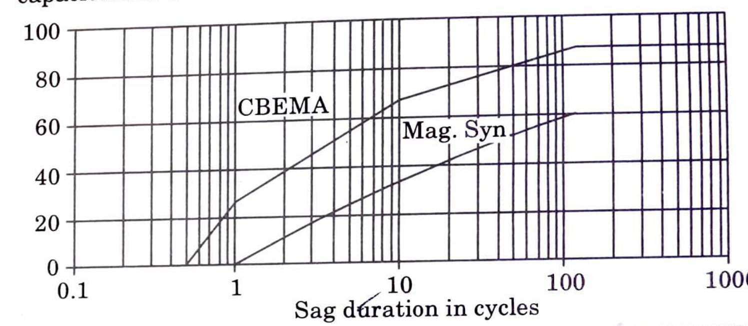


Fig. 1.19.3. Magnetic synthesizer voltage sag ride-through capability.

5. This energy storage enables the output of a clean waveform with little harmonic distortion. Finally, three-phase power is supplied through a zigzag transformer.
6. Figure 1.19.3 shows a magnetic synthesizer's voltage sag ride-through capability as compared to the CBEMA curve, as specified by one manufacturer.

Que 1.20. **What are major power quality issues ? Explain in detail.**

AKTU 2017-18, Marks 10

Answer

Power quality issues :

A. Power frequency disturbances :

1. These are low-frequency phenomena that result in voltage sags or swells.
2. These may be source or load generated due to faults or switching operations in a power system.

B. Power system transients :

1. These are fast, short-duration events that produce distortions such as notching, ringing, and impulse.

2. The mechanisms by which transient energy is propagated in power lines, transferred to other electrical circuits, and eventually dissipated are different from the factors that affect power frequency disturbances.

C. Power system harmonics :

1. These are low-frequency phenomena characterized by waveform distortion, which introduces harmonic frequency components.
2. Voltage and current harmonics have undesirable effects on power system operation and power system components.
3. In some instances, interaction between the harmonics and the power system parameters (R-L-C) can cause harmonics to multiply with severe consequence.

D. Electromagnetic interference :

1. EMI refers to the interaction between electric and magnetic fields and sensitive electronic circuits and devices.
2. EMI is predominantly a high-frequency phenomenon. The mechanism of coupling EMI to sensitive devices is different from that for power frequency disturbances and electrical transients.

E. Radio frequency interference :

RFI is the interaction between conducted or radiated radio frequency fields and sensitive data and communication equipment.

F. Power factor :

1. In some cases, low power factor is responsible for equipment damage due to component overload.
2. For the most part, power factor is an economic issue in the operation of a power system.

Que 1.21. **Discuss the common problems and their solutions related to power quality in wiring and grounding of electrical systems.**

AKTU 2014-15, Marks 10

Answer

A. Typical wiring and grounding problems : There are many problems with wiring and grounding which are discussed as :

a. Problems with conductors and connectors :

S. No.	Problem observed	Possible cause
1.	Burnt smell at the panel, junction box, or load equipment.	Faulted conductor, bad connection, arcing, or overloaded wiring.
2.	Panel or junction box is warm to the touch.	Faulty circuit breaker or bad connection.
3.	Buzzing (corona effect).	Arcing.
4.	Scorched insulation.	Overloaded wiring, faulted conductor, or bad connection.
5.	No voltage at load equipment.	Tripped breaker, bad connection, or faulted conductor.
6.	Intermittent voltage at load equipment.	Bad connection or arcing.
7.	Scorched panel or junction box.	Bad connection or faulted conductor.

b. Missing safety ground : If the safety ground is missing, a fault in the equipment from the phase conductor to the enclosure results in line potential on the exposed surfaces of the equipment. No breakers will trip, and a hazardous situation results.

c. Multiple neutral-to-ground connections :

1. Downline neutral-to-ground bonds result in parallel paths for the load return current where one of the paths becomes the ground circuit.
2. This can cause misoperation of protective devices. Also, during a fault condition, the fault current will split between the ground and the neutral, which could prevent proper operation of protective devices.

d. Ungrounded equipment : Isolated grounds are sometimes used due to the perceived notion of obtaining a "clean" ground.

e. Additional ground rods :

1. A portion of the lightning stroke current will flow on the building wiring (green ground conductor and/or conduit) to reach the additional ground rods.
2. This creates a possible transient voltage problem for equipment and a possible overload problem for the conductors.

f. Ground loops :

1. If two devices are grounded via different paths and a communication cable between the devices provides another ground connection between them, a ground loop results.

2. Slightly different potentials in the two power system grounds can cause circulating currents in this ground loop if there is indeed a complete path.
3. Even if there is not a complete path, the insulation that is preventing current flow may flash over because the communication circuit insulation levels are generally quite low.
4. Likewise, very low magnitudes of circulating current can cause serious noise problems.

B. Solutions to wiring and grounding problems :

a. Ground Electrode (rod) :

1. The ground rod provides the electrical connection from the power system ground to earth. The item of primary interest in evaluating the adequacy of the ground rod is the resistance of this connection.
2. The resistance of the ground-rod connection is important because it influences transient voltage levels during switching events and lightning transients.

b. Service entrance connections :

1. The primary components of a properly grounded system are found at the service entrance. The neutral point of the supply power system is connected to the grounded conductor (neutral wire) at this point.
2. This safety ground also provides a ground fault return path to the point where the power source neutral conductor is grounded.

c. Panel board :

1. It is important to note that there should not be a neutral-to-ground connection at the panel board. This neutral-to-ground connection is prohibited in the NEC as it would result in load return currents flowing in the ground path between the panel board and the service entrance.
2. In order to maintain an equipotential grounding system, the ground path should not contain any load return current. Also, fault currents would split between the neutral conductor and the ground return path. Protection is based on the fault current flowing in the ground path.

d. Isolated ground :

1. The noise performance of the supply to sensitive loads can sometimes be improved by providing an isolated ground to the load. This is done using isolated ground receptacles, which are orange in color.
2. If an isolated ground receptacle is being used downline from the panel board, the isolated ground conductor is not connected to the conduit or enclosure in the panel board, but only to the ground conductor of the supply feeder.

e. Separately derived systems :

1. Separately derived systems are used to provide a local ground reference for sensitive loads. The local ground reference can have significantly

reduced noise levels as compared to the system ground if an isolation transformer is used to supply the separately derived system.

2. An additional benefit is that neutral currents are localized to the load side of the separately derived system.
3. This can help reduce neutral current magnitudes in the overall system when there are large numbers of single-phase nonlinear loads.

Que 1.22. **What types of instruments are used for monitoring power quality ? Describe the applications of oscilloscope and spectrum analyzer for power quality monitoring.**

+ Reading

AKTU 2014-15, Marks 05

Answer

A. Power quality measurement equipment : Basic categories of instruments that may be applicable include :

1. Wiring and grounding test devices.
2. Multimeters.
3. Oscilloscopes.
4. Disturbance analyzers.
5. Harmonic analyzers and spectrum analyzers.
6. Combination disturbance and harmonic analyzers.
7. Flicker meters.
8. Energy monitors.

B. Oscilloscopes application : The common application of oscilloscope are below :

a. Power analysis : Oscilloscopes can be used to measure and analyze the operating characteristics of power conversion devices, circuits, and line-power harmonics.

b. Jitter analysis : Today, high-bandwidth circuits have extremely fast clocks and signals. Oscilloscopes are used to characterize and debug signal jitter as well as timing for clocks, clock-to-data and datastream analysis.

c. Data storage device testing : Oscilloscopes are used to test CD/DVD and disk drive designs by measuring disk performance, media noise and optical recording characteristics.

d. Time-domain reflectometry : Time Domain Reflectometry (TDR) is a way to measure impedance values and variations (such as faults) along transmission cables, cables connectors or microstrips on a circuit board.

C. **Application of spectrum analyzer :** Spectrum analyzers are used to obtain a wide variety of information from various kinds of signals, including the following :

i. Spectral purity of continuous wave (CW) signals.
ii. Percentage of modulation of amplitude modulated (AM) signals.
iii. Deviation of frequency modulated (FM) signals.
iv. Noise such as impulse and random noise.
v. Filter frequency response.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What is power quality ? Discuss the parameters that define the quality of electrical power. Explain the term "Good Power Quality".

Ans. Refer Q. 1.1.

Q. 2. What are the objectives of standardization of power quality phenomena ? State and explain important standard used to define and classify power quality disturbances.

Ans. Refer Q. 1.3.

Q. 3. What are different types of electrical transients that occur in power system ?

Ans. Refer Q. 1.4.

Q. 4. Define overvoltage and undervoltage. Also explain different causes of the overvoltage and undervoltage in power systems.

Ans. Refer Q. 1.6.

Q. 5. What are causes of interruptions ? How do short duration interruptions differ from sustained interruptions ? What is the importance of interruptions ?

Ans. Refer Q. 1.8.

Q. 6. With a typical ferro-resonant circuit diagram discuss, how a ferrous-resonant transformers handless voltages sag conditions.

Ans. Refer Q. 1.10.

Q. 7. Distinguish between voltage sag and undervoltage. Briefly discuss the techniques used for sag or dip mitigation.

Ans. Refer Q. 1.12.

Q. 8. Explain the following types of waveform distortions :
A. DC offset
B. Interharmonic
C. Noise
D. Notching.

Ans. Refer Q. 1.15.

Q. 9. Explain the various types of power system disturbances and their impacts on power quality.

Ans. Refer Q. 1.18.

Q. 10. State and explain different mitigation methods and operational measures to minimize the voltage disturbances of customer site.

Ans. Refer Q. 1.19.

☺☺☺

2

UNIT

Voltage Sag

CONTENTS

PART-1

Sources of Voltage Sag : Motor Starting, Arc Furnace, Fault Clearing etc.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.1. **What is voltage sag ? Explain motor starting and arc furnace.**

AKTU 2017-18, Marks 10

OR

Give the sources of voltage sag.

Answer

A. **Voltage sag :** Refer Q. 1.9, Page 1–9A, Unit-1.

B. **Sources of voltage sag :**

i. **Motor starting :**

1. Motors have the undesirable effect of drawing several times their full load current while starting.
2. This large current will (by flowing through system impedances) cause a voltage sag which may dim lights, cause contactors to dropout, and disrupt sensitive equipment.
3. The situation is made worse by an extremely poor starting displacement factor usually in the range of 15 to 30 percent.

ii. **Arc furnace :**

1. The voltage across an electric arc, which is relatively independent of current magnitude, consists of three components : anode drop, cathode drop and arc column component, which amounts to about 12 volts/cm of arc length.
2. The three basic changes in operating states of an electric arc furnace, which can produce distinguishable voltage disturbances on power system, are open circuit condition, short circuit condition and the normal operation.
3. Because of the non-linear resistance, an arc furnace acts as a source of current harmonics of the second to seventh order, especially during the meltdown period.
4. Voltage fluctuations are produced in this way through impedance on the value of harmonic currents supplied and the effective impedances at the harmonic frequencies.

Que 2.2. **How the fault clearing issues in voltage sag and interruption can be reduce ?**

Answer

1. Fault clearing practices have a great influence on the voltage sag and interruption performance at a distribution-connected load.
2. Fault prevention activities include tree trimming, adding line arresters, insulator washing, and adding animal guards. Insulation on utility lines cannot be expected to withstand all lightning strokes.
3. Tower footing resistance is an important factor in backflashowers from static wire to a phase wire.
4. If the tower footing resistance is high, the surge energy from a lightning stroke will not be absorbed by the ground as quickly.
5. On distribution feeders, shielding may also be an option as is placing arresters along the line frequently.
6. Of course, one of the main problems with overhead distribution feeders is that storms blow tree limbs into the lines. In areas where the vegetation grows quickly, it is a formidable task to keep trees properly trimmed.
7. Improved fault-clearing practices may include adding line reclosers, eliminating fast tripping, adding loop schemes, and modifying feeder design.
8. These practices may reduce the number and/or duration of momentary interruptions and voltage sags, but utility system faults can never be eliminated completely.
9. Therefore, the detection of faults and the clearing of the fault current must be done with the maximum possible speed without resulting in false operations for normal transient events.

PART-2

Estimating Voltage Sag Performance and Principle of Protection, Solution at End User Level-Isolation Transformer, Voltage Regulator, Static UPS, Rotary UPS and Active Series Compensator.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.3. **How to estimate the voltage sag performance ?**

OR

Write technical notes on any three of the following :

i. **Area of vulnerability.**
ii. **CBEMA curves.**
iii. **IEEE 519 standard.**
iv. **Disturbance at customer side.**
v. **Objectives of power quality monitoring.**

AKTU 2015-16, Marks 15

Answer

i. **CBEMA curves :** Refer Q. 1.5, Page 1–5A, Unit-1.

ii. **IEEE 519 standard :** Refer Q. 1.5, Page 1–5A, Unit-1.

iii. **Disturbance at customer side :**

a. **Over voltage :** Refer Q. 1.6, Page 1–6A, Unit-1.

b. **Under voltage :** Refer Q. 1.6, Page 1–6A, Unit-1.

iv. **Objectives of power quality monitoring :**

1. Power quality investigation often requires monitoring to identify the exact problem and to verify the solutions which are implemented.
2. Before embarking and extensive monitoring programs, it is important to develop and understanding of the customers facility, equipment being affected, wiring and grounding practices and operating considerations.
3. Often power quality problems can be solved without extensive monitoring by asking the right questions when talking to customer and performing an ideal site survey.

v. **There are various ways to estimate the voltage sag performance :**

A. **Area of vulnerability :**

1. The area of vulnerability is defined as the minimum voltage magnitude a piece of equipment can withstand or tolerate without misoperation or failure.
2. This is also known as the equipment voltage sag immunity or susceptibility limit. An area of vulnerability is determined by the total circuit miles of exposure to faults that can cause voltage magnitudes at an end-user facility to drop below the equipment minimum voltage sag ride-through capability.
3. Fig. 2.3.1 shows an example of an area of vulnerability diagram for motor contactor and adjustable-speed-drive loads at an end-user facility served from the distribution system.
4. The loads will be subject to faults on both the transmission system and the distribution system.
5. The actual number of voltage sags that a facility can expect is determined by combining the area of vulnerability with the expected fault

performance for this portion of the power system. The expected fault performance is usually determined from historical data.

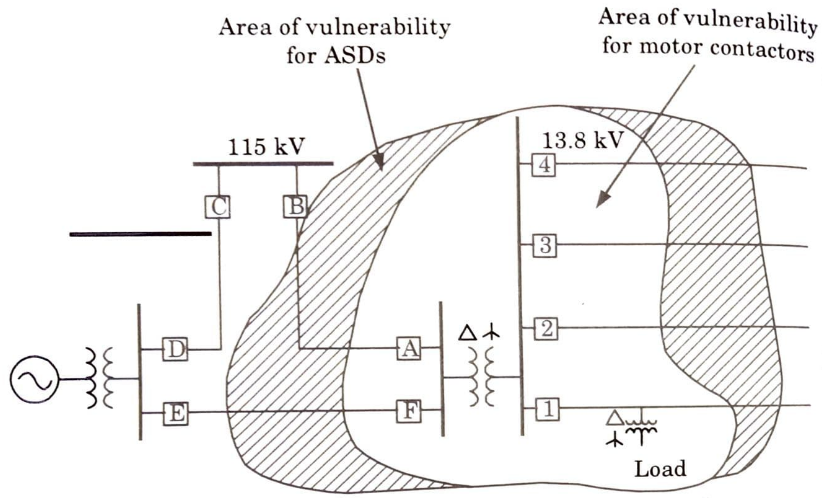


Fig. 2.3.1. Illustration of an area of vulnerability.

B. Equipment sensitivity to voltage sag :

1. Equipment within an end-user facility may have different sensitivity to voltage sags. Equipment sensitivity to voltage sags is very dependent on the specific load type, control settings, and applications.
2. Consequently, it is often difficult to identify which characteristics of a given voltage sag are most likely to cause equipment to misoperate.
3. The most commonly used characteristics are the duration and magnitude of the sag.
4. Other less commonly used characteristics include phase shift and unbalance, missing voltage, three-phase voltage unbalance during the sag event, and the point-in-the-wave at which the sag initiates and terminates.

C. Transmission system sag performance evaluation :

1. The voltage sag performance for a given customer facility will depend on whether the customer is supplied from the transmission system or from the distribution system.
2. For a customer supplied from the transmission system, the voltage sag performance will depend on only the transmission system fault performance.
3. On the other hand, for a customer supplied from the distribution system, the voltage sag performance will depend on the fault performance on both the transmission and distribution system.

4. Transmission line faults and the subsequent opening of the protective devices rarely cause an interruption for any customer because of the interconnected nature of most modern-day transmission networks.
5. These faults do, however, causes voltage sags. Depending on the equipment sensitivity, the unit may trip OFF, resulting in substantial monetary losses.
6. ASPEN (Advanced System for Power Engineering) programs can calculate the voltage throughout the system resulting from fault around the system. It is also calculate the area of vulnerability in the specific location.

D. Utility distribution system sag performance evaluation :

1. Customers that are supplied at distribution voltage levels are impacted by faults on both the transmission system and the distribution system.
2. The analysis at the distribution level must also include momentary interruptions caused by the operation of protective devices to clear the fault
3. Fig. 2.3.2 shows a typical distribution system with multiple feeders and fused branches, and protective devices. The utility protection scheme plays an important role in the voltage sag and momentary interruption performance.
4. The critical information needed to compute voltage sag performance can be summarized as follows :

i. Number of feeders supplied from the substation.
ii. Average feeder length.
iii. Average feeder reactance.
iv. Short-circuit equivalent reactance at the substation.

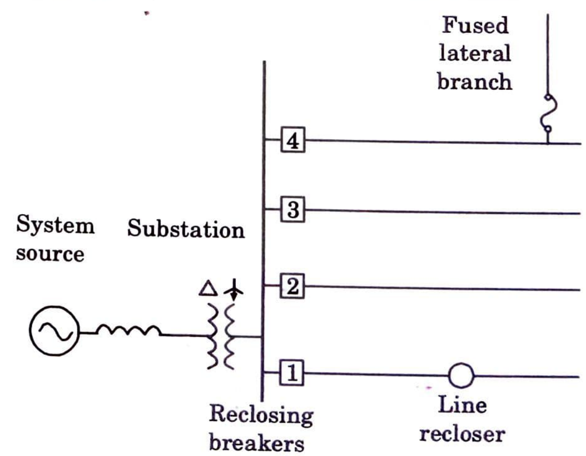


Fig. 2.3.2. Typical distribution system illustrating protection device.

Que 2.4. **Explain the working of different uninterruptable power supplies.**

AKTU 2018-19, Marks 10

OR

Explain the working of an online UPS with a detailed diagram. Also point out its superiority over offline UPS.

AKTU 2014-15, Marks 10

OR

With suitable block diagram, explain the working difference between "Online UPS" and "Offline UPS".

AKTU 2016-17, Marks 15

Answer

A. Online UPS :

The Fig. 2.4.1 shows a typical configuration of an Online UPS.

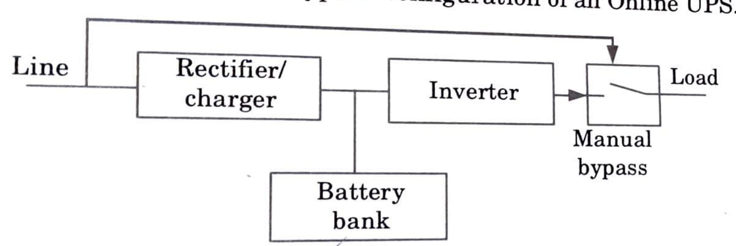


Fig. 2.4.1. Online UPS.

1. In this design, the load is always fed through the UPS.
2. 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.
3. If the incoming AC power fails, the inverter is fed from the batteries and continues to supply the load.
4. In addition to providing ride-through for power outages, an online UPS provides very high isolation of the critical load from all power line disturbances. However, the online operation increases the losses and may be unnecessary for protection of many loads.

B. Stand by UPS or Off-line UPS : A standby power supply is sometimes termed as Off-line UPS :

i. It is referred as Off-line, 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.

ii. The transfer time from the normal source to the battery-backed inverter is important.

iii. The CBEMA curve shows that 8 ms is the lower limit on interruption through for power conscious manufacturers. Therefore a transfer time of 4 ms would ensure continuity of operation for the critical load.

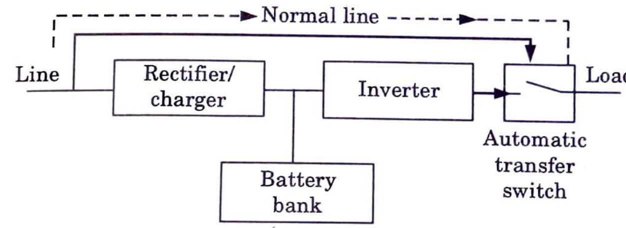


Fig. 2.4.2. Standby UPS.

iv. A standby power supply does not typically provide any transient protection or voltage regulation as does an Online UPS.

C. Hybrid UPS : Similar in design to the standby UPS, the hybrid UPS utilizes a voltage regulator on the UPS output to provide regulation to the load and momentary ride through when the transfers from normal to UPS supply is made.

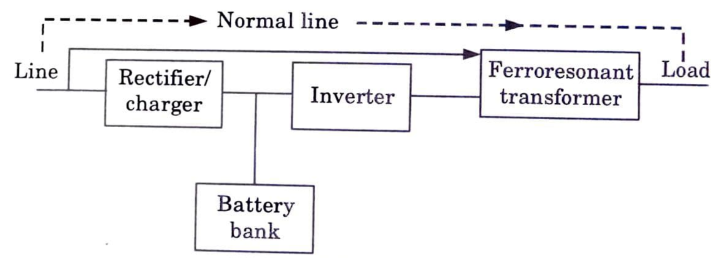


Fig. 2.4.3. Hybrid UPS.

Que 2.5. **Discuss the motor generator sets with the help of block diagram.**

Answer

A. M-G sets :

1. Motor-Generator (M-G) sets come in a wide variety of sizes and configurations. This is a mature technology that is still useful for isolating critical loads from sags and interruptions in the power system. The concept is very simple, as illustrated in Fig. 2.5.1.
2. A motor powered by the line drives a generator that powers the load. Flywheels on the same shaft provide greater inertia to increase ride through time.

3. When the line suffers a disturbance, the inertia of the machines and the flywheels maintains the power supply for several seconds.
4. This arrangement may also be used to separate sensitive loads from other classes of disturbances such as harmonic distortion and switching transients.

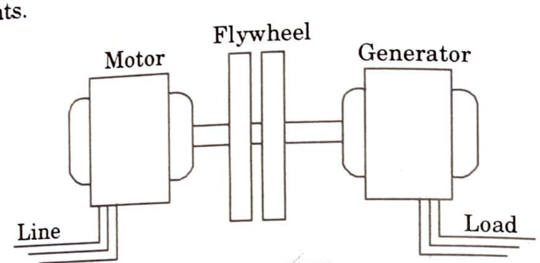


Fig. 2.5.1.

5. Another type of M-G set uses a special synchronous generator called a written-pole motor that can produce a constant 60-Hz frequency as the machine slows.
6. It is able to supply a constant output by continuously changing the polarity of the rotor's field poles. Thus, each revolution can have a different number of poles than the last one.
7. Constant output is maintained as long as the rotor is spinning at speeds between 3150 and 3600 revolutions per minute (rpm).
8. Flywheel inertia allows the generator rotor to keep rotating at speeds above 3150 rpm once power shuts OFF.
9. The rotor weight typically generates enough inertia to keep it spinning fast enough to produce 60 Hz for 15 s under full load.
10. Another means of compensating for the frequency and voltage drop while energy is being extracted is to rectify the output of the generator and feed it back into an inverter.
11. This allows more energy to be extracted, but also introduces losses and cost.

B. Disadvantages : While simple in concept, M-G sets have disadvantages for some types of loads :

a. There are losses associated with the machines, although they are not necessarily larger than those in other technologies.
b. Noise and maintenance may be issues with some installations.
c. The frequency and voltage drop during interruptions as the machine slows. This may not work well with some loads.

Que 2.6. **Discuss the working of active series compensator.**

AKTU 2016-17, Marks 10

OR

Explain active series compensator with neat diagram.

AKTU 2017-18, Marks 10

OR

Discuss the active series compensator and give its application.

Answer

A. Active series compensator : Refer Q. 1.19, Page 1–18A, Unit-1

B. Application :

1. Active synchronous series compensators (SSCs) are used to compensate the voltage quality problems of the supply system, such as sag, flicker, notch, swell, fluctuations, imbalance, and regulation.
2. They protect sensitive loads from interruptions, which cause loss of production and mal-operation of other critical equipment such as medical and healthcare systems.

Que 2.7. **What are series and shunt compensator ? Compare their role for power quality improvement.**

AKTU 2014-15, Marks 10

Answer

A. Series compensation :

1. Series compensation is the method of improving the system voltage by connecting a capacitor in series with the transmission line.
2. In other words, in series compensation, reactive power is inserted in series with the transmission line for improving the impedance of the system.
3. It improves the power transfer capability of the line. It is mostly used in extra and ultra high voltage line.

B. Shunt compensation :

1. In shunt compensation, FACTS are connected in parallel with the power system transmission line. It works as a controllable current source.
2. A reactive current is injected into the line to maintain constant voltage magnitude by varying shunt impedance.
3. Therefore, the transmittable active power is increased but at the expense of increasing the reactive power demand. There are two methods of shunt compensations :

a. Shunt capacitive compensation :

i. This method is used to improve the power factor. Whenever an inductive load is connected to the transmission line, power factor lags because of lagging load current.

ii. To compensate it, a shunt capacitor is connected, which draws current leading to the source voltage. The net result is improvement in power factor.

b. Shunt inductive compensation :

i. This method is used either when charging the transmission line or when there is very low load at the receiving end. Due to very low or no load, a very low current flows through the transmission line.

ii. Shunt capacitance in the transmission line causes voltage amplification (Ferranti effect). The receiving end voltage (V_r) may become double the sending end voltage (V_s) (generally in case of very long transmission lines). To compensate it, shunt inductors are connected across the transmission line.

Que 2.8. **What are the principle of voltage sag performance ? Given solution at end user level.**

AKTU 2017-18, Marks 10

Answer

A. Principle of voltage sag performance :

1. The voltage sag performance for a given customer facility will depend on whether the customer is supplied from the transmission system or from the distribution system.
2. For a customer supplied from the transmission system, the voltage sag performance will depend on only the transmission system fault performance.
3. On the other hand, for a customer supplied from the distribution system, the voltage sag performance will depend on the fault performance on both the transmission and distribution systems.

B. Solutions at the end-user level :

1. **Ferro-resonance transformer :** Refer Q. 1.10, Page 1–10A, Unit-1.
2. **Magnetic synthesizer :** Refer Q. 1.19, Page 1–18A, Unit-1.
3. **UPS :** Refer Q. 2.4, Page 2–7A, Unit-2.
4. **Super conducting magnetic energy storage (SMES) devices :**

a. An SMES device can be used to alleviate voltage sags and brief interruptions.

b. The energy storage in an SMES-based system is provided by the electric energy stored in the current flowing in a superconducting magnet. Since the coil is lossless, the energy can be released almost instantaneously.

c. Through voltage regulator and inverter banks, this energy can be injected into the protected electrical system in less than 1 cycle to compensate for the missing voltage during a voltage sag event.

d. A typical SMES system can protect loads of up to 8 MVA for voltage sags as low as 0.25 pu. It can provide up to 10 s of voltage sag ride-through depending on load size.

e. Fig. 2.8.1 shows an example where the grid voltage experiences a voltage sag of 0.6 pu for approximately 7 cycles.

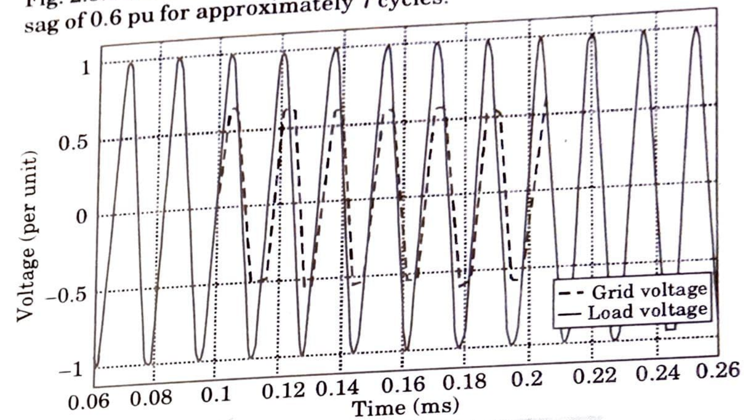


Fig. 2.8.1. SMES-based system **providing** ride-through during voltage sag event.

f. The SMES-based system has several advantages over battery-based UPS systems :

1. SMES-based systems have a much smaller footprint than batteries for the same energy storage and power delivery capability.
2. The stored energy can be delivered to the protected system more quickly.

Que 2.9. **Describe the rotary UPS with the help of block diagram.**

Answer

1. A typical rotary UPS is shown in Fig. 2.9.1. It consists of an AC motor, a DC machine, an AC generator, and a battery bank. Electric machines are mechanically coupled.
2. During the normal mode of operation, the AC line supplies the AC motor, which drives the DC machine.
3. The DC machine drives the AC generator, which supplies the load. During the stored energy mode of operation, the battery bank supplies the DC machine, which in turn drives the AC generator.
4. The AC generator supplies the load. The rotary UPS systems are more reliable than the static UPS systems.
5. However, they require more maintenance and have a much larger size and weight. But, they have many advantages making them desirable in high power applications.
6. One of the advantages of the rotary UPS systems is that the transient overload capability is 300 to 600 % of the full load for rapid fault clearing.

7. The transient overload capability for the static UPS systems is typically 150 % for a short term.
8. The performance of the rotary UPS systems with nonlinear loads is good because of the low output impedance.
9. The input current THD is very low, typically 3 % or less. The electromagnetic interference (EMI) is also low. The efficiency is usually 85 % or higher.

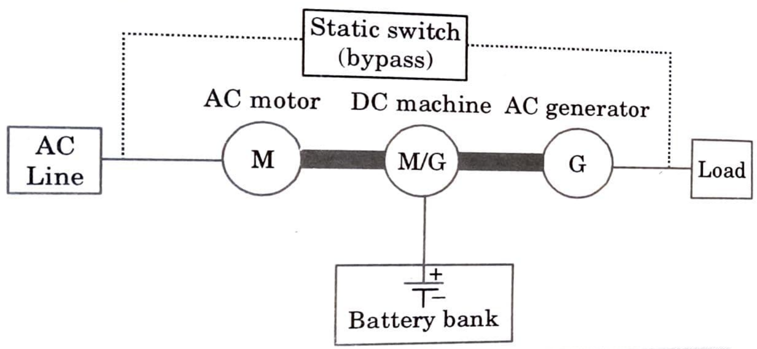


Fig. 2.9.1. Block diagram of a typical rotary UPS system.

Que 2.10. **Discuss the working of voltage regulator and give its type.**

Answer

1. A voltage regulator is used to regulate voltage levels. When a steady, reliable voltage is needed, then the voltage regulator is the preferred device.
2. It generates a fixed output voltage that remains constant for any changes in an input voltage or load conditions. It acts as a buffer for protecting components from damages.

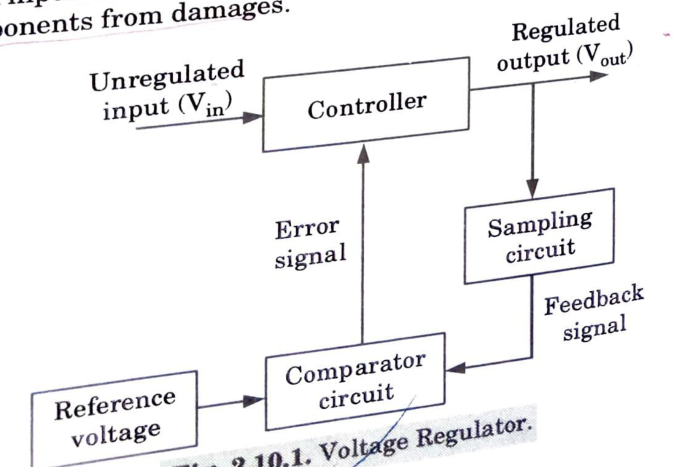


Fig. 2.10.1. Voltage Regulator.

3. A voltage regulator is a device with a simple feed-forward design and it uses negative feedback control loops.
4. There are mainly two types of voltage regulators :
a. Linear voltage regulators.
b. Switching voltage regulators.

Que 2.11. **Describe the working of isolation transformer.**

Answer

1. Fig. 2.11.1 shows a diagram of an isolation transformer used to attenuate high-frequency noise and transients as they attempt to pass from one side to the other.

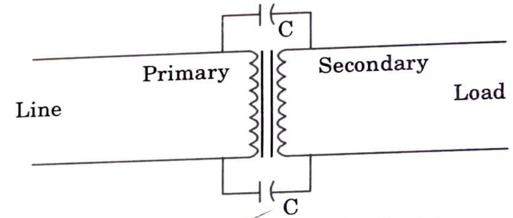


Fig. 2.11.1. Isolation transformer.

2. However, some common-mode and normal-mode noise can still reach the load.
3. An electrostatic shield, as shown in Fig. 2.11.2, is effective in eliminating common-mode noise.

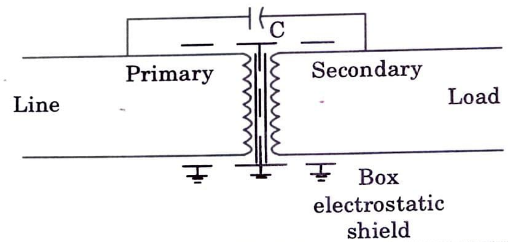


Fig. 2.11.2. Isolation transformer with electrostatic shield

4. However, some normal-mode noise can still reach the load due to magnetic and capacitive coupling.
5. The chief characteristic of isolation transformers for electrically isolating the load from the system for transients is their leakage inductance.
6. 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.

7. 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.
8. Capacitor-switching and lightning transients coming from the utility system can be attenuated, thereby preventing nuisance tripping of adjustable-speed drives and other equipment.
9. An additional use of isolation transformers is that they allow the user to define a new ground reference, or separately derived system. This is new neutral-to-ground bond limits neutral-to-ground voltages at sensitive equipment.

Que 2.12. **Briefly explain the uses of isolations transformer, voltage regulator and active series compensator.**

AKTU 2018-19, Marks 10

Answer

A. Isolation transformer :

1. Isolation transformers are used in small sizes for isolation in pulse circuits.
2. Isolation transformers are used to provide electrical isolation in medical equipment.
3. Isolation transformers are used for power supply of devices that are not at ground potential.
4. Isolation transformers are used in electronics testing and servicing to provide safety, without which touching a live part of the circuit with hazardous voltage can cause severe damage.

B. Voltage regulator :

1. A voltage regulator is used to regulate voltage levels. When a steady, reliable voltage is needed, then the voltage regulator is the preferred device.
2. It generates a fixed output voltage that remains constant for any changes in an input voltage or load conditions.
3. It acts as a buffer for protecting components from damages.

C. Active series compensator : Refer Q. 1.9, Page 1–18A, Unit-1.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What is voltage sag ? Explain motor starting and arc furnace.

Ans. Refer Q. 2.1.

Q. 2. Write technical notes on any three of the following :

i. Area of vulnerability.
ii. CBEMA curve.
iii. IEEE 519 standard.
iv. Disturbance at customer side.
v. Objectives of power quality monitoring.

Ans. Refer Q. 2.3.

Q. 3. Explain the working of different uninterruptable power supplies.

Ans. Refer Q. 2.4.

Q. 4. Discuss the working of active series compensator.

Ans. Refer Q. 2.6.

Q. 5. What are series and shunt compensator ? Compare their role for power quality improvement.

Ans. Refer Q. 2.7.

Q. 6. What are the principle of voltage sag performance ? Given solution at end user level.

Ans. Refer Q. 2.8.

Q. 7. Briefly explain the uses of isolations transformer, voltage regulator and active series compensator.

Ans. Refer Q. 2.12.

☺☺☺

UNIT 3

Electrical Transients

CONTENTS

PART-1

Sources of Transient Overvoltage, Atmosheric and Switching Transients, Motor Starting Transients, PF Correction Capacitor Switching Transients, UPS Switching Transients.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.1. **What are the sources of transient overvoltage ? Explain some with suitable example.**

AKTU 2017-18, Marks 10

Answer

A. Sources of transient overvoltage :

a. Lightning :

1. Lightning is a potent source of impulsive transients.
2. Some of the places where lightning can strike that result in lightning currents being conducted from the power system into loads.
3. The most obvious conduction path occurs during a direct strike to a phase wire, either on the primary or the secondary side of the transformer.
4. This can generate very high overvoltage, but some analysts question whether this is the most common way that lightning surges enter load facilities and cause damage.

b. Switching loads ON or OFF :

1. Switching normal loads in a facility can produce transients. The majority of plant loads draw large amounts of current when initially turned ON.
2. Transformers draw inrush currents, when switched ON, that range between 10 and 15 times their normal full-load current. This current lasts between 5 and 10 cycles.
3. Alternating current motors draw starting currents that vary between 500 and 600 % of the normal full-load running current.
4. Fluorescent lights draw inrush currents when first turned ON. Large current drawn through the impedance of the power system sets up transient voltages that affect electrical components sensitive to sags, subcycle oscillations or voltage notch.

5. There are instances when conditions are such that harmonic frequency currents in the inrush current interact with the power system inductance and capacitance and cause resonance conditions to develop.

c. Interruption of fault circuits :

1. During fault conditions, large currents are generated in an electrical system. The fault currents are interrupted by overcurrent devices such as circuit breakers or fuses.
2. Fig. 3.1.1 shows a simplified electrical circuit where an electrical fault is cleared by a circuit breaker. 'C' represents the capacitance of the electrical system up to the point where the over current device is present.
3. Interruption of the fault current generates overvoltage impulse in the electrical system, and the magnitude of the voltage depends on the amount of fault current and the speed with which the fault is interrupted.

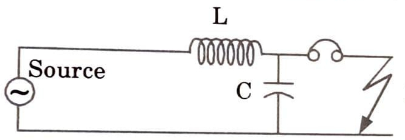


Fig. 3.1.1. Electrical fault at the output side of a circuit breaker.

d. Capacitor bank switching :

1. One of the more common causes of electrical transients is switching of capacitor banks in power systems.
2. Electrical utilities switch capacitor banks during peak load hours to offset the lagging kVAr demand of the load.
3. The leading kVArs drawn by the capacitor banks offset the lagging kVAr demand of the load, reducing the net kVA load on the circuit.
4. Switching of capacitor banks is accompanied by a surge of current which is initially limited by the characteristic impedance of the power system and resistance of the line.
5. A sharp reduction in the voltage is followed by a voltage rise, which decays by oscillation at a frequency determined by the inductance and capacitance of the circuit.
6. Several cases of power system component failures and malfunctions due to capacitor bank switching operations have been seen by the author.
7. Typically, the voltage rise due to capacitor switching operation can attain values 1.5 to 2 times the nominal voltage.

Que 3.2. **Discuss the atmospheric cause phenomena in transient over voltage.**

Answer

1. Over potential surge due to lightning discharge is the most common natural cause of electrical equipment failure. The phenomenon of lighting

strike can be described as follows. A negative charge builds up on a cloud, as indicated in Fig. 3.2.1.

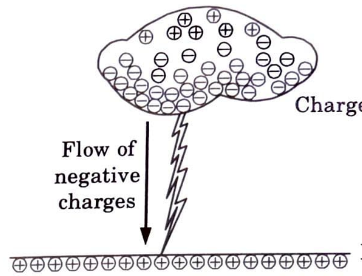


Fig. 3.2.1. Lightning discharge due to charge buildup in the clouds.

2. A corresponding positive charge can build up on the surface of the earth. A voltage difference of hundreds of millions of volts can exist between the cloud and the earth due to the opposing charges.
3. When the voltage exceeds the breakdown potential of air (about 3×10^6 V/m or 75 kV/inch), a lightning flash occurs.
4. A lightning strike can typically produce a voltage rise in about 1 to 2 μsec that can decline to a value of 50 % of the peak voltage in approximately 50 to 100 μsec.
5. A typical lightning impulse wave might appear as shown in Fig. 3.2.2.

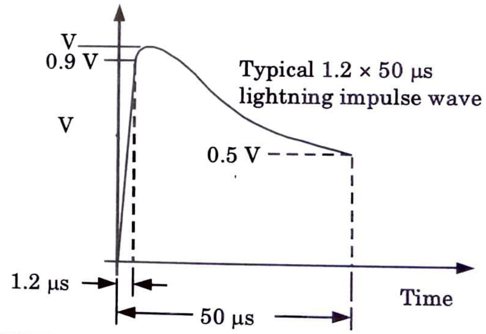


Fig. 3.2.2. Lightning impulse waveform characterized by a rise to 90 % value in 1.2 μs and a fall to 50 % value in 50 μs.

6. A common misconception is that a direct lightning strike is needed to produce destructive overvoltage.
7. In fact, it is rare that a failure in an electrical system is due to a direct lightning strike.
8. More often, the electrical and magnetic fields caused by indirect lightning discharge induce voltages in the power lines that result in device failures.

9. Also, lightning discharge current flowing through the earth creates a potential difference between the power lines and ground and in extreme cases causes equipment failure.
10. Isolation transformers provide limited protection from lightning strikes.
11. Because lightning is a short-duration, high-frequency phenomenon, a portion of the lightning energy will couple directly from the primary winding to the secondary winding of the transformer through the interwinding capacitance.
12. Transformers provided with a grounded shield between the primary and the secondary windings provide better protection against lightning energy present at the transformer primary winding.
13. Lightning arresters, when properly applied, can provide protection against lightning-induced low voltages.
14. Arresters have a well-defined conduction voltage below which they are ineffective. This voltage depends on the rating of the arrester itself.
15. For optimum protection, the arrester voltage should be matched to the lightning impulse withstand of the equipment being protected.

Que 3.3. **Discuss the motor start transient with the help of waveform.**

Answer

Motor start transient :

1. Fig. 3.3.1 shows a transient produced when a 50 HP induction motor with integral power factor correction was started across the line.
2. The notch in the voltage waveform at the instant of starting was produced by the presence of the capacitor.
3. The quick voltage recovery was followed by ringing characteristics.
4. The transient lasted less than half of a cycle, but it was sufficient to affect the operation of large chillers located nearby which contained solid-state starters with sensitive voltage-sensing circuitry.
5. Because of the severity of the motor starting transient, the chillers started to shut down.
6. In a situation such as this, it is often prudent to apply correction to the sensitive circuitry rather than try to eliminate the problem itself or apply correction to the power system as a whole.

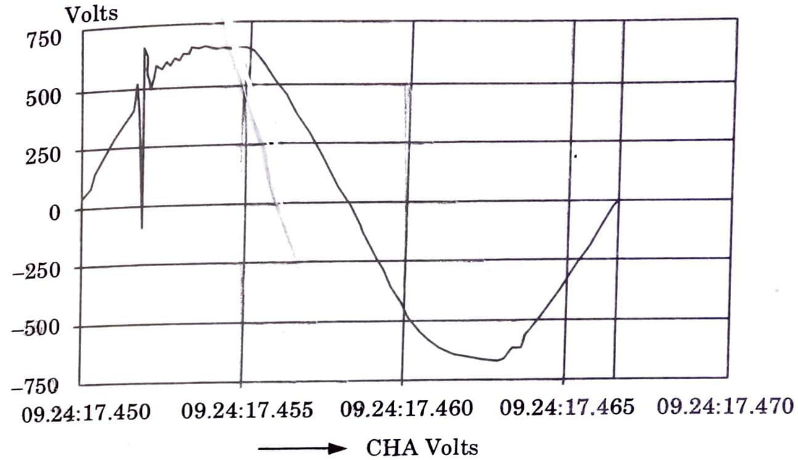


Fig. 3.3.1. Transient due to motor starting. The motor had an input capacitor for power factor correction, and the motor and capacitor were turned ON simultaneously.

Que 3.4. **Explain power factor improvement using capacitor switching transient.**

AKTU 2017-18, Marks 10

OR

Explain the working of capacitor switching operation.

Answer

1. Capacitor switching is one of the most common switching events on utility systems. Capacitors are used to provide reactive power to correct the power factor, which reduces losses and supports the voltage on the system.
2. Fig. 3.4.1 shows the One-line diagram of a typical utility feeder capacitor-switching situation.
3. In this particular case, the capacitor switch contacts close at a point near the system voltage peak.
4. This is a common occurrence for many types of switches because the insulation across the switch contacts tends to breakdown when the voltage across the switch is at a maximum value.
5. 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.
6. Because the power system source is inductive, the capacitor voltage overshoots and rings at the natural frequency of the system.

7. At the monitoring location shown in Fig. 3.4.1, the initial change in voltage will not go completely to zero because of the impedance between the observation point and the switched capacitor.
8. However, the initial drop and subsequent ringing transient that is indicative of a capacitor-switching event will be observable to some degree.

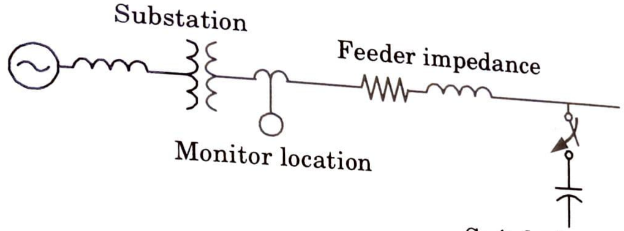


Fig. 3.4.1. One-line diagram of a capacitor switching operation corresponding to the waveform.

Que 3.5. **What are the advantages and disadvantages of using capacitor bank in a power system ? With neat diagram explain the capacitor switching operation.** **AKTU 2014-15, Marks 05**

Answer

A. Advantages :
1. Losses are low in static capacitors.
2. Do not require a foundation for installation.
3. They are light weight so it can be easily installed.

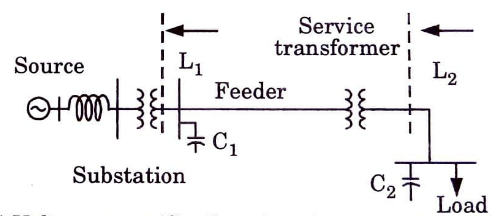
B. Disadvantages :
1. Once the capacitors spoiled, then repairing is costly.
2. The age of static capacitor bank is less (8-10 years).
3. With changing load, we have to ON or OFF the capacitor bank, which causes switching surges on the system.
4. If the rated voltage increases, then it may cause damage.

C. Capacitor switching operation : Refer Q. 3.4, Page 3–6A, Unit-3.

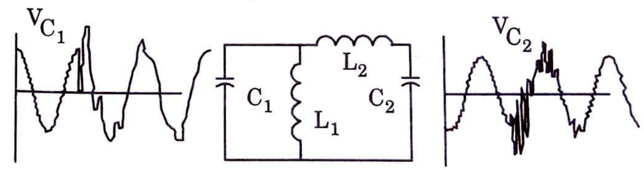
Que 3.6. **Explain the phenomena of voltage magnification at customer side due to energizing capacitor on utility system and discuss the remedy.** **AKTU 2014-15, Marks 05**

Answer

1. A potential side effect of adding power factor correction capacitors at the customer location is that they may increase the impact of utility capacitor switching transients on end-use equipment.
2. The transient is generally no higher than 2.0 pu on the primary distribution system, although ungrounded capacitor banks may yield somewhat higher values.
3. Load-side capacitors can magnify this transient overvoltage at the end-user bus for certain low-voltage capacitor and step-down transformer sizes.
4. The circuit of concern for this phenomenon is illustrated in Fig. 3.6.1. Transient overvoltages on the end-user side may reach as high as 3.0 to 4.0 pu on the low-voltage bus under these conditions, with potentially damaging consequences for all types of customer equipment.
5. Magnification of utility capacitor-switching transients at the end-user location occurs over a wide range of transformer and capacitor sizes.
6. Resizing the customer's power factor correction capacitors or step-down transformer is therefore usually not a practical solution.
7. One solution is to control the transient overvoltage at the utility capacitor. This is sometimes possible using synchronous closing breakers or switches with preinsertion resistors.



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



(b) Equivalent circuit

Fig. 3.6.1. Voltage magnification of capacitor bank switching.

8. At the customer location, high-energy surge arresters can be applied to limit the transient voltage magnitude at the customer bus.
9. It is important to note that the arresters can only limit the transient to the arrester protective level. This will typically be approximately 1.8 times the normal peak voltage (1.8 pu).

10. This may not be sufficient to protect sensitive electronic equipment that might only have a withstand capability of 1.75 pu [1200 V Peak Inverse Voltage (PIV) rating of many Silicon Controlled Rectifiers (SCRs) used in the industrial environment].
11. Another means of limiting the voltage magnification transient is to convert the end-user power factor correction banks to harmonic filters.
12. An inductance in series with the power factor correction bank will decrease the transient voltage at the customer bus to acceptable levels.
13. This solution has multiple benefits including providing correction for the displacement power factor, controlling harmonic distortion levels within the facility, and limiting the concern for magnified capacitor-switching transients.
14. In many cases, there are only a small number of load devices, such as adjustable-speed motor drives, that are adversely affected by the transient.
15. It is frequently more economical to place line reactors in series with the drives to block the high-frequency magnification transient.

Que 3.7. **Write short note on :**

i. **Capacitor switching transient**

ii. **UPS switching transients.**

AKTU 2018-19, Marks 10

Answer

i. **Capacitor switching transients :** Refer, Q. 3.4, Page 3–6A, Unit-3.

ii. **UPS switching transients :**

1. Typically, we associate voltage notches with adjustable speed drives.

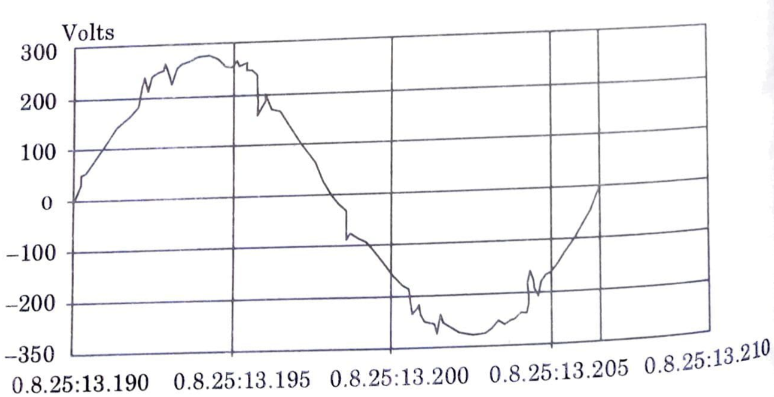


Fig. 3.7.1. Voltage notches produced at the output of an Uninterruptible Power Source (UPS) unit.

2. Voltage notches are also common with the outputs of Uninterruptible Power Source (UPS) units due to power electronic switching circuitry associated with the UPS units.
3. Unless provided with wave shaping and filtering circuitry, the output of the UPS can contain substantial notches.
4. Fig. 3.7.1 shows the output waveform of a UPS unit supplying 250 V output.
5. If the notch level becomes excessive, problems can arise in the operation of sensitive communication or data-processing loads.
6. The voltage notch phenomenon is a repetitive event, even though we define transients as subcycle events.

PART-2

Neutral Voltage Swing etc; Devices for Overvoltage Protection.

Questions-Answers
Long Answer Type and Medium Answer Type Questions

Que 3.8. **Discuss about neutral voltage swing.**

Answer

1. Normally neutral voltage should be within 0.5 V with respect to the ground.

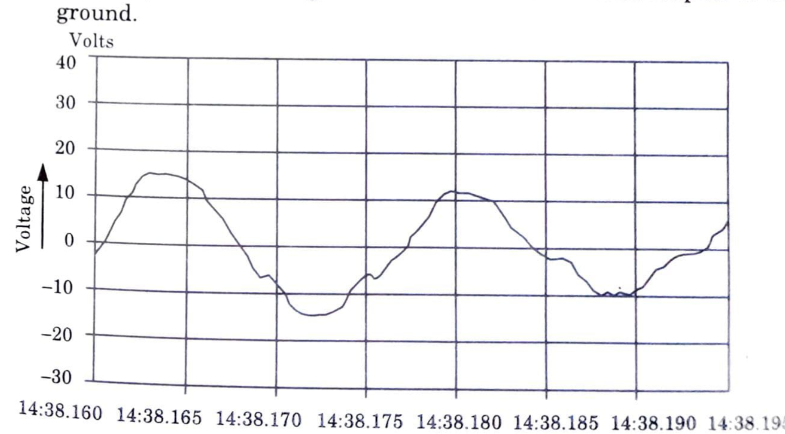


Fig. 3.8.1. Large neutral voltage swings responsible for problems in a university computer laboratory.

2. The voltage-to-transformer ratio is 60:1 is connected to the ground at the source. This tends to hold the neutral potential close to the ground.
3. In a typical building, neutral-to-ground voltages become higher as we move away from the source feeding the facility.
4. In some instances, depending on the loads and the distance between the source and the load, neutral-to-ground voltage can measure 2 to 3 V.
5. The case illustrated by Fig. 3.8.1 is an extreme one where neutral-to-ground voltages reached levels higher than 10 V.

Que 3.9. **What are the devices for overvoltage protection ? Explain at least two giving suitable diagram.**

AKTU 2017-18, Marks 10

OR

Explain the sources of transient overvoltage also the devices used for overvoltage protection.

AKTU 2018-19, Marks 10

Answer

Devices used for overvoltage protection :

1. **Isolation transformers :** Refer Q. 2.11, Page 2–14A, Unit-2.
2. **Surge arresters :**
   i. A surge arrester is a device to protect electrical equipment from over-voltage transients caused by external (lightning) or internal (switching) events.
   ii. To protect a unit of equipment from transients occurring on an attached conductor, a surge arrester is connected to the conductor just before it enters the equipment.
   iii. The surge arrester is also connected to ground and functions by routing energy from an over-voltage transient to ground.
3. **Crowbar devices :**
   i. Crowbar devices are normally open devices which conduct during overvoltage transients. These devices usually manufactured with a gap filled with air or with special gas.
   ii. The gap arcs over when sufficiently high overvoltage transient appears. Once the gap arcs over, power frequency current or "follow current" will continue to flow in the gap until next current zero.
4. **Clamping devices :**
   i. Clamping devices for AC circuits are commonly non-linear resistor (varistors) which conduct very low amounts of current until an overvoltage occurs.

   ii. Then they start to conduct heavily and their impedance drops rapidly with increasing voltage. These devices effectively conduct increasing amount of current (and energy) to limit the voltage rise of a surge.

Que 3.10. **How utilities can deal with problems related to capacitors switching transients ?**

Answer

Capacitor switching transients are very common and usually not damaging. The following problems can deal utility related capacitor switching transients :

1. **Switching times :**
   a. Timing of switching may be unfortunate for some sensitive industrial loads.
   b. Picks up at a certain time each day and decide to switch the capacitors coincident with that load incurring.
2. **Pre-insertion resistors :**
   a. Pre-insertion resistors can reduce the capacitor switching transient consideration. The first peak of the transient is usually the might damaging.
   b. The idea is to insert a resistor in to the circuit briefly so that the first peak is damped significantly.
   c. Switches with pre-insertion reactor (inductor) is helpful in limiting the higher frequency component of the transients.
3. **Synchronous closing :**
   a. For reducing transients, capacitor switching is to use a synchronous close breaker.
   b. Synchronous closing prevents transients by timing the contact closure that the system voltage closely matches the capacitor voltage as the instant the contacts mate.
   c. This avoids the step change in voltage that normally occurs when capacitors are switched, causing the circuit to oscillate.
4. **Capacitor location :**
   a. For distribution feeder banks a switched capacitor may be too, close to a sensitive customer or at a location where the transient over voltage tends to be much higher.
   b. Often it may be possible to move the capacitor down line or to another branch of circuit and eliminate the problem.

Que 3.11. **What are fundamental principles of "over voltage protection" ? Illustrate these principles with suitable diagram.**

Answer

A. **Principles of overvoltage protection :** The fundamental principles of over voltage protection of load equipment are :
a. Limit the voltage across sensitive insulation.
b. Divert the surge current away from the load.
c. Block the surge current from entering the load.
d. Bond ground references together at the equipment.
e. Reduce or prevent, surge current from flowing between ground.
f. Create a low pass filter using limiting and blocking principles.

B. **Explanation :**
1. The main function of surge arresters and Transient Voltage Surge Suppressors (TVSS) is to limit the voltage that can appear between two points in the circuit.
2. Arrester application is to place them directly across sensitive insulation that is protected so that the voltage seen by the insulation is limited to a safe value.
3. In Fig. 3.11.1 the first arrester is connected from the line to the neutral ground bond at the service entrance. It limits the line voltage V_1 from rising too high relative to the neutral and ground voltage at the panel.
4. The surge energy will be discharged through the first arrester directly into ground.
5. In Fig. 3.11.1 there is another possible path for the surge current to flow into, the signal cable indicated by the dotted line and bonded to the safety ground.

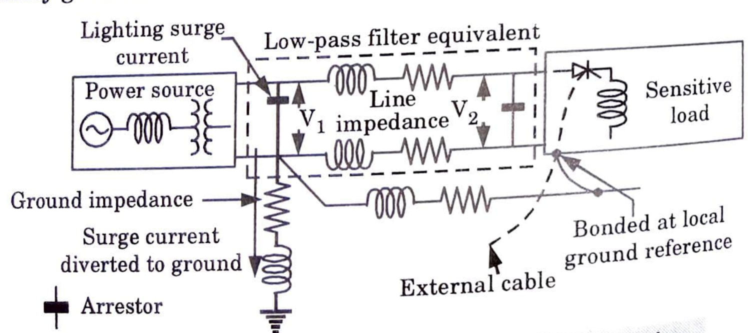


Fig. 3.11.1. demonstrating principle of protection.

6. Second arrester is applied at the load again directly across the insulation to be protected.
7. Surge suppressors will have suppression on all line to ground, all line to neutral, and neutral to ground.

8. Blocking can be done relatively easily for high frequency transients by placing an inductor or choke in series with the load. High voltage drop across the inductor.
9. The blocking function is frequently combined with the voltage limiting function to form a low-pass filter in which there is a shunt limiting device on either side of the series choke.
10. The line provides the blocking function is proportional to its length. Such a circuit has very beneficial over voltage protection.
11. The amount of current flowing between the grounds may be reduced by improving all the intentional grounds at the service entrance.

Que 3.12. **Explain the various strategies for utilities to decrease the impact of lighting.**

AKTU 2014-15, Marks 05

Answer

A. **Shielding :**
1. Shielding overhead utility lines is common at transmission voltage levels and in substations, but is not common on distribution lines because of the added cost of taller poles and the lower benefit due to lower flashover levels of the lines.
2. On distribution circuits, the grounded neutral wire is typically installed underneath the phase conductors to facilitate the connection of line-to-neutral connected equipment such as transformers and capacitors.
3. Shielding is not quite as simple as adding a wire and grounding at every few poles.
4. When lightning strikes the shield wire, the voltages at the top of the pole will still be extremely high and could cause backflashovers to the line.
5. This will result in a temporary fault. To minimize this possibility, the path of the ground lead down the pole must be carefully chosen to maintain adequate clearance with the phase conductors.
6. Also, the grounding resistance plays an important role in the magnitude of the voltage and must be maintained as low as possible.

B. **Line arresters :**
1. Another strategy for lines that are struck frequently is to apply arresters periodically along the phase wires. Normally, lines flashover first at the pole insulators.
2. Therefore, preventing insulator flashover will reduce the interruption and sag rate significantly. Neither shielding nor line arresters will prevent all flashovers from lightning.
3. The aim is to significantly reduce flashovers in particular trouble spots. In Fig. 3.12.1 periodically spaced line arresters help to prevent flashovers.

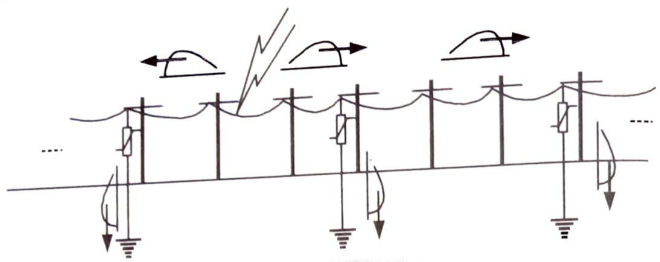


Fig. 3.12.1.

4. In Fig. 3.12.1, the arresters bleed OFF some of the stroke current as it passes along the line. The amount that an individual arrester bleeds OFF will depend on the grounding resistance.
5. The idea is to space the arresters sufficiently close to prevent the voltage at unprotected poles in the middle from exceeding the basic impulse level of the line insulators.
6. This usually requires an arrester at every second or third pole. In the case of a feeder supplying a highly critical load, or a feeder with high ground resistance, it may be necessary to place arresters at every pole.

C. Low-side surges :

1. Fig. 3.12.2 shows one possible scenario. Lightning strikes the primary line, and the current is discharged through the primary arrester to the pole ground lead.
2. This lead is also connected to the X_2 bushing of the transformer at the top of the pole.

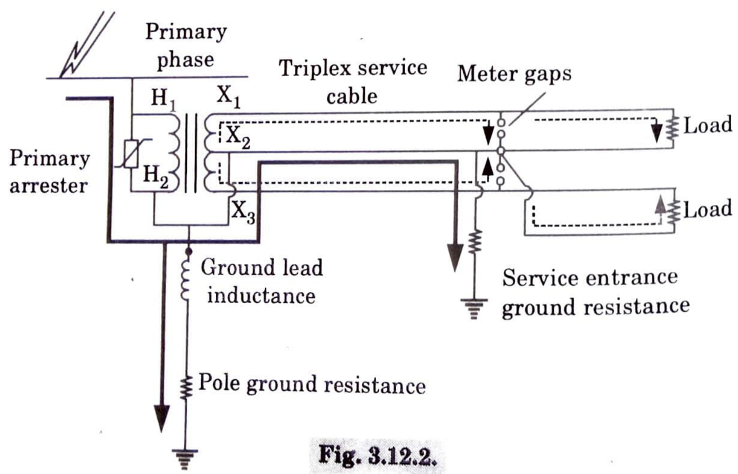


Fig. 3.12.2.

3. Thus, some of the current will flow toward the load ground. The amount of current into the load ground is primarily dependent on the size of the pole ground resistance relative to the load ground.

4. The current that flows through the secondary cables causes a voltage drop in the neutral conductor that is only partially compensated by mutual inductive effects with the phase conductors.
5. Thus, there is a net voltage across the cable, forcing current through the transformer secondary windings and into the load as shown by the dashed lines in Fig. 3.12.2.
6. If there is a complete path, substantial surge current will flow. As it flows through the transformer secondary, a surge voltage is induced in the primary, sometimes causing a layer-to-layer insulation failure near the grounded end.
7. If there is not a complete path, the voltage will build up across the load and may flash over somewhere on the secondary.
8. The amount of voltage induced in the cable is dependent on the rate of rise of the current, which is dependent on other circuit parameters as well as the lightning stroke.

Que 3.13. **Describe load switching transients. Also discuss different protection needed to overcome with the load-switching transient problems.**

Answer

A. Load switching transients :

1. Deenergizing inductive circuit with air-gap switches, such as relays and conductors, can generate burst of high frequency impulses.
2. There is very little energy in these types of transient due to their short duration, but they can interfere with the operation of electronic load.

B. Different protection needed to overcome with the load switching transient problem :

a. Nuisance tripping of ASDs (Adjustable Speed Drives) :

i. The most effective way to eliminate nuisance tripping of small drives is to isolate them from the power system with AC line chokes.

ii. The additional series inductance of the choke reduces the transient voltage magnitude that appears at the input to the ASDs.

b. Transients from load switching :

i. High frequency filters and isolation transformer can be used to protect against conduction of electrical fast transient on power cables.

ii. Shield is required to prevent coupling into equipment and data lines.

c. Transformer energizing :

i. This problem occurs with large transformers energized simultaneously with large power factor correction capacitor banks in large industrial facilities.

ii. The dynamic over voltage problem can be eliminated simply by not energizing the capacitor and transformer together.

Que 3.14. **Write a short note on low impedance power conditioners.**

Answer

Low impedance power conditioners :

1. Low Impedance Power Conditioners (LIPCs) are used primarily to interface with the switch mode power supplies found in electronic equipment.
2. LIPCs differ from isolation transformers in that these conditioners have much lower impedance and have a filter as part of their design (Fig. 3.14.1).

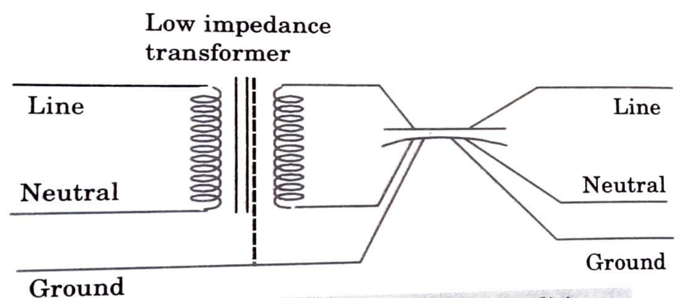


Fig. 3.14.1. Low-impedance power conditioner.

3. 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).
4. The new neutral-to-ground connection that can be made on the load side because of the existence of an isolation transformer.
5. However, low to medium frequency transients (capacitor switching) can cause problems for LIPCs.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What are the sources of transient over voltage ? Explain some with suitable example.

Ans. Refer Q. 3.1.

Q. 2. Explain power factor improvement using capacitor switching transient.

Ans. Refer Q. 3.4.

Q. 3. What are the advantages and disadvantages of using capacitor bank in a power system ? With neat diagram explain the capacitor switching operation.

Ans. Refer Q. 3.5.

Q. 4. Explain the phenomena of voltage magnification at customer side due to energizing capacitor on utility system and discuss the remedy.

Ans. Refer Q. 3.6.

Q. 5. Write short note on
i. Capacitor switching transient
ii. UPS switching transients

Ans. Refer Q. 3.7.

Q. 6. What are the devices for over voltage protection ? Explain at least two giving suitable diagram.

Ans. Refer Q. 3.9.

Q. 7. Explain the various strategies for utilities to decrease the impact of lighting.

Ans. Refer Q. 3.12.

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UNIT 4

FACTS Systems

CONTENTS

PART-1

Introduction : Terms and Definition, FACT Controllers.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.1. **What do you mean by FACTS ?**

Answer

FACTS :

1. FACTS stand for Flexible AC Transmission Systems.
2. They are used for power flow control, effective load sharing among parallel corridors, voltage regulation, enhancement of transient stability and mitigation of system oscillations.
3. FACTS employ high speed thyristor for switching in or out transmission line components such as capacitors, reactors or phase shifting transformer for some desirable performance of the systems.
4. This technology is not a single high-power, but rather a collection of controllers, which can be applied individually or in coordination with others to control one or more of the system parameters.

Que 4.2. **Explain the various types of FACTS controllers.**

Answer

Types of FACTS controller :

a. Series controller :

1. Series controllers inject a voltage in series with the line. As long as the voltage is in phase quadrature with the line current, series controller supplies reactive power only.
2. Series controller controls the current/power flow and damp oscillation.

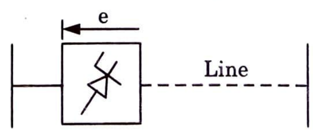


Fig. 4.2.1. Series controller.

b. Shunt controllers :

1. Shunt controllers, may be variable impedance, variable sources or a combination of these.
2. Shunt controller inject current into the system at the point of connection.
3. Shunt controller is good to control the voltage at and ground the point of connection through injection of reactive current (leading / lagging).

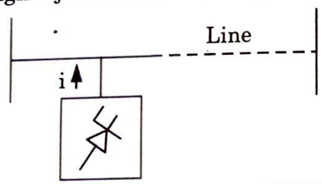


Fig. 4.2.2. Shunt controller.

c. Combined series-series controllers : It could be a combination of separate series controllers, which are controlled in a coordinated manner, in a multi-line transmission system.

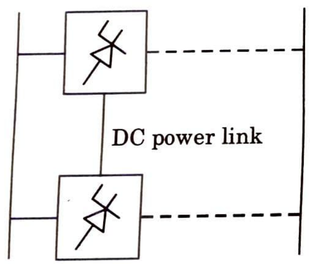


Fig. 4.2.3. Combined series-series controller.

d. Combined series-shunt controllers :

1. This could be a combination of separate shunt and series controller, which are controlled in a coordinated manner or a unified power flow controller (UPFC) with series and shunt elements.
2. UPFC can provide effective current / power control along with voltage control.

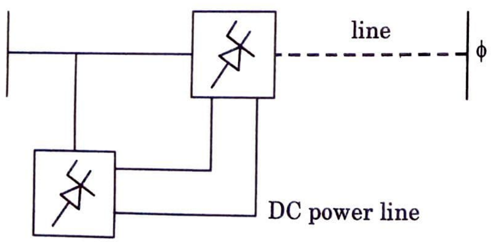


Fig. 4.2.3. Combined series-shunt controllers.

Que 4.3. **What do you mean by FACTS controllers ? What are the advantage and disadvantages of FACTS controllers also its importance ?**

Answer

A. **FACTS controllers :** A power-electronic based system and other static equipment that provide control of one or more AC transmission system parameters.

B. **Advantages :**

1. It enhances controllability.
2. It increases power transfer capability of the network.
3. It increases the reliability of AC grids and reduces power delivery costs.
4. The improve transmission quality and efficiency of power transmission by supplying inductive and reactive power to the grid.

C. **Disadvantages :** FACTS consist of combination of traditional power system components (such as transformers, reactors, switches, capacitors) which makes it very costly.

D. **Importance :** Mechanical circuit breakers like relays, contactors etc., are not very reliable and hence can not compensate power loss due to reactive power of transmission systems which can be performed by facts controllers are its main importance.

PART-2

Type of FACT Devices i.e., SSC, SVC, TSC, SSSC, TCSC, UPFC, Basic Relationship for Power Flow Control.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.4. **Explain basic circuit configuration of STATCOM or static synchronous compensator (SSC).**

Answer

1. The STATCOM has been defined as per CIGRE/IEEE with following three operating structural components :

   a. First component is static : based on solid state switching devices with no rotating components.

b. Second component is synchronous : analogous to an ideal synchronous machine with 3 sinusoidal phase voltages at fundamental frequency.

c. Third component is compensator : provided with reactive compensation.

2. The typical connection of STATCOM to AC bus is shown in Fig. 4.4.1. It consists of the coupling transformer, input filter, voltage source converter (VSC) and a controller.

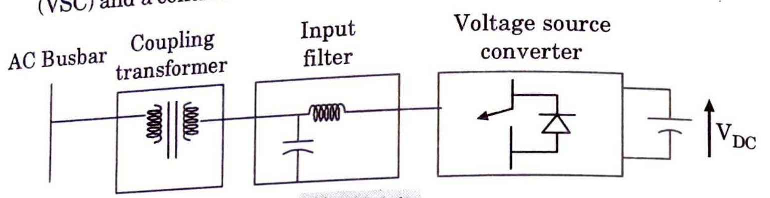


Fig. 4.4.1.

3. The STATCOM is a static compensator composed of inverters with a capacitor in its DC side, coupling transformers and control system.

Que 4.5. **Explain the principle of operation of STATCOM or SSC. Also draw its equivalent circuit.**

Answer

1. A STATCOM is a controlled reactive-power source. It provides the desired reactive-power generation and absorption entirely by means of electronic processing of the voltages and current waveforms in a voltage-source converter (VSC).
2. A single-line STATCOM power circuit is shown in Fig. 4.5.1(*a*), where a VSC is connected to a utility bus through magnetic coupling.
3. In Fig. 4.5.1(*b*), a STATCOM is seen as an adjustable voltage source behind a reactance-meaning that capacitor banks and shunt reactors are not needed for reactive power generation and absorption, thereby giving a STATCOM a compact design, or small footprint, as well as low noise and low magnetic impact.
4. The exchange of reactive power between the converter and the AC system can be controlled by varying the amplitude at the 3-phase output voltage E_s of the converter as illustrated in Fig. 4.5.1(*c*).
5. That is, if the amplitude of the output voltage is decreased below the utility bus voltage, E_t, then the current flows from the AC system to the converter and the converter absorbs inductive reactive power from the AC system.

6. If the output voltage equals the AC system voltages, the reactive power exchange becomes zero, in which case the STATCOM is said to be in a floating state.
7. Adjusting the phase shift between the converter-output voltage and the AC system voltage can similarly control real power exchange between the converter and the AC system.

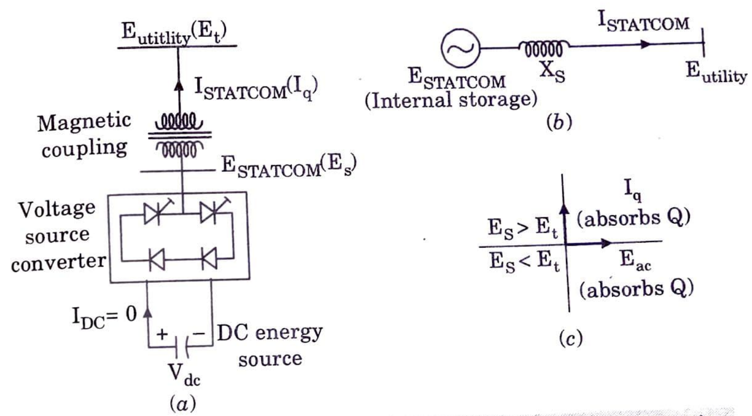


Fig. 4.5.1. The STATCOM principle diagram (*a*) a power circuit, (*b*) an equivalent circuit and (*c*) a power exchange.

8. A STATCOM provides the desired reactive power by exchanging the instantaneous reactive power among the phase of the AC system.
9. The mechanism by which the converter internally generates and/or absorbs the reactive power can be understood by considering the relationship between the output and input powers of the converter.
10. The converter switches connect the DC-input circuit directly to the AC-output circuit.

Que 4.6. **What is the importance of STATCOM characteristic ?**

Answer

1. The characteristic of a STATCOM reveals that it is capable of yielding the full output of capacitive generation almost independently of the system voltage (constant current output at lower voltages).
2. This capability is particularly useful for situations in which the STATCOM is needed to support the system voltage during and after faults where voltage collapse would otherwise be a limiting factor.

3. Fig. 4.6.1 also illustrates that the STATCOM has an increased transient rating in both the capacitive and the inductive operating regions.
4. The maximum attainable transient overcurrent in the capacitive region is determined by the maximum current turn-OFF capability of the converter switches.
5. In the inductive region, the converter switches are naturally commutated: therefore, the transient-current rating of the STATCOM is limited by the maximum allowable junction temperature of the converter switches.

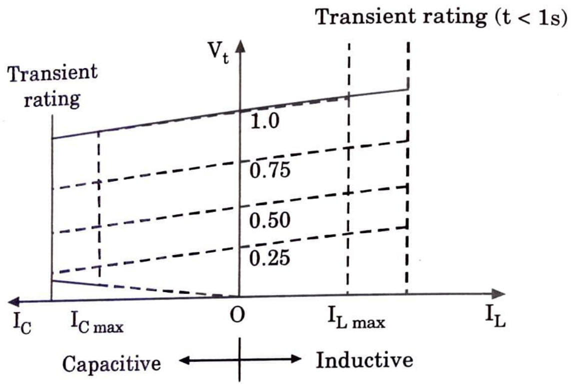


Fig. 4.6.1. The V-I characteristic of the STATCOM.

Que 4.7. **Discuss the working principle of DSTATCOM. How load compensation can be done using DSTATCOM ?**

AKTU 2014-15, Marks 10

OR

Explain the operation of Distribution Static Compensator (DSTATCOM) used for sag mitigation. **AKTU 2017-18, Marks 10**

OR

Discuss load compensation and voltage regulation using DSTATCOM.

AKTU 2018-19, Marks 10

AKTU 2016-17, Marks 15

Answer

A. Working principle with voltage regulation :

1. The basic principle of a DSTATCOM installed in a power system is the generation of a controllable AC voltage source by a Voltage Source Inverter (VSI) connected to a DC capacitor (energy storage device).

2. The AC voltage source, in general, appears behind a transformer leakage reactance.
3. The active and reactive power transfer between the power system and the DSTATCOM is caused by the voltage difference across this reactance.
4. The DSTATCOM is connected to the power networks where the voltage-quality problem is a concern.
5. All required voltages and currents are measured and are fed into the controller to be compared with the commands.
6. The controller then performs feedback control and outputs a set of switching signals to drive the main semiconductor switches (IGBT's, which are used at the distribution level) of the power converter accordingly.
7. The AC voltage control (or voltage regulation) is achieved by firing angle control. Ideally the output voltage of the VSI is in phase with the bus (where the DSTATCOM is connected) voltage.
8. In steady state, the DC side capacitance is maintained at a fixed voltage and there is no real power exchange, except for losses.

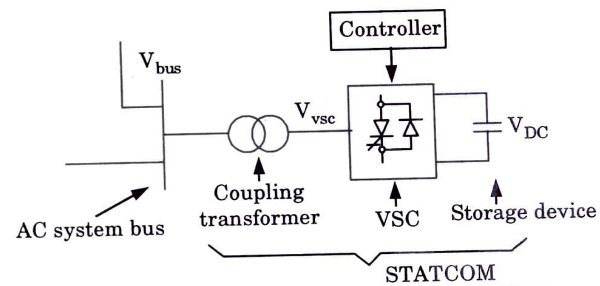


Fig. 4.7.1. Block diagram of the voltage source converter based DSTATCOM.

9. The DSTATCOM differs from other reactive power generating devices (such as shunt capacitors, static VAr compensators etc.) in the sense that the ability for energy storage is not a rigid necessity but is only required for system unbalance or harmonic absorption.
10. There are two control objectives implemented in the DSTATCOM :

i. One is the AC voltage regulation of the power system at the bus where the DSTATCOM is connected.

ii. Second DC voltage control across the capacitor inside the DSTATCOM.

iii. To mitigate voltage sag power quality issue.

B. Load compensation :

1. In the load-compensation mode, DSTATCOM is controlled in current mode. The control system of DSTATCOM has to generate reference currents, compensating harmonic, unbalance and fundamental reactive components of non-linear load supply currents.
2. The required rated power of load-compensating DSTATCOM depends only on reactive power, harmonic distortion and power of the compensated load.
3. In general, DSTATCOM is capable of compensating current disturbances from harmonics to long-duration effects, including active power transients.
4. The possibility and effectiveness of compensation of a particular voltage-quality problem depends on the topology and rated power of the controller as well as on the capacity of the energy-storage system connected at the DSTATCOM DC side.

Que 4.8. **Define custom power devices. Discuss the load compensation using DSTATCOM.**

AKTU 2015-16, Marks 15

Answer

A. Custom power devices :

1. Custom Power Devices (CPDs) use power electronic controllers to provide reliable and good quality power for customers.
2. Therefore, the CPD provides the necessary dynamic voltage restoration with hybrid active filters, which leads to improvement in power quality by improving the voltage profile and by mitigating the harmonics in the supply current.
3. Fig. 4.8.1 shows the configuration of the CPD based on a Dynamic Voltage Restorer (DVR). It consists of an energy storage device such as a battery, an inverter, filter and interfacing transformer.

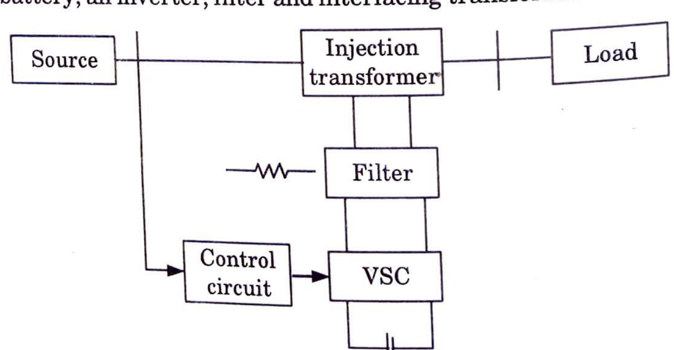


Fig. 4.8.1. Configuration of CPD.

4. Through constant monitoring of the supply current at the point of common coupling, a variation in the level of harmonic, *i.e.*, the deviation from the sinusoidal may be detected by monitoring the zero crossing, which triggers the DVR controller to supply the necessary amount of compensating reactive current.

B. Load compersation : Refer Q. 4.7, Page 4–7A, Unit-4.

Que 4.9. **What are the basic principles of operations of SVC in power system network ?**

Answer

Static VAr Compensator (SVC) :

1. SVC stands for Static VAr compensator. IEEE define SVC as : "A shunt connected static VAr generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electric power system."
2. They comprise of switched or fixed capacitive bank and switched reactor bank in parallel.
3. They draw reactive power from the line thereby regulating voltage, improve stability, control overvoltage and reduce voltage flicker.
4. They also reduce unbalanced voltage and current.

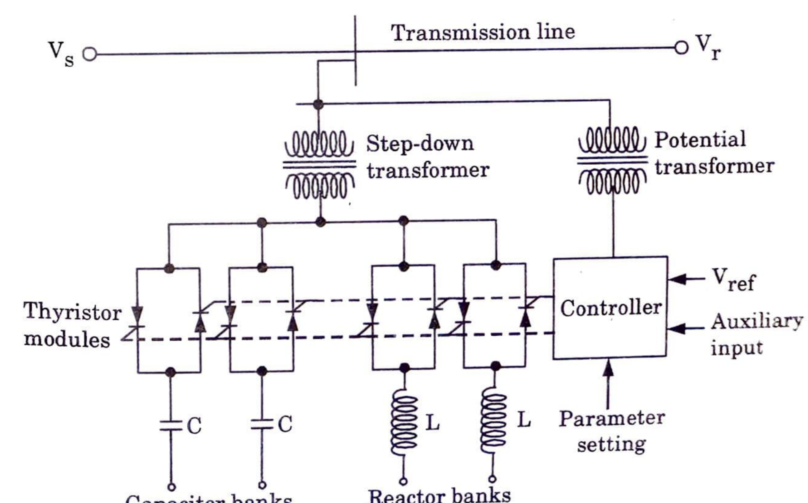


Fig. 4.9.1. General arrangement of static VAr compensator.

5. In HVDC application these compensators provide the required reactive power and damp out sub-harmonic oscillations.

6. They use static VAr compensators for VAr control and hence, are also known as static VAr switches or systems.

Que 4.10. **Give comparison between SVC and STATCOM.**

Answer

S. No.	STATCOM	SVC
1.	STATCOM can be operated over its full output current range even at very low, system voltage levels.	Maximum attainable compensating current of SVC decrease linearly with AC system voltage.
2.	STATCOM is superior to SVC for providing voltage support under large distribution.	Maximum VAr output decreases linearly with square of the voltage.
3.	STATCOM may have an increased transient rating in both the inductive and capacitive region compared to SVC.	SVC has no means to increase the VAr generation since the maximum capacitive current it can deliver is determined by the size of the capacitor.
4.	It is more effective in improving transient stability.	Less effective in improving stability.
5.	STATCOM has the potential of interfacing a suitable energy storage with ac system for real power exchange.	No provision for real power exchange.

Que 4.11. **Describe the working of TSC with the help of circuit diagram.**

Answer

Thyristor switched capacitor (TSC) :

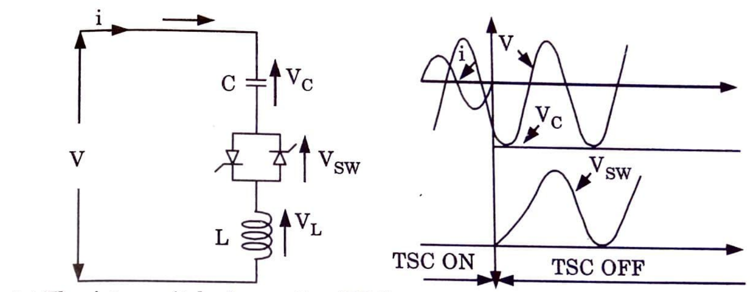
1. It consists of a capacitor, a bidirectional thyristor valve, and a relatively small surge current limiting reactor.
2. This reactor is needed to limit the surge current in the thyristor valve under abnormal operating conditions.
3. Under steady state condition, when the thyristor valve is closed and the TSC branch is connected to a sinusoidal AC voltage source, $v = V \sin \omega t$, the current in the branch is given by,

$$i(\omega t) = V \frac{n^2}{n^2 - 1} \omega C \cos \omega t$$

where $n = \frac{1}{\sqrt{\omega^2 LC}} = \sqrt{\frac{X_C}{X_L}}$

Amplitude of voltage across capacitor is

$$V_C = \frac{n^2}{n^2 - 1} V$$



(a) Thyristor switched capacitor (TSC) (b) Waveform current and voltage

Fig. 4.11.1.

4. TSC branch can be disconnected at any current zero by prior removal of the gate drive to thyristor.
5. At the current zero crossing the capacitor voltage is at its peak value.
6. Disconnected capacitor stays charged to this value and the voltage across the non-conducting thyristor valve varies between zero and peak-to-peak value of the applied AC voltage.
7. In the case of TSC, switching in the capacitor must take place at that specific instant in each cycle at which conditions for minimum transients are satisifed, that is, when the voltage across the thyristor valve is zero or minimum.
8. For this reason, a TSC branch can provide only a step-like change in the reactive current it draws (minimum or zero).
9. TSC branch represents a single capacitive admittance which is either connected to, or disconnected from the AC system.

$V_{C\,max}$ = Voltage limit.

$I_{C\,max}$ = Current limit.

B_C = Admittance of capacitor.

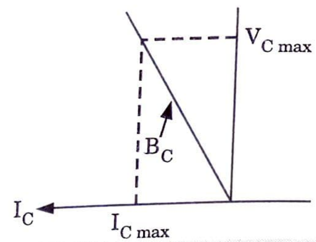


Fig. 4.11.2. Operating V-I area of a single TSC.

Que 4.12. **Discuss the working of SSSC with the help of circuit diagram.**

Answer

1. It is a static synchronous generator operated without an external energy source as a series compensator whose output voltage is in quadrature with and controllable independently of, the line current for the purpose of increasing or decreasing the overall reactive voltage drop across the line and there by controlling the transmitted electric power.
2. The schematic of a SSSC is shown in Fig. 4.12.1(i). The equivalent circuit of the SSSC is shown in Fig. 4.12.1(ii).

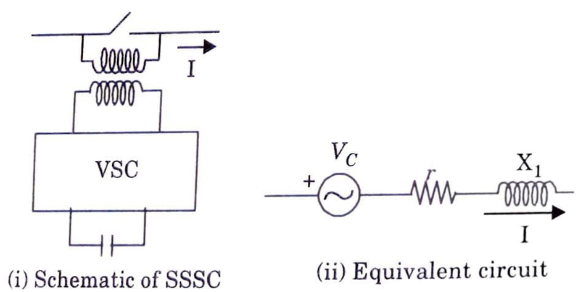


Fig. 4.12.1.

3. The magnitude of V_C can be controlled to regulate power flow.
4. The winding resistance and leakage reactance of the connecting transformer appear in series with the voltage source V_c.
5. If there is no energy source on the DC side, neglecting losses in the converter and the DC capacitor, the power balance in steady state leads to $Re[V_c I^*] = 0$.
6. Since, the losses are always present, the phase shift between I and V_c is less than 90° (in steady state).

7. $$\hat{V}_c = V_c(\cos\gamma - j\sin\gamma)\,e^{j\phi} = (V_{c_p} - jV_{c_r})\,e^{j\phi}$$

Where ϕ = Phase angle of the line current,

γ = Angle by which $\hat{V}_c$ lags the current V_{c_p},

V_{c_r} = In-phase and quadrature components of the injected voltage (with reference to the line current).

8. The positive reactive voltage implies capacitor mode of operation while negative reactive voltage implies inductive mode of operation.

Que 4.13. **Explain the equivalent diagram of TCSC. What are the advantages and disadvantages of TCSC in power system network ?**

Answer

A. TCSC :

1. TCSC stands for Thyristor-Controlled Series Capacitor. IEEE defines TCSC as : "A capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor controlled reactor in order to provide a smoothly variable series capacitive reactance.
2. The schematic diagram of the TCSC circuit is show in Fig. 4.13.1. If the impedance of the reactor X_L is sufficiently smaller than that of the capacitor X_C, it can be operated in an ON-OFF manner.
3. Varying the delay angle 'α' can vary inductive impedance of the TCR (Thyristor Controlled Reactor). Thus, the TCSC can provide a continuously variable capacitor by means of partially cancelling the effective compensating capacitance by the TCR (Thyristor Controller Reactor).
4. Thus, the steady-state impedance of the TCSC is that of the parallel LC circuit, consisting of fixed capacitive impedance X_C and variable inductive impedance X_L.
5. The effective impedance of the TCSC is given by :

$$X_T(\alpha) = \frac{X_C X_L(\alpha)}{X_L(\alpha) - X_C}$$

Where, $$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin 2\alpha} \quad \text{and, } X_C = -\frac{1}{2\pi f_C}$$

and, $X_L = \omega L$ and α is the delay angle measured from the crest of the capacitor voltage or the zero crossing of the line current

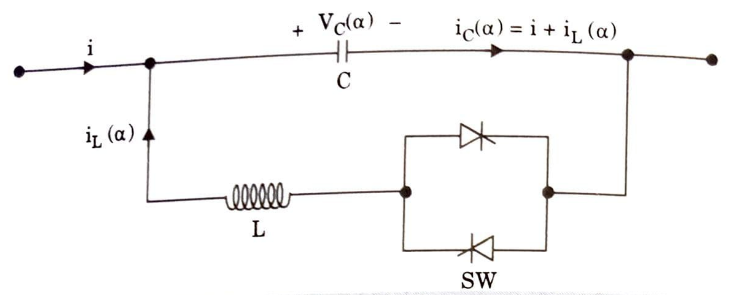


Fig. 4.13.1. Thyristor-Controlled Series Capacitor (TCSC).

6. TCR is connected in parallel with a fixed capacitor so as to control the reactance by varying thyristor fixing angle α. For the variation of α from 0 to 90°, TCR reactance $X_L(\alpha)$ varies from actual inductive reactance (X_L) to infinity.
7. This controlled reactor is connected across the series capacitor, so that the variable capacitive reactance is possible across the TCSC which modify the transmission line reactance.

B. Advantages of TCSC :

1. Rapid and continuous control of transmission line reactance.
2. Dynamic control of power flow in selected transmission lines within the network to enable power flow conditions.
3. Damping of power swings from local and inter-area oscillations.

C. Disadvantages of TCSC :

1. Oscillation can be excited by a number of reasons such as line faults or a sudden change of generator output.
2. TCSC cannot reverse the power flow in a line, unlike HVDC controller and phase swifter.

Que 4.14. **Explain the UPFC with the help of block diagram.**

Answer

UPFC :

1. UPFC stands for Unified Power Flow Controller.
2. According to IEEE definition UPFC is : "A combination of Static Synchronous Compensator (STATCOM) and a static series compensator (SSSC) which are coupled via a common DC link, to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM, and are controlled to provide concurrent real and reactive series like compensation without an external electrical energy source".

3. The UPFC, by the means of angularly unconstrained series voltage injection is able to regulate or control the real and reactive power flow in the line.
4. It consists of an advanced shunt and series compensator with a common DC link as shown Fig. 4.14.1. The energy storage capacity of the DC capacitor is generally small.

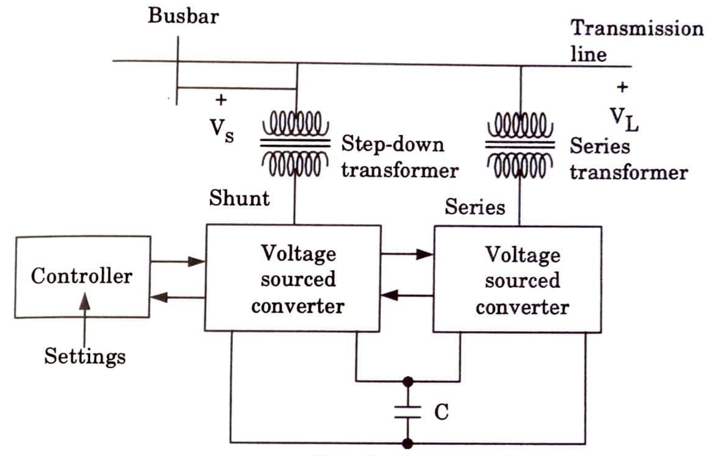


Fig. 4.14.1. Unified power flow controller.

5. Therefore, the active power drawn (generated) by shunt converter should be equal to the active power generated (drawn) by the series converter.
6. Otherwise, the DC-link voltage may increase or decrease with respect to the rated voltage, depending on the net power absorbed and generated by both converters.
7. On the other hand, the reactive power in the shunt or series converter can be chosen independently, giving a greater flexibility to the power flow control.

Que 4.15. **What are power conditioners ? Explain working principle of Unified Power Quality Conditioner (UPQC) ?**

AKTU 2014-15, Marks 10

OR

Explain the working principle of Unified Power Quality Conditioner (UPQC).

AKTU 2018-19, Marks 10

OR

Explain Unified Power Quality Conditioner (UPQC).

AKTU 2017-18, Marks 10

Answer

A. Power conditioner :

1. A power conditioner is an electrical component designed to improve the quality of power supplied to a component by supplying voltage at the level that allows that component to operate properly.
2. It is associated with a voltage regulator, which improves the quality of power through transient impulse protection, power factor correction or noise suppression.
3. A power conditioner has the ability to regulate and clean AC power by delivering dynamic power adjustments and removing spikes, surges, noise, sags and frequency irregularities, which may damage or adversely affect the performance of any equipment load.
4. Power conditioning is recognized by the IEEE, NEMA and other standards. Power conditioners are used by both individual users and large corporations.
5. A power conditioner may also be known as a power line conditioner or a line conditioner.

B. Principle of operation UPQCs :

1. The main objective of UPQCs is to mitigate multiple power quality problems in a distribution system.
2. A UPQC mitigates most of the voltage quality problems such as sag, swell, surges, noise, spikes, notches, flicker, unbalance, fluctuations, regulation, and harmonics present in the supply system and a series compensator.
3. A UPQC has two VSCs connected to a common DC bus, one VSC is connected in series (known as the DVR or series compensator) of AC lines through an injection transformer and another VSC is connected in shunt (known as the DSTATCOM or shunt compensator) normally connected across the consumer loads as shown in Fig. 4.15.1.

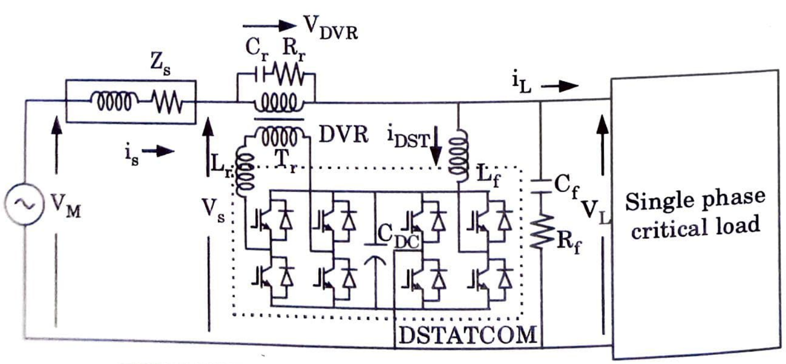


Fig. 4.15.1. A single phase right shunt UPQC.

4. Both the VSCs use PWM control, therefore, they require small ripple filters to mitigate switching ripples.
5. They require Hall Effect voltage and current sensors for feedback signals and normally a Digital Signal Processor (DSP) is used to implement the required control algorithm to generate gating signals for the solid-state devices of both VSCs of the UPQC.
6. The series VSC used as the DVR is normally controlled in PWM voltage control mode to inject appropriate voltages in series with the AC mains and the shunt VSC used as the DSTATCOM is normally controlled in PWM current control mode to inject appropriate currents in parallel with the load in the system.
7. The UPQC also needs many passive elements such as a DC bus capacitor, AC interacting inductors, injection and isolation transformers, and small passive filters.

Que 4.16. **What are the basic parameters controlled by FACTS controller in power system networks ? What are the advantages and disadvantages of UPFC over SVC or TCSC ?**

Answer

A. Parameters of FACTS Controllers :

1. FACTS devices are fabricated using solid state controllers, their response is fast.
2. FACTS devices can be utilized to improve voltage profile of the system by coordinating control of FACTS controller in multimachine power system.
3. FACTS controllers can be utilized to improve the quality and efficiency of power system operations.
4. It can be utilized to increase system security and power system reliability.
5. Loop flow control can be enhanced.
6. To increase system stability and loading capability.

B. Advantages of UPFC over SVC or TCSC :

1. UPFC by means of angularly unconstrained series voltage injection is able to control, concurrently or selectively, the transmission line voltage, impedance and angle.
2. UPFC also provides independently controllable shunt reactive compensation while SVC and TCSC does not.
3. This controller offers advantages in terms of static and dynamic operation of power system.
4. Since UPFC is combination of SSSC and STATCOM, it provides concurrent real and reactive series line compensation without of external

electric energy source and make this device versatile than SVC and TCSC.

C. **Disadvantages of UPFC over SVC and TCSC :**

1. If there are any disturbances or faults in the source side, the UPFC will not work.
2. The UPFC operates only under balanced sine wave source.

Que 4.17. Explain the different types of network reconfiguration devices with a circuit diagram.

AKTU 2016-17, Marks 10

Answer

Network reconfiguring device : The network reconfiguring devices are usually called switchgear and they include current limiting, circuit breaking and current transferring devices. These devices are series connected devices.

A. **Solid State Current Limiter (SSCL) :**

1. This network reconfiguring device limits a fault current by quickly inserting a series inductance in the fault path.
2. The schematic diagram of the solid state current limiter is shown in Fig. 4.17.1.
3. The solid state current limiter consists of two opposite poled switches in parallel with an inductor. This inductor is called current limit inductor.
4. The current limiter is connected in series with a feeder such that it can restrict the current in case of a fault downstream.
5. In the healthy state, the opposite poled switches remains closed. These switches are opened when a fault is detected and then fault current is flows through an inductor.

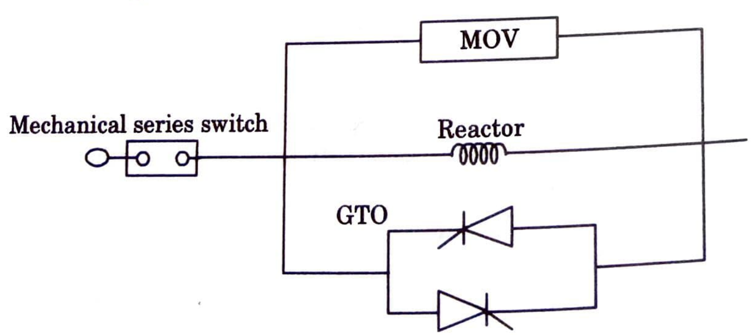


Fig. 4.17.1. Solid State Current Limiter (SSCL).

B. **Solid state breaker (SSB) :**

1. Fig. 4.17.2 shows a schematic diagram of a solid state breaker SSB. The function of a solid state breaker (SSB) is to disconnect the faulty element from the system.
2. It operates faster than a mechanical circuit breaker. This circuit breaker has almost the same topology as that of an (SSCL) only the difference is that a limiting inductor is connected in series with an opposite poled thyristors pair.
3. The pair of thyristor is switched ON simultaneously as the bidirectional switch GTO is switched OFF once a fault is detected. This will force the fault current to flow through the limiting inductor.

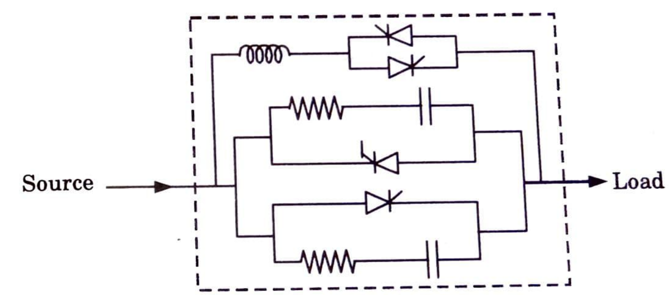


Fig. 4.17.2. Solid State Breaker (SSB).

C. **Solid State Transfer Switch (SSTS) :**

1. Fig. 4.17.3 shows a schematic diagram of a Solid State Transfer Switch (SSTS). This network configuring device transfers the power from the preferred feeder to the alternate feeder.

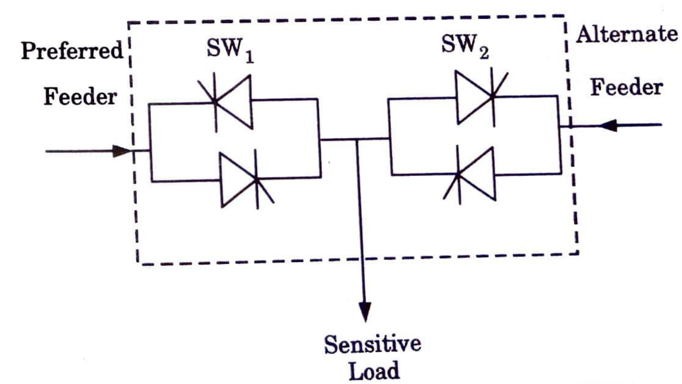


Fig. 4.17.3. Solid State Transfer Switch (SSTS).

2. The power transfer takes place when the voltage sag/swell occurs in the preferred feeder.

3. Solid state transfer switch consists of two opposite poled switch which is made of thyristor.
4. It is used for the protection of the sensitive loads. Let SW_1 and SW_2 are the switches made from thyristor. Switch SW_1 is at preferred feeder side and switch SW_2 is at alternate feeder side as shown in Fig. 4.17.3.
5. Let the voltage sag problem occurs in the preferred feeder then SSTS closes the switch SW_2 and current starts flowing through the alternate feeder to the load and the switch SW_1 disconnected.

Que 4.18. **Discuss the concept of FACTS and power flow.**

Answer

A. FACTS : Refer Q. 4.1, Page 4–2A, Unit-4.

B. Power flow :

1. FACTS (Flexible AC transmission system) technology opens new opportunities for controlling power and enhancing the capacity of present system. In a typical radial system

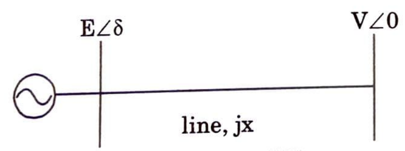


Fig. 4.18.1.

2. Power flow in the line is given by

$$P = \frac{EV}{X} \sin \delta$$

which is limited by :

a. Thermal capability of the line
b. Dielectric capability
c. Stability limit.

3. A control as power flow can be achieved by adjusting the parameter including series impedance, voltage, phase angle etc.
4. FACTS controllers control the above interrelated parameter to enable the line to carry power close to its thermal limits.
5. A well chosen FACTS-controller can overcome the limitation of a designated transmission line or a corridor.

C. Possibilities of power flow control in AC line are :

a. Control of line impedance (with a thyristor controlled series capacitor).
b. Control of angle (phase angle regulator).

c. Injecting a voltage in series with the line (may be perpendicular to the current flow or in line or at any angle with respect to driving voltage).
d. Combination of line impedance control with a series controlled and voltage regulation with a shunt controlled.

Que 4.19. **Define basic power flow conditions in power analysis. Also state its results.**

Answer

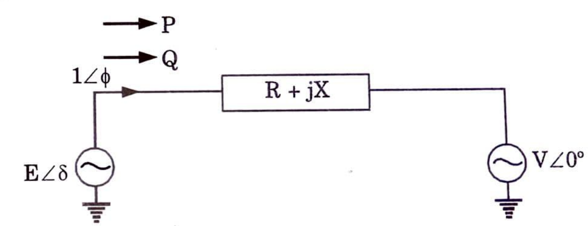


Fig. 4.19.1.

1. $$E\angle\delta = V\angle 0° + I\angle{-\phi}\,(R + jX)$$

2. $$E \cos \delta + jE\sin \delta = V + I\,(\cos \phi - j\sin \phi)\,(R + jX)$$

$$= V + IR \cos \phi + IX \sin \phi + j(IX \cos \phi - IR \sin \phi)$$

By separating the real and imaginary term, we get

$$E \cos \delta = V + IR \cos \phi + IX \sin \phi$$

$$E \sin \delta = IX \cos \phi - IR \sin \phi$$

3. If δ is so small, $E \cos \delta \cong E$

$$E - V = IR \cos \phi + IX \sin \phi$$

$$\Delta V = \frac{RP + XQ}{V}$$

$$E \sin \delta = IX \cos \phi - IR \sin \phi$$

$$E \sin \delta = \frac{XP - RQ}{V}$$

4. If the system is so large, $R \approx 0$

$$\Delta V = \frac{XQ}{V}$$

$$Q = \frac{(\Delta V)V}{X}$$

$$Q \propto (\Delta V) \quad \text{...(4.19.1)}$$

5. Eq. (4.19.1) shows that for transmission of reactive power Q from sending end to receiving end, sending end potential should be more than receiving end potential.

6.
$$E \sin \delta = \frac{XP}{V}$$
$$P = \frac{EV}{X} \sin \delta$$
$$P \propto \sin \delta$$
$$\sin \delta \propto \delta$$
$$P \propto \delta$$

7. Hence for transmission of active power from sending end to receiving end, the sending end should have phase advancement over receiving end.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What do you mean by FACTS ?

Ans. Refer Q. 4.1.

Q. 2. Explain the various types of FACTS controllers.

Ans. Refer Q. 4.2.

Q. 3. What do you mean by FACTS controllers ? What are the advantage and disadvantages of FACTS controllers also its importance ?

Ans. Refer Q. 4.3.

Q. 4. Discuss the working principle of DSTATCOM. How load compensation can be done using DSTATCOM ?

Ans. Refer Q. 4.7.

Q. 5. Define Custom Power Devices. Discuss the load compensation using DSTATCOM.

Ans. Refer Q. 4.8.

Q. 6. What are the basic principles of operations of SVC in power system network ?

Ans. Refer Q. 4.9.

Q. 7. Describe the working of TSC with the help of circuit diagram.

Ans. Refer Q. 4.11.

Q. 8. What are power conditioners ? Explain working principle of Unified Power Quality Conditioner (UPQC) ?

Ans. Refer Q. 4.15.

☺☺☺

UNIT 5

Harmonics

CONTENTS

PART-1

Causes of Harmonics, Current and Voltage Harmonics Measurement of Harmonics.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.1. **What do you understand by harmonics ? Also explain the cause of harmonics.**

Answer

A. **Harmonics :** Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate.

B. **Causes of harmonics :**

1. Harmonic distortion is caused by non-linear devices in the power system. A nonlinear device is one in which the current is not proportional to the applied voltage.
2. Figure 5.1.1 illustrates this concept by the case of a sinusoidal voltage applied to a simple non-linear resistor in which the voltage and current vary according to the curve shown.

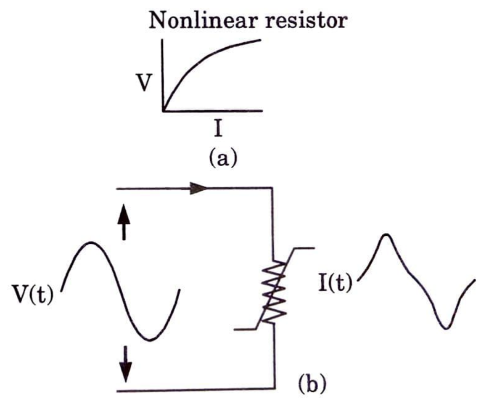


Fig. 5.1.1. Current distortion caused by non-linear resistance.

3. While the applied voltage is perfectly sinusoidal, the resulting current is distorted. Increasing the voltage by a few percent may cause the current to double and take on a different wave shape.

4. This is the source of most harmonic distortion in a power system. Fig. 5.1.2 illustrates that any periodic, distorted waveform can be expressed as a sum of sinusoids.

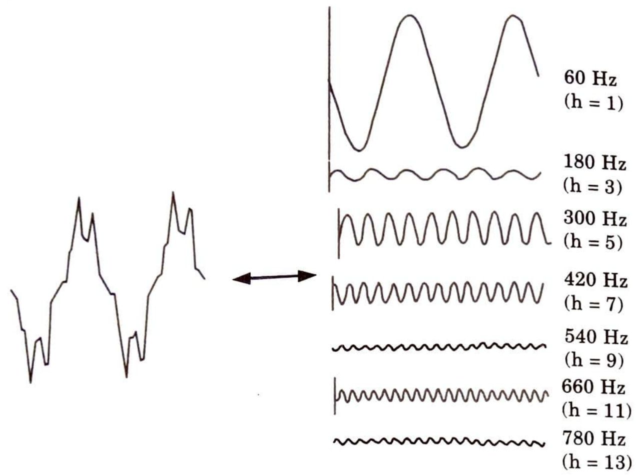


Fig. 5.1.2. Fourier series representation of a **distorted waveform.**

5. When a waveform is identical from one cycle to the next, it can be represented as a sum of pure sine waves in which the frequency of each sinusoid is an integer multiple of the fundamental frequency of the distorted wave. This multiple is called a harmonic of the fundamental.
6. Usually, the higher-order harmonics (above the range of the 25th to 50th, depending on the system) are negligible for power system analysis.
7. While they may cause interference with low-power electronic devices, they are usually not damaging to the power system.
8. Harmonics causes voltage waveforms with multiple zero-crossings which disrupt timing circuits. These resonances generally occur on systems with underground cable but no power factor correction capacitors.
9. In transformers, also, the source of harmonics is the shunt branch (magnetizing impedance) of the common 'T' model; the leakage impedance is linear.
10. Thus, the main sources of harmonic distortion will ultimately be end-user loads.
11. This is not to say that all end users who experience harmonic distortion will themselves have significant sources of harmonics, but that the harmonic distortion generally originates with some end-user's load or combination of loads.

Que 5.2. **Discuss about odd and even order harmonics.**

Answer

1. As their names imply, odd harmonics have odd numbers (*e.g.*, 3, 5, 7, 9, 11), and even harmonics have even numbers (*e.g.*, 2, 4, 6, 8, 10).
2. Harmonic number 1 is assigned to the fundamental frequency component of the periodic wave.
3. Harmonic number 0 represents the constant or DC component of the waveform.

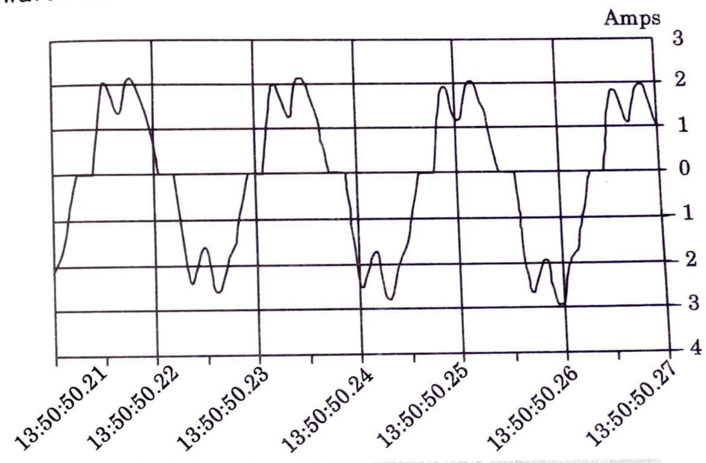


Fig. 5.2.2. Current waveform with DC component.

4. The DC component is the net difference between the positive and negative of one complete waveform cycle.
5. Figure 5.2.1 shows a periodic waveform with net DC content. The DC component of a waveform has undesirable effects, particularly on transformers, due to the phenomenon of core saturation.
6. The majority of non-linear loads produce harmonics that are odd multiples of the fundamental frequency.
7. The uneven operation may be due to the nature of the application or could indicate problems with the load circuitry.
8. Transformer magnetizing currents contain appreciable levels of even harmonic components and so do arc furnaces during startup.

Que 5.3. **What is harmonics number ?**

Answer

1. Harmonic number (h) refers to the individual frequency elements that comprise a composite waveform.
2. For example, h = 3 refers to the third harmonic component with a frequency equal to third times the fundamental frequency.

3. If the fundamental frequency is 60 Hz, then the 3rd (third) harmonic frequency is 180 Hz. The harmonic number 6 is a component with a frequency of 360 Hz.
4. Also, some applications use frequencies other than 50 or 60 Hz; for example, 400 Hz is a common frequency in the aerospace industry, while some AC systems for electric traction use 25 Hz as the frequency.
5. The inverter part of an AC adjustable speed drive can operate at any frequency between zero and its full rated maximum frequency, and the fundamental frequency then becomes the frequency at which the motor is operating.

Que 5.4. **Discuss about harmonic phase rotation and phase angle relationship.**

Answer

1. In a balanced three-phase electrical system, the voltages and currents have a positional relationship as shown in Fig. 5.4.1.

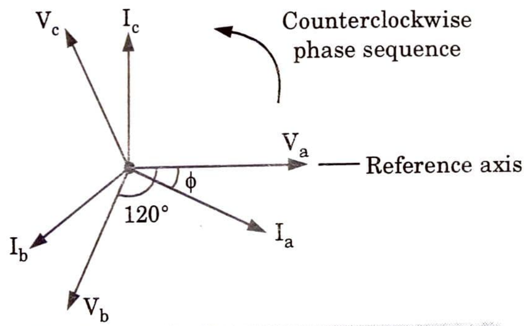


Fig. 5.4.1. Balanced three-phase power system.

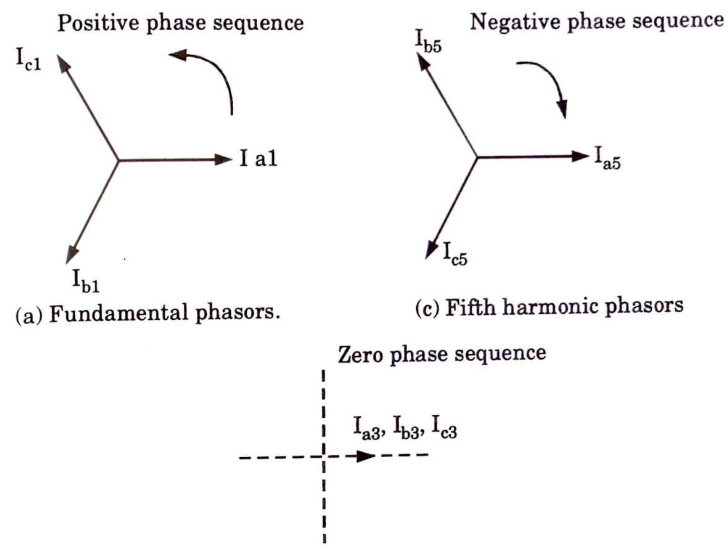
2. The three voltages are 120° apart and so are the three currents.
3. For harmonic analyses, these relationships are still applicable, but the fundamental components of voltages and currents are used as reference.
4. All other harmonics use the fundamental frequency as the reference. The fundamental frequencies have a positive-phase sequence.
5. The angle between the fundamental voltage and the fundamental current is the displacement power factor angle.
6. The following relationships are true for the fundamental frequency current components in a three-phase power system :

$$i_{a1} = I_{a1} \sin \omega t \quad ...(5.4.1)$$

$$i_{b1} = I_{b1} \sin (\omega t - 120°) \quad ...(5.4.2)$$

$$i_{c1} = I_{c1} \sin (\omega t - 240°) \quad ...(5.4.3)$$

7. The negative displacement angles indicate that the fundamental phasors i_{b1} and i_{c1} trail the i_{a1} phasor by the indicated angle. Fig. 5.4.2(a) shows the fundamental current phasors.



(a) Fundamental phasors. (c) Fifth harmonic phasors

(b) Third harmonic phasors.

Fig. 5.4.2.

8. The expressions for the third harmonic currents are :

$$i_{a3} = I_{a3} \sin 3\omega t \quad ...(5.4.4)$$

$$i_{b3} = I_{b3} \sin 3(\omega t - 120°) = I_{b3} \sin (3\omega t - 360°)$$

$$= I_{b3} \sin 3\omega t \quad ...(5.4.5)$$

$$i_{c3} = I_{c3} \sin 3 (\omega t - 240°) = I_{c3} \sin (3\omega t - 720°)$$

$$= I_{c3} \sin 3\omega t \quad ...(5.4.6)$$

9. The expressions for the third harmonics show that they are in phase and have zero displacement angle between them. Fig. 5.4.2(b) shows the third harmonic phasors.
10. The third harmonic currents are known as zero sequence harmonics due to the zero displacement angle between the three phasors.
11. The expressions for the fifth harmonic currents are :

$$i_{a5} = I_{a5} \sin 5\omega t \quad ...(5.4.7)$$

$$I_{b5} = I_{b5} \sin 5(\omega t - 120°) = I_{b5} \sin (\omega t - 600°)$$

$$= I_{b5} \sin (5\omega t - 240°) \quad ...(5.4.8)$$

$$I_{c5} = I_{c5} \sin 5(\omega t - 240°) = I_{c5} \sin (5\omega t - 1200°)$$

$$= I_{c5} \sin (5\omega t - 120°) \quad ...(5.4.9)$$

12. Fig. 5.4.2(c) shows the fifth harmonic phasors. Note that the phase sequence of the fifth harmonic currents is clockwise and opposite to that of the fundamental.
13. The fifth harmonics are negative sequence harmonics.

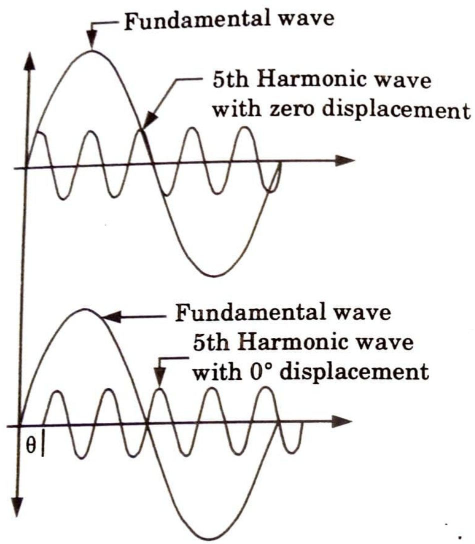


Fig. 5.4.3.

Que 5.5. **What do you understand by linear and nonlinear loads ? Compare them with suitable examples.** **AKTU 2014-15, Marks 05**

OR

Describe the following terms with suitable example :
1. **Inrush current**
2. **Power factor**
3. **Transient**
4. **Voltage imbalance**
5. **Nonlinear loads** **AKTU 2017-18, Marks 10**

Answer

1. **Inrush current :** When transformer is switched ON it takes in large lagging current known as inrush current.
2. **Power factor :**

a. The power factor is defined as the ratio of the active power (P) and voltamperes (S).

$$\text{Power factor} = \frac{P}{S} = \frac{P}{VI}$$

b. For sinusoidal waveforms the power factor is the cosine of the phase angle ϕ between voltage and current.

$$\text{Power factor} = \cos \phi$$

3. **Transient :** Refer Q. 1.4, Page 1–3A, Unit-1.
4. **Voltage imbalance :** Refer Q. 1.14, Page 1–15A, Unit-1.
5. **Non-linear loads :**

1. For non-linear loads the impedance is not constant, and the current is not proportion or the same as the voltage.
2. The current drawn by non-linear loads is not sinusoidal but is periodic, meaning that the current wave looks the same from, cycle to cycle.
3. Non-linear loads have low impedance so they use as much as three times the peak current as a resistive load.
4. Typical non-linear loads are electronic switch power supplies, DC/AC drive and induction furnace/arc furnace.

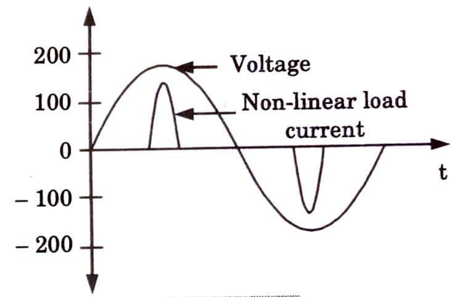


Fig. 5.5.1.

6. **Linear loads :**

1. For linear loads the impedance is constant, and the current is proportional to or the same as the voltage.
2. A linear element in a power system is a component in which the current is proportional to the voltage.
3. Typical linear loads are incandescent lights, motors and heaters.

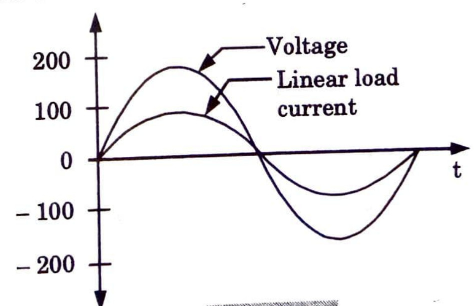


Fig. 5.5.2.

Que 5.6. **Write a short note on :**

1. Harmonic indices 2. Interharmonic **AKTU 2017-18, Marks 10**

Answer

1. **Harmonic measurement techniques (Harmonic indices) :** The two most commonly used indices for measuring the harmonic content of a waveform are :

a. Total Harmonic Distortion (THD) :

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

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

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

b. Total Demand Distortion (TDD) :

1. Current distortion levels can be characterized by a THD value.
2. A small current may have a high THD but not be a significant threat to the system. For example, many ASDs will exhibit high THD values for the input current when they are operating at very light loads.
3. Some analysts have attempted to avoid this difficulty by referring THD to the fundamental of the peak demand load current rather than the fundamental of the present sample.
4. This is called total demand distortion and serves as the basis for the guidelines in IEEE
5. Standard 519-1992, recommended practices and requirements for harmonic control in electrical power systems. It is defined as follows :

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

Where, I_L is the peak, or maximum demand load current at the fundamental frequency component.

2. **Interharmonic :** Refer Q. 1.15, Page 1–15A, Unit-1.

Que 5.7. **What are the causes of voltage and current harmonics ? Discuss the harmonics measurement techniques.**

AKTU 2015-16, Marks 10

AKTU 2016-17, Marks 15

AKTU 2018-19, Marks 10

OR

Explain the different types of harmonics.

Answer

A. Harmonic measurement techniques : Refer Q. 5.6, Page 5–9A, Unit-5.

B. Types of harmonics :

a. Current harmonics :

1. In a normal alternating current power system, the current varies sinusoidally at a specific frequency, usually (50 or 60 hertz). When a linear electrical load is connected to the system, it draws a sinusoidal current at the same frequency as the voltage.
2. Current harmonics are caused by non-linear loads. When a non-linear load, such as a rectifier is connected to the system, it draws a current that is not necessarily sinusoidal.
3. The current waveform can become quite complex, depending on the type of load and its interaction with other components of the system.

b. Voltage harmonics :

1. Voltage harmonics are mostly caused by current harmonics. The voltage provided by the voltage source will be distorted by current harmonics due to source impedance.
2. If the source impedance of the voltage source is small, current harmonics will cause only small voltage harmonics.
3. It is typically the case that voltage harmonics are indeed small compared to current harmonics.
4. For that reason, the voltage waveform can usually be approximated by the fundamental frequency of voltage.

Que 5.8. **What kinds of harmonics are generated due to switching operation of devices like IGBT, MOSFET and BJT etc. Explain the problems associated with kind of harmonics.**

AKTU 2018-19, Marks 10

Answer

A. Types of harmonics : Refer Q. 5.7, Page 5–9A, Unit-5.

B. Problem associated with harmonics : The problem associated with harmonics are :

1. Malfunction of other loads.

2. Additional heating and possible overvoltage due to resonance condition in the utility distribution and transmission equipment.
3. Error in metering and malfunction of utility relays.
4. Interface with communication and control signals.
5. Very poor power factor of operation.

PART-2

Effects of Harmonics on : Transformers, AC Motors, Capacitor Banks, Cables, Protection Devices, Energy Metering and Communication lines etc.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.9. **Explain the impact of harmonic distortion on :**

i. **Capacitors**
ii. **Transformers**
iii. **Motors.** **AKTU 2018-19, Marks 10**

OR

What are the effects of harmonics on Transformer and AC motors ? **AKTU 2017-18, Marks 10**

OR

What do you understand by harmonics ? What are different types of harmonics ? Explain the different detrimental effects of harmonics with suitable examples. **AKTU 2014-15, Marks 10**

OR

Discuss the effect of harmonics on the transformers and AC motors in details. **AKTU 2016-17, Marks 10**

Answer

A. **Harmonics :** Refer Q. 5.1, Page 5–2A, Unit-5.

B. **Types of harmonics :** Refer Q. 5.7, Page 5–9A, Unit-5.

C. **Effects of harmonics :**

a. **Impact on motors :**

1. Electric motors experience losses due to hysteresis and eddy currents set up in the iron core of the motor. These are proportional to the frequency of the current.
2. Since the harmonics are at higher frequencies, they produce higher core losses in a motor. This results in increased heating of the motor core.

b. **Impact on capacitors :**

1. The current flowing in the capacitor bank is also significantly large and rich in a monotonic harmonic during resonance.
2. A capacitor bank experiences high voltage distortion during resonance.
3. This current waveform typically indicates that the system is in resonance and a capacitor bank is involved.
4. In such a resonance condition, the rms current is typically higher than the capacitor rms current rating which leads to various losses.

c. **Impact on transformers :**

1. Transformers are designed to deliver the required power to the connected loads with minimum losses at fundamental frequency.
2. Harmonic distortion of the current, in particular, as well as of the voltage will contribute significantly to additional heating.
3. Due to harmonic the RMS current of the transformer being higher than its capacity.
4. Eddy current and core losses are increased due to harmonics in the transformer.

Que 5.10. **Discuss the effect of harmonics on cables.**

Answer

1. Current flowing in a cable produces I^2R losses. When the load current contains harmonic content, additional losses are introduced.
2. To compound the problem, the effective resistance of the cable increases with frequency because of the phenomenon known as skin effect.
3. Skin effect is due to unequal flux linkage across the cross section of the conductor which causes AC currents to flow only on the outer periphery of the conductor.
4. The capacity of a cable to carry nonlinear loads may be determined as follows :

i. The skin effect factor is calculated first. The skin effect factor depends on the skin depth, which is an indicator of the penetration of the current in a conductor.

ii. Skin depth (δ) is inversely proportional to the square root of the frequency,

$$\delta = S / \sqrt{f}$$

where S = A proportionality constant based on the physical characteristics of the cable and its magnetic permeability

f = Frequency of the current.

iii. If R_{dc} is the DC resistance of the cable, then the AC resistance at frequency f,

$$(R_f) = K \times R_{dc}$$

where, K is a constant.

Que 5.11. **Describe the effect of harmonics on protective devices.**

Answer

1. Harmonic currents influence the operation of protective devices. Fuses and motor thermal overload devices are prone to nuisance operation when subjected to nonlinear currents.
2. This factor should be given due consideration when sizing protective devices for use in a harmonic environment.
3. Electromechanical relays are also affected by harmonics. Depending on the design, an electromechanical relay may operate faster or slower than the expected times for operation at the fundamental frequency alone.
4. Such factors should be carefully considered prior to placing the relays in service.

Que 5.12. **Explain the effect of harmonics on communication lines.**

Answer

1. Harmonic currents flowing on the utility distribution system or within an end-user facility can create interference in communication circuits sharing a common path.
2. Voltages induced in parallel conductors by the common harmonic currents often fall within the bandwidth of normal voice communications.
3. Harmonics between 540 (ninth harmonic) and 1200 Hz are particularly disruptive. The induced voltage per ampere of current increases with frequency.

4. Triplen harmonics (3^{rd}, 9^{th}, 15^{th}) are especially troublesome in four-wire systems because they are in phase in all conductors of a three-phase circuit and, therefore, add directly in the neutral circuit, which has the greatest exposure with the communications circuit.
6. Harmonic currents on the power system are coupled into communication circuits by either induction or direct conduction.
7. Fig. 5.12.1 illustrates coupling from the neutral of an overhead distribution line by induction.
8. This was a severe problem in the days of open wire telephone circuits.

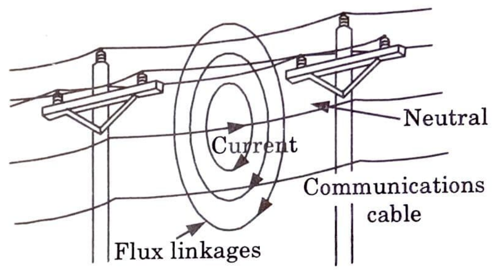


Fig. 5.12.1. Inductive coupling of power system residual current to telephone circuit.

9. Now, with the prevalent use of shielded, twisted-pair conductors for telephone circuits, this mode of coupling is less significant.
10. The direct inductive coupling is equal in both conductors, resulting in zero net voltage in the loop formed by the conductors.
11. Inductive coupling can still be a problem if high currents are induced in the shield surrounding the telephone conductors.
12. Current flowing in the shield causes an IR drop, which results in a potential difference in the ground references at the ends of the telephone cable. Shield currents can also be caused by direct conduction.

Que 5.13. **Describe the effect of harmonics on energy metering.**

Answer

1. When electricity is passed through any circuit, there will be some losses, depending on the nature of the load. Due to vibrant characteristics of load, the current wave becomes complex in characteristics.
2. Harmonics are superposition of waveforms, having very high frequency. Induction furnaces, switch mode power supplies of modern consumer goods, etc., are major sources of harmonic current.

3. The presence of unwanted harmonics will overload transformers, and create low pf. The failure of the equipment due to harmonics occurs without any warning.
4. The effect of harmonics on power metering equipment and other components depends on the physical location, loading, etc. A same pattern of harmonic can affect two installations in different manners.
5. The voltage generated by utilities need not be sinusoidal, constant amplitude and frequency. If the applied voltage is sinusoidal, resulting the load to draw sinusoidal current, the system is characterized as 'linear' one. Here Ohm's law is strictly followed.
6. But some of the modern equipment will not obey this route. The resistance of the device will not be constant and transforms during each sine wave.
7. The increasing use of electronic equipment, furnaces, computers, air conditioners, poor-quality lighting sources, etc. has polluted the power quality, *i.e.*, stable voltage, undistorted waveform, and reducing harmonics to an accepted level is a challenge before any utility which considers power quality seriously.
8. The performance of static energy meters deteriorates due to harmonic signals in the power distribution system. Non-linear loads generate harmonics and export it to the utility. Electronic meters that register harmonic energy flow register consumption less than the actual.
9. If power supply, which is distorted by a harmonic component, is supplied to another linear load, then the electronic meter registers more energy than the actual since the harmonic current waveform is in phase with harmonic voltage.
10. It is observed that 3^{rd}, 5^{th} and 13^{th} harmonics current is more effective than other harmonics as the harmonic amplitude (both voltage and current) decreases with increase in the harmonic level.
11. Non-linear loads generate harmonic signals up to 13^{th} harmonic which will flow from the load side to the bus in such a way that the current harmonic signal will be out of phase with respect to that voltage.
12. If a consumer is successful in generating harmonics, the accuracy of the measuring gadget will be endangered. If a 'device' that is capable of generating harmonics is introduced in any part of the power circuit, the chance of physical tracing would not be so easy.

PART-3

Harmonics Mitigation Techniques.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.14. Discuss the Harmonics Mitigation Techniques in detail.

AKTU 2016-17, Marks 10

OR

Discuss the effect of harmonics on transformers and AC motors in detail. How can this be mitigated ?

AKTU 2015-16, Marks 10

Answer

A. **Effect of Harmonics :** Refer Q. 5.9, Page 5–11A, Unit-5.

B. **Mitigation techniques :**

a. **In-line reactors or chokes :**

1. A simple method to control harmonic distortion generated by adjustable-speed drives involves a relatively small reactor, or choke, inserted at the line input side of the drive. This is particularly effective for PWM-type drives.
2. The inductance slows the rate at which the capacitor on the DC bus can be charged and forces the drive to draw current over a longer time period. The net effect is a lower-magnitude current with much less harmonic content while still delivering the same energy.

b. **Zig-zag transformers :**

1. Zig-zag transformers are often applied in commercial facilities to control zero-sequence harmonic components. A zig-zag transformer acts like a filter to the zero-sequence current by offering a low-impedance path to neutral.
2. This reduces the amount of current that flows in the neutral back toward the supply by providing a shorter path for the current.
3. To be effective, the transformer must be located near the load on the circuit that is being protected.
4. Thus, the zigzag transformer can almost always reduce neutral currents due to zero-sequence harmonics to acceptable levels.

c. **Active filters :**

1. 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.
2. However, they have the distinct advantage that they do not resonate with the system. Active filters can work independently of the system impedance characteristics.
3. Thus, they can be used in very difficult circumstances where passive filters cannot operate successfully because of parallel resonance problems.

Que 5.15. What are the passive filters ? Explain the factors to be considered for designing a passive filter. Also explain their limitations.

AKTU 2014-15, Marks 10

AKTU 2015-16, Marks 15

Answer

A. **Passive filters :**

1. 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.
2. 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.

B. **Design :**

1. For an effective filter design, its impedance must be less than the source impedance.
2. It may result in large size of the filter in a stiff system with low source impedance, which may result in overcompensation of the reactive power.
3. This overcompensation may cause overvoltage on switching in and undervoltage on switching out the passive filter.
4. 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.

C. **Limitation of passive filters :**

1. The passive filters are not adaptable to varying system conditions and remain rigid once they are installed in an application. The size and tuned frequency cannot be altered easily.
2. The change in operating condition of the system may result in detuning of the filter and it may cause increased distortion. Such a change may happen undetected provided there is online detection or monitoring in the system.

Que 5.16. Explain the different types of hybrid filter connections. What are the reasons of their popularity ?

AKTU 2014-15, Marks 10

Answer

Hybrid filters :

1. Hybrid filters, consisting of series and shunt passive filters as shown in Fig. 5.16.1 and Fig. 5.16.2 can be used in many industrial applications.
2. Both passive shunt and passive series filters have some drawbacks if they are used individually.
3. However, a passive hybrid filter, consisting of a single tuned passive series filter with a single tuned passive shunt filter and a high-pass passive shunt filter, offers very good filtering characteristics.
4. A single tuned passive series filter is able to block resonance between the supply and the passive shunt filter and absorbs excess reactive power of the passive shunt filter at light load conditions.
5. This type of hybrid passive filter offers very good filtering characteristics under varying loads.
6. Similarly, other types of passive hybrid filters such as low-pass broadband filters are considered a good option, which consist of leakage reactance of a series transformer for stepping down the voltage for the load.
7. And then a capacitor at the load offering good filtering characteristics with a low cutoff frequency and preventing harmonics from penetrating into the high voltage side above this cutoff frequency.
8. Moreover, a combination of a passive shunt filter and a small series active filter is considered a low-cost ideal hybrid filter for many large power rating applications.

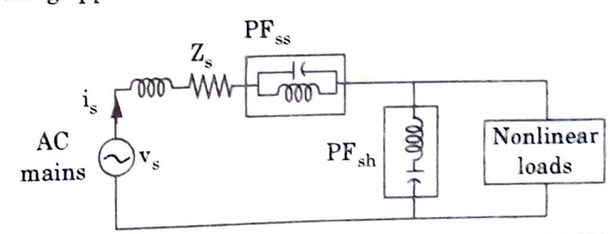


Fig. 5.16.1. A hybrid filter as a combination of passive series (PF_{ss}) and passive shunt (PF_{sh}) filters.

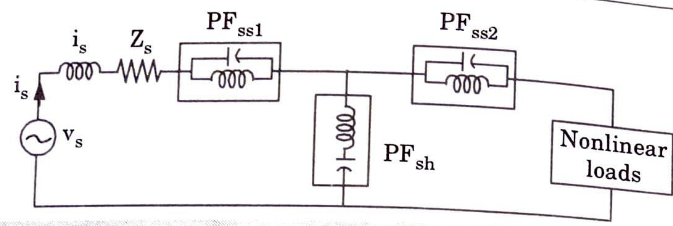


Fig. 5.16.2. A hybrid filter as a combination of passive series (PF_{ss1}), passive shunt (PF_{sh}), and passive series (PF_{ss2}).

Que 5.17. **What are the causes of voltage and current harmonic ? Determine RMS and THD of the following waveform.**

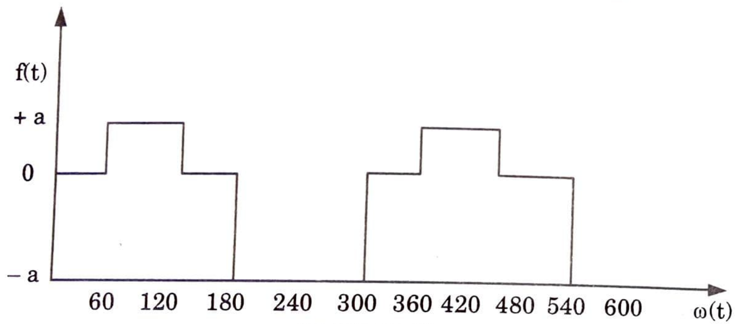


Fig. 5.17.1.

AKTU 2017-18, Marks 10

Answer

A. **Cause :** Refer Q. 5.7, Page 5–9A, Unit-5.

B. **Numerical :**

1.
$$\text{RMS} = \left[\frac{1}{2\pi}\left\{(a)^2\frac{\pi}{3} + (2a)^2 \times \frac{\pi}{3} + (a)^2 \times \frac{\pi}{3}\right\}\right]^{1/2}$$
$$= \left[\frac{1}{2\times 3} \times 6a^2\right]^{1/2} = a$$

2. THD,
$$x_{1\,\text{rms}} = \frac{2x_{DC}}{\sqrt{2}\pi} = \frac{2x\dfrac{2a}{\sqrt{2}}}{\sqrt{2}\pi} = \frac{2a}{\pi}$$
$$\text{RMS harmonic} = \sqrt{a^2 - \left(\frac{2a}{\pi}\right)^2}$$

$$= \frac{a}{\pi}\sqrt{\pi^2 - 4}$$
$$\text{THD} = \frac{\dfrac{a}{\pi}\sqrt{\pi^2-4}}{\dfrac{2a}{\pi}} = \frac{\sqrt{\pi^2-4}}{2} = 1.21$$

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Discuss about odd and even order harmonics.
Ans. Refer Q. 5.2.

Q. 2. What do you understand by linear and nonlinear loads ? Compare them with suitable examples.
Ans. Refer Q. 5.5.

Q. 3. Write a short note on :
1. **Harmonic indices**
2. **Interharmonic**

Ans. Refer Q. 5.6.

Q. 4. What are the causes of voltage and current harmonics ? Discuss the harmonic measurement techniques.
Ans. Refer Q. 5.7.

Q. 5. What kinds of harmonics are generated due to switching operation of devices like IGBT, MOSFET and BJT etc. Explain the problems associated with kind of harmonics.
Ans. Refer Q. 5.8.

Q. 6. What are the effects of harmonics on Transformer and AC motors ?
Ans. Refer Q. 5.9.

Q. 7. Discuss the effect of harmonics on cables.
Ans. Refer Q. 5.10.