PVP 23

Code: 23EE6402

II B.Tech - II Semester – Honors Examinations – APRIL 2026

ELECTRIC POWER QUALITY
(HONORS in ELECTRICAL & ELECTRONICS ENGINEERING)

Duration: 3 hours Max. Marks: 70

Note: 1. This question paper contains two Parts A and B.
2. Part-A contains 10 short answer questions. Each Question carries 2 Marks.
3. Part-B contains 5 essay questions with an internal choice from each unit. Each Question carries 10 marks.
4. All parts of Question paper must be answered in one place.

BL – Blooms Level CO – Course Outcome

PART – A

		BL	CO
1.a)	Differentiate between impulsive and oscillatory transients.	L2	CO1
b)	Mention the effects of voltage sag on equipment.	L1	CO1
c)	What is meant by switching transients?	L1	CO2
d)	State the principle of overvoltage protection.	L1	CO2
e)	Illustrate the effects of voltage flicker on lighting loads.	L3	CO3
f)	State the need for voltage regulation in power systems.	L1	CO3
g)	Explain the effect of harmonics on energy meters.	L4	CO3
h)	Distinguish voltage distortion and current distortion.	L2	CO4
i)	Identify any two power quality issues caused by DG.	L2	CO5
j)	Illustrate the objectives of PQ monitoring.	L3	CO5

PART – B

			BL	CO	Max. Marks
UNIT-I					
2	a)	Classify and explain the general power quality problems with examples.	L2	CO1	5 M
	b)	Discuss voltage fluctuation and flicker, their causes and impact on lighting loads.	L2	CO2	5 M
OR					
3	a)	Analyze the impact of poor power quality on electrical equipment.	L3	CO2	5 M
	b)	Explain power frequency variations and their influence on system stability.	L2	CO1	5 M
UNIT-II					
4	a)	Explain the impact of transient overvoltages on Utility system lightning.	L2	CO2	5 M
	b)	Evaluate different overvoltage protection techniques used in modern power systems.	L4	CO2	5 M
OR					
5	a)	Describe the principles of overvoltage protection with suitable examples.	L2	CO3	5 M
	b)	Discuss utility capacitor switching transients, their causes, effects, and mitigation methods.	L2	CO3	5 M
UNIT-III					
6	a)	Evaluate the effectiveness of capacitor banks in voltage regulation.	L3	CO3	5 M
	b)	Analyze how distributed energy resources can be used for voltage regulation.	L3	CO3	5 M

OR					
7	a)	Illustrate the principles of regulating the voltage.	L2	CO2	5 M
	b)	Explain end-user capacitor applications and their benefits.	L2	CO3	5 M
UNIT-IV					
8	a)	Analyze the effect of harmonic distortion on capacitors, motors.	L3	CO4	5 M
	b)	Describe the concept of Point of Common Coupling and its importance in harmonic control.	L2	CO3	5 M
OR					
9	a)	Explain the working principle of active power filters and their advantages.	L2	CO5	5 M
	b)	Derive the expression for total harmonic distortion, total demand distortion and explain their importance in power systems.	L2	CO3	5 M
UNIT-V					
10	a)	Explain the interface of DG with the utility system, including converters and protection schemes.	L2	CO5	5 M
	b)	Describe the historical development of PQ measuring instruments.	L2	CO5	5 M
OR					
11	a)	Explain different types of PQ measurement equipment and their functions.	L2	CO5	5 M
	b)	Analyze the operating conflicts between DG and utility systems.	L3	CO5	5 M

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SCHEME OF EVALUATION

PART-A

1. **a) Differentiate between, impulsive and oscillatory 2M**

Ans: Any 2 differences Each 1M

b) Mention the effects of voltage sag on equipment 2M

Ans: Any 2 effects Each 1M

c) What is meant by switching transients 2M

Ans: Meaning of switching transients 2M

d) State the principle of overvoltage protection 2M

Ans: Principle of overvoltage protection 2M

e) Illustrate the effects of voltage flicker on lighting 2M

Ans: Any 2 effects Each 1M

f) State the need for voltage regulation in power 2M

Ans: Need for voltage regulation 2M.

g) Explain the effect of harmonics on energy meters. 2M

Ans: effect of harmonics on energy meters **2M**

h)Distinguish voltage distortion and current distortion. 2M

Ans: Any 1 difference Each 1M

i) Identify any two power quality issues caused by DG. 2M

Ans: Any two power quality issues caused by DG Each 1M

j) Illustrate the objectives of PQ monitoring. 2M

Ans: Any 2 objectives Each 1M

PART - B

UNIT-I

2 a) Classify and explain the general power quality problems with examples.

Ans: Any 3 classifications Each 1M= 3*1=3M
Examples : 2M

b) Discuss voltage fluctuation and flicker, their causes and impact on lighting loads

Ans: Voltage fluctuation 2.5M Flicker 2.5M

OR

3 a)Analyze the impact of poor power quality on electrical equipment.
Ans: Impact of poor power quality on any 2 electrical equipment Each 2.5M
2*2.5M=5M

b) Explain power frequency variations and their influence on system stability.
Ans: Power frequency Variations 5M

UNIT-II

4. a) Explain the impact of transient overvoltages on Utility system lightning.

Ans: Any 2 impacts on utility system lightning Each 2.5M 2*2.5M=5M

b) Evaluate different overvoltage protection techniques used in modern power systems.

Ans: Any 2 overvoltage protection techniques Each 2.5M 2*2.5M=5M

OR

5. a) Describe the principles of overvoltage protection with suitable examples.

Ans: principles of overvoltage protection 5M

b) Discuss utility capacitor switching transients their causes, effects, and mitigation methods.

Ans: Any 2 causes , effects, mitigation methods Each 2.5M
2*2.5M=5M

UNIT-III

6. a) Evaluate the effectiveness of capacitor banks in voltage regulation.

Ans: Importance of capacitor banks in voltage regulation 5M

b) Analyze how distributed energy resources can be used for voltage regulation.

Ans: Importance of distributed energy resources for voltage regulation 5M

OR

7.a) Illustrate the principles of regulating the voltage,

Ans: Principles of regulating the voltage 5M

b) Explain end-user capacitor applications and their benefits,

Ans: Any 2 end user capacitor applications Each 2.5M 2*2.5=5M

UNIT-IV

8. a) Analyze the effect of harmonic distortion on capacitors, motors.

Ans: effect of harmonic distortion on capacitors 2.5M

effect of harmonic distortion on motors 2.5M

b) Describe the Concept of Point of Common Coupling and its importance in harmonic control.

Ans: Concept of PCC 2.5M Importance in harmonic control 2.5M

OR

9. a) Explain the working principle of active power filters and their advantages,

Ans: Working principle of Active power filters 4M Advantages 1M

'b) Derive the expression for total harmonic distortion, total demand distortion and explain their j importance in power systems

Ans: THD expression with importance 2.5M TDD expression with importance 2.5M

UNIT-V

10. a) Explain the interface of DG with the utility system, including converters and protection schemes.

Ans: Various interfaces with explanation 2M

Converter interface 3M

b) Describe the historical development of PQ measuring instruments,

Ans: Historical development of PQ measuring instruments 5M

OR

11.a) Explain different types of PQ measurement equipment and their functions

Ans: Any two PQ measurement equipment with function Each 2.5M 2*2.5M=5M

b) Analyze the operating conflicts between DG and utility systems

Ans: Any two operating conflicts between DG & utility systems Each 2.5M 2*2.5M=5M

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PART-A

1. **a) Differentiate between, impulsive and oscillatory**

Ans: **Impulsive:** Sudden, unidirectional spike (e.g., lightning).
Oscillatory: Voltage/current fluctuates back and forth (damped waveform).

b) Mention the effects of voltage sag on equipment

Ans: Equipment shutdown or malfunction, Data loss in computers, Reduced motor torque

c)What is meant by switching transients

Ans: Short-duration overvoltages caused by switching operations in power systems.

d) State the principle of overvoltage protection

Ans: Divert excess voltage safely to ground using devices like surge arresters

e) Illustrate the effects of voltage flicker on lighting

Ans: Visible lamp flickering ,Eye strain and discomfort

f) State the need for voltage regulation in power

Ans: To maintain constant voltage for proper operation of equipment.

g) Explain the effect of harmonics on energy meters.

Ans: Causes inaccurate readings (over/under registration).

h)Distinguish voltage distortion and current distortion.

Ans: **Voltage distortion:** Deviation in voltage waveform

Current distortion: Deviation in current waveform due to nonlinear loads

i) Identify any two power quality issues caused by DG.

Ans: Voltage fluctuations, Harmonics

j) Illustrate the objectives of PQ monitoring.

Ans: Detect disturbances, Ensure reliable power supply, Improve system performance

PART - B

UNIT-I

2 a) Classify and explain the general power quality problems with examples.

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

The IEC classifies electromagnetic phenomena into the groups as given below.

(i) Conducted low-frequency phenomena:

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

(ii) Radiated low-frequency phenomena

Magnetic fields
Electric fields

(iii) Conducted high-frequency phenomena

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

(iv) Radiated high-frequency phenomen

Magnetic fields
Electric fields
Electromagnetic fields
Continuous waves

Transients

(v) **Electrostatic discharge phenomena (ESD)**
(vi) **Nuclear Electromagnetic Pulse (NEMP)**

b) Discuss voltage fluctuation and flicker, their causes and impact on lighting loads

Ans: Voltage fluctuations: Voltage fluctuations are systematic variations of the voltage envelope or a series of random voltage changes, the magnitude of which does not normally exceed the voltage ranges specified by ANSI C84.1 of 0.9 to 1.1 p.u

IEC 61000-2-1 defines various types of voltage fluctuations. IEC 61000-2-1 Type (d) voltage fluctua tions, which are characterized as a series of random or continuous volt age fluctuations. Loads that can exhibit continuous, rapid variations in the load cur rent magnitude can cause voltage variations that are often referred to as flicker. The term flicker is derived from the impact of the voltage fluctuation on lamps such that they are perceived by the human eye to flicker.

An example of a voltage waveform which produces flicker is shown in Fig. 2.12. This is caused by an arc furnace, one of the most common causes of voltage fluctuations on utility transmission and distribution systems. The flicker signal is defined by its rms magnitude expressed as a percent of the fundamental. Voltage flicker is measured with respect to the sensitivity of the human eye.

Voltage flicker: Voltage flicker is not technically a long-term voltage varia tion, it is included in this chapter because the root cause of problems is the same: The system is too weak to support the load. Also, some of the solutions are the same as for the slow-changing voltage regulation problems. The voltage variations resulting from flicker are often within the normal service voltage range, but the changes are sufficiently rapid to be irritating to certain end users.

In the early 1900s, many studies were done on humans to deter mine observable and objectionable levels of flicker. Many curves, such as the one shown in Fig. 7.14, were developed by various companies to determine the severity of flicker. The flicker curve shown in Fig. 7.14 was developed by C. P. Xeniş and W. Perine in 1937 and was based upon data obtained from 21 groups of observers. In order to account for the nature of flicker, the observers were exposed to vari ous waveshape voltage variations, levels of illumination, and types of lighting.

OR

3 a)Analyze the impact of poor power quality on electrical equipment.
Ans: Poor power quality directly translates into equipment failure, downtime, and financial loss. Different power quality problems affect electrical equipment:

1. Impact on Motors and Drives
Induction motors are highly sensitive to voltage variations and imbalance.

- Voltage sag Reduced torque, motor stalling, overheating
- Voltage unbalance Causes negative sequence currents → excessive heating (even 2-3% imbalance can increase temperature drastically)
- Harmonics Additional losses (eddy currents, hysteresis) insulation stress

Example: Industrial pumps tripping during voltage dips in distribution feeders.
2. Impact on Transformers
Transformers suffer mainly from waveform distortion.

- Harmonics Increased copper and core losses overheating
- DC components Core saturation noise, vibration
- Overvoltage transients Insulation breakdown

Example: Overheating of distribution transformers in IT parks due to nonlinear loads (SMPS).
3. Impact on Power Electronic Equipment
Devices like computers, PLCs, and VFDs are highly sensitive.

- Voltage dips/interruption System shutdown, data loss
- Transients Damage to semiconductor devices (IGBTs, MOSFETs)
- Harmonics Malfunction of control circuits

Example: PLC-controlled manufacturing line stopping due to momentary voltage sag.
4. Impact on Lighting Systems
Lighting is directly affected by voltage quality.

- Voltage fluctuations Flicker visual discomfort, reduced productivity
- Overvoltage Reduced lamp life
- Harmonics Ballast overheating (in fluorescent lamps)

Example: Flickering lights near arc furnace industries.
5. Impact on Capacitors and Power Factor Correction Equipment

- Harmonics Resonance conditions capacitor overheating or explosion
- Overvoltage Dielectric failure

Example: Capacitor bank failure in industrial plants with heavy VFD loads.

b) Explain power frequency variations and their influence on system stability.

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

- **Sources:** Due to faults on the bulk power transmission system, a large block of load being disconnected, or a large source of generation going off-line. On modern interconnected power system, frequency variations are rare. 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 change.

Pst samples are normally reported at 10-min intervals. The Plt value is produced every 2h from the Pst values. The size of the frequency shift and its duration depend on the load characteristics and the response of the generation control system to load changes.

UNIT-II

4. a) Explain the impact of transient overvoltages on Utility system lightning.

Ans: Many power quality problems stem from lightning. Not only can the high-voltage impulses damage load equipment, but the temporary fault that follows a lightning strike to the line causes voltage sags and interruptions. Here are some strategies for utilities to use to decrease the impact of lightning.

Shielding

One of the strategies open to utilities for lines that are particularly susceptible to lightning strikes is to shield the line by installing a grounded neutral wire over the phase wires. This will intercept most lightning strokes before they strike the phase wires. 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. Shielding is not quite as simple as adding a wire and grounding it every few poles

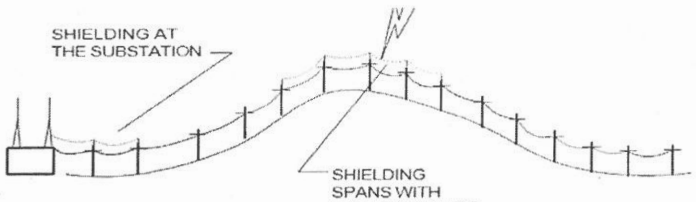

Figure 2.29 Shielding a portion of a distribution feeder to reduce the incidence of temporary lightning-induced faults.

Figure 2.29 illustrates this concept. It is not uncommon for a few spans near the substation to be shielded.

Line arresters

Another strategy for lines that are struck frequently is to apply arresters periodically along the phase wires. Normally, lines flash over first at the pole insulators. Therefore, preventing insulator flashover will reduce the interruption and sag rate significantly. Stansberry[6] argues that this is more economical than shielding and results in fewer line flashovers. Neither shielding nor line arresters will prevent all flashovers from lightning.

Cable protection

One increasingly significant source of extended power outages on underground distribution (UD) systems is cable failures.

Many utilities are exploring ways of extending the cable life by arrester protection. Cable replacement is so costly that it is often worthwhile to retrofit the system with arresters even if the gain in life is only a few years. Depending on voltage class, the cable may have been installed with only one arrester at the riser pole or both a riser- pole arrester and an open-point arrester (see Fig. 2.35).

To provide additional protection, utilities may choose from a number of options:

1. Add an open-point arrester, if one does not exist.
2. Add a third arrester on the next-to-last transformer.
3. Add arresters at every transformer.
4. Add special low-discharge voltage arresters.
5. Inject an insulation-restoring fluid into the cable.

b) Evaluate different overvoltage protection techniques used in modern power systems.

Ans:

Surge arresters and transient voltage surge suppressors

Arresters and TVSS devices protect equipment from transient over- voltages by limiting the maximum voltage, and the terms are some- times used interchangeably. However, TVSSs are generally associated with devices used at the load equipment. The elements that make up these devices can be classified by two different modes of operation, crowbar and clamping. Crowbar devices are normally open devices that conduct current during overvoltage transients. Clamping devices for ac circuits are commonly nonlinear resistors (varistors) that conduct very low amounts of current until an overvoltage occurs. Then they start to conduct heavily, and their impedance drops rapidly with increasing voltage.

Low-pass filters

Low-pass filters use the pi-circuit principle illustrated to achieve even better protection for high-frequency transients. For general usage in electric circuits, low-pass filters are composed of series inductors and parallel capacitors. This *LC* combination provides a low- impedance path to ground for selected resonant frequencies. In surge protection usage, voltage clamping devices are added in parallel to the capacitors. In some designs, there are no capacitors.

A common hybrid protector that combines two surge suppressors and a low-pass filter to provide maximum protection. It uses a gap-type protector on the front end to handle high-energy transients.

Low-impedance power conditioners

Low-impedance power conditioners (LIPCs) are used primarily to interface with the switch-mode power supplies found in electronic equipment. LIPCs differ from isolation transformers in that these conditioners have a much lower impedance and have a filter as part of their design .The filter is on the output side and protects against high-frequency, source-side, common-mode, and normal-mode disturbances (i.e., noise and impulses).

OR

5. a) Describe the principles of overvoltage protection with suitable examples.

Ans:

Principles of Overvoltage Protection

The fundamental principles of overvoltage protection of load equipment are

Limit the voltage across sensitive insulation.

1. Divert the surge current away from the load.
2. Block the surge current from entering the load.
3. Bond grounds together at the equipment.
4. Reduce, or prevent, surge current from flowing between grounds.
5. Create a low-pass filter using limiting and blocking principles.

Figure 2.16 illustrates these principles, which are applied to protect from a lightning strike.The main function of surge arresters and transient voltage surge suppressors (TVSSs) is to limit the voltage that can appear between two points in the circuit.

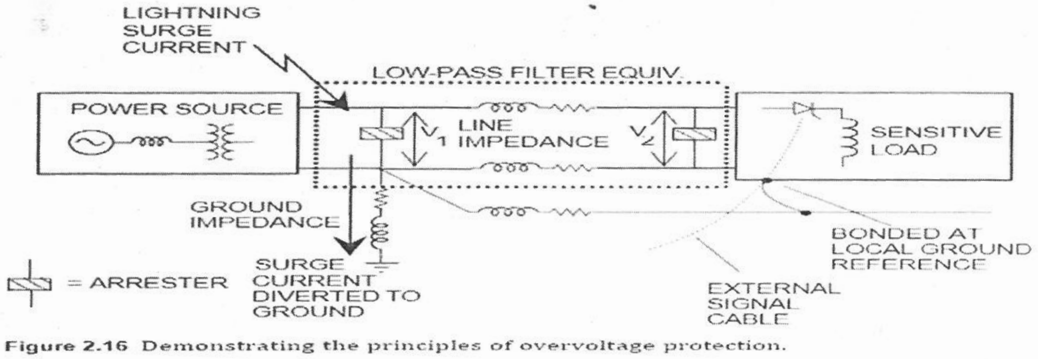

Figure 2.16 Demonstrating the principles of overvoltage protection.

In Fig. 2.16 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. Keep in mind that the local ground may not remain at zero potential during transient impulse events. Surge suppression devices should be located as closely as possible to the critical insulation with a minimum of lead length on all terminals. This phenomenon is a common reason for failure of electronic devices.

b) Discuss utility capacitor switching transients their causes, effects, and mitigation methods.

Ans:

Utility Capacitor-Switching Transients: This section describes how utilities can deal with problems related to capacitor-switching transients.

Switching times

Capacitor-switching transients are very common and usually not dam- aging. However, the timing of switching may be unfortunate for some sensitive industrial loads. For example, if the load picks up the same time each day, the utility may decide to switch the capacitors coincident with that load increase.

Pre insertion resistors

Pre insertion resistors can reduce the capacitor-switching transient considerably. The first peak of the transient is usually the most dam aging. The idea is to insert a resistor into the circuit briefly so that the first peak is damped significantly.

Synchronous closing

Another popular strategy for reducing transients on capacitor switching is to use a synchronous closing breaker. This is a relatively new technology for controlling capacitor-switching transients. Synchronous closing prevents transients by timing the contact closure such that the system voltage closely matches the capacitor voltage at the instant the contacts mate.

This breaker would normally be applied on the utility sub- transmission or transmission system (72- and 145-kV classes). This is a three-phase SF_6 breaker.

A vacuum switch made for this purpose. It is applied on 46-kV-class capacitor banks. It consists of three independent poles with separate controls. The timing for synchronous closing is determined by anticipating an upcoming voltage zero. One phase of a newer type of three-phase synchronous switch used for distribution capacitor banks. This particular technology uses a vacuum switch encapsulated in a solid dielectric.

Capacitor location

For distribution feeder banks, a switched capacitor may be too close to a sensitive load or at a location where the transient overvoltages tend to be much higher. Often, it may be possible to move the capacitor downline or to another branch of the circuit and eliminate the problem. The strategy is to either create more damping with more resistance in the circuit or to get more impedance between the capacitor and the sensitive load.

The success of this strategy will depend on a number of factors. Of course, if the capacitor is placed at a large load to supply reactive power specifically for that load, moving the bank may not be an option. Then, techniques for soft switching or switching at noncritical times must be explored.

UNIT-III

6. a) Evaluate the effectiveness of capacitor banks in voltage regulation.

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

1. **Shunt capacitors:**
   - The presence of a shunt capacitor at the end of a feeder results in a gradual change in voltage along the feeder.
   - Ideally, the percent voltage rise at the capacitor would be zero at no load and rise to maximum at full load.
   - However, with shunt capacitors, percent voltage rise is essentially independent of load
   - Therefore, automatic switching is often employed in order to deliver the desired regulation at high loads.
   - Application of shunt capacitors may also result in a variety of harmonic problems
2. **Series capacitors:**
   - Unlike the shunt capacitor, a capacitor connected in series with the feeder results in a voltage rise at the end of the feeder that varies directly with load current.
   - Voltage rise is zero at no load and maximum at full load.
   - Thus, series capacitors do not need to be switched in response to changes in load.

Moreover, a series capacitor will require far smaller kV and kvar ratings than a shunt capacitor delivering equivalent regulation.

But series capacitors have several disadvantages:

1. Firstly, they cannot provide reactive compensation for feeder loads. Shunt capacitors, on the other hand, are effective when system capac ity is limited by high feeder current as well.
2. Secondly, series capacitors cannot tolerate fault current. This would result in a catastrophic overvoltage and must be prevented by bypassing the capacitor through an automatic switch. These include resonance and/or hunting with synchronous and induction motors, and ferroresonance with transformers. Because of these concerns, the application of series capacitors on distribution systems is very limited.

b) Analyze how distributed energy resources can be used for voltage regulation.

Ans: **Regulating utility voltage with distributed resources:** It is becoming more popular for utility distribution planners to consider distributed generation (DG) and storage devices to defer investments in substations and transmission lines until the load has grown to a sufficient size to warrant the larger investment.

Most of the utility-owned installations have been located in utility distribution substations. This offers load relief for the substation and transmission facilities, but contributes little else to the quality of power for the distribution feeder. Now, many distribution engineers are con sidering the benefits of moving the devices out onto the feeder to gain additional system capacity, loss reduction, improved reliability, and voltage regulation.

While few utility distribution planners will rely on customer-owned generation for base capacity, it is more palatable to employ them to help cover contingencies. Utilities usually have sectionalizing switches installed so that portions of a distribution feeder can be served from different feeders or substations during emergencies. If the fault occurs at the time of peak load, it may be impossible to pick up any more load from other feeders in the normal manner simply by closing a switch. However, a generator located near the switch tie point can potentially provide enough power to support the additional load at a satisfactory voltage. A more normal connection of DG is to use power and power factor control. This minimizes the risk of islanding. Although the DG no longer attempts to regulate the voltage, it is still useful for voltage regulation purposes during constrained loading conditions by displacing some active and reactive power.

To exploit dispersed sources for voltage regulation, one is limited in options to the types of devices with steady, controllable outputs such as reciprocating engines, combustion turbines, fuel cells, and battery stor age. Randomly varying sources such as wind turbines and photo voltaics are unsatisfactory for this role and often must be placed on a relatively stiff part of the system or have special regulation to avoid voltage regulation difficulties. DG used for voltage regulation must also be large enough to accomplish the task.

OR

7.a) Illustrate the principles of regulating the voltage,

Ans: Principles of regulating the voltage**:** Utilities generally try to maintain the service voltage supplied to an end user within ±5 percent of nominal. Under emergency conditions, for short periods, ANSI Standard C84.1 permits the utilization voltage to be in the range of 6 to 13 percent of the nominal voltage.

The root cause of most voltage regulation problems is that there is too much impedance in the power system to properly supply the load . Another way of describing this is to say that the power system is too weak for the load. Therefore, the voltage drops too low under heavy load. Conversely, when the source voltage is boosted to overcome the impedance, there can be an overvoltage condition when the load drops too low.

The corrective measures usually involve either compensating for the impedance Z or compensating for the voltage drop IR+ jIX caused by the impedance.
Some common options for improving power system voltage regulation, in the approximate order of priority that a utility might apply, are

1. Add shunt capacitors to reduce the current I and shift it to be more in phase with the voltage.
2. Add voltage regulators, which boost the apparent V1.
3. Reconductor lines to a larger size to reduce the impedance Z.
4. Change substation or service transformers to larger sizes to reduce impedance Z.
5. Add some kind of dynamic reactive power (var) compensation, which serves the same purpose as capacitors for rapidly changing loads.
6. Add series capacitors to cancel the inductive impedance drop IX

b) Explain end-user capacitor applications and their benefits,

Ans: End user capacitor application:The reasons that an end user might decide to apply power factor correction capacitors are to

- Reduce electric utility bill
- Reduce I2R losses and, therefore, heating in lines and transformers
- Increase the voltage at the load, increasing production and/or the efficiency of the operation
- Reduce current in the lines and transformers, allowing additional load to be served without building new circuits.

There can be power quality problems as a result of adding capacitors. The most common are harmonics problems. While power factor correction capacitors are not harmonic sources, they can interact with the system to accentuate the harmonics.

1. **Location for power factor correction capacitors:**

- The benefits realized by installing power factor correction capacitors include the reduction of reactive power flow on the system.
- Often, capacitors will be installed with large induction motors (C3 in Fig. 7.11). This allows the capacitor and motor to be switched as a unit.
- Large plants with extensive distribution systems often install capacitors at the primary voltage bus (C1) when utility billing encourages power factor correction.
- Location of larger harmonic filters on the main distribution bus (C2) provides the required compensation and a low-impedance path for harmonic currents to flow, keeping the harmonic currents off the utility system.
- One disadvantage of placing capacitors only at the utilization or main

distribution bus is that there is no reduction of current and line losses within the plant.

- Loss and current reduction are achieved when the capacitors (C4) are distributed.
- throughout the system.
- Some industrial end users install capacitors at the motor control centers, which is often more economical than putting the capacitors on each motor.
- The capacitors' controls can be tied in with the motor controls so that the capacitors are switched when needed.

2. **Voltage rise:**

- The voltage rise from placing capacitors on an inductive circuit is a two-edged sword from the power quality standpoint.
- If the voltage is low, then the capacitors provide an increase to bring the voltage back into tolerable limits.
- If the capacitors are left energized when the load is turned off, the voltage can rise too high, resulting in a sustained overvoltage.

UNIT-IV

8. a) Analyze the effect of harmonic distortion on capacitors, motors.

Ans: **Impact on capacitors**

The current flowing in the capacitor bank is also significantly large and rich in a monotonic harmonic. Figure 4.22 shows a current waveform of a capacitor bank in resonance with the system at the 11th harmonic. The harmonic current shows up distinctly, resulting in a waveform that is essentially the 11th harmonic riding on top of the fundamental frequency. This current wave- form typically indicates that the system is in resonance and a capacitor bank is involved. In such a resonance condition, the rms current is typically higher than the capacitor rms current rating.

IEEE Standard for Shunt Power Capacitors (IEEE Standard 18- 1992) specifies the following continuous capacitor ratings:

- 135 percent of nameplate kvar
- 110 percent of rated rms voltage (including harmonics but excluding transients)
- 180 percent of rated rms current (including fundamental and harmonic current)

The fundamental full-load current for the 1200-kvar capacitor bank is determined from The capacitor is subjected principally to two harmonics: the fifth and the seventh. The voltage distortion consists of 4 percent fifth and 3 per- cent seventh. This results in 20 percent fifth harmonic current and 21 percent seventh harmonic current.

Impact on motors

Motors can be significantly impacted by the harmonic voltage distortion. Harmonic voltage distortion at the motor terminals is translated into harmonic fluxes within the motor. Harmonic fluxes do not con- tribute significantly to motor torque, but rotate at a frequency different than the rotor synchronous frequency, basically inducing high-frequency currents in the rotor. The effect on motors is similar to that of negative-sequence currents at fundamental frequency: The additional fluxes do little more than induce additional losses.

At harmonic frequencies, motors can usually be represented by the blocked rotor reactance connected across the line. The lower-order harmonic voltage components, for which the magnitudes are larger and the apparent motor impedance lower, are usually the most important for motors.

There is usually no need to derate motors if the voltage distortion remains within IEEE Standard 519-1992 limits of 5 percent THD and 3 percent for any individual harmonic. Excessive heating problems begin when the voltage distortion reaches 8 to 10 percent and higher. Such distortion should be corrected for long motor life.

Motors appear to be in parallel with the power system impedance with respect to the harmonic current flow and generally shift the system resonance higher by causing the net inductance to decrease. Whether this is detrimental to the system depends on the location of the system resonance prior to energizing the motor. Motors also may contribute to the damping of some of the harmonic components depending on the *X*/*R* ratio of the blocked rotor circuit. In systems with many smaller-sized motors, which have a low *X*/*R* ratio, this could help attenuate harmonic resonance.

b) Describe the Concept of Point of Common Coupling and its importance in harmonic control.

Ans: Concept of point of common coupling

Evaluations of harmonic distortion are usually performed at a point between the end user or customer and the utility system where another customer can be served. This point is known as the point of common coupling.[1]The PCC can be located at either the primary side or the secondary side of the service transformer depending on whether or not multiple customers are supplied from the transformer. In other words, if multi- ple customers are served from the primary of the transformer, the PCC is then located at the primary. On the other hand, if multiple customers are served from the secondary of the transformer, the PCC is located at the secondary.

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

OR

9. a) Explain the working principle of active power filters and their advantages,

Ans: Active filters are relatively new types of devices for eliminating harmonics. They are based on sophisticated power electronics and are much more expensive than passive filters. However, they have the distinct advantage that they do not resonate with the system.

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

The basic idea is to replace the portion of the sine wave that is missing in the current in a nonlinear load. An electronic control monitors the line voltage and/or current, switching the power electronics very precisely to track the load current or voltage and force it to be sinusoidal.

Advantages:

1. Excellent Harmonic Compensation

   APFs dynamically eliminate harmonics (5th, 7th, 11th, etc.)

   Can handle multiple harmonic orders simultaneously

   Maintain low Total Harmonic Distortion (THD) within standards

2. No Resonance Problem

- Passive filters may cause resonance with system impedance
- APFs do not create resonance issues
- Improves system stability and reliability.

'b) Derive the expression for total harmonic distortion, total demand distortion and explain their j importance in h power systems

Ans: **Total harmonic distortion**

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

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. This index can be calculated for either voltage or current: where M_h is the rms value of harmonic component h of the quantity M. The rms value of a distorted waveform is the square root of the sum of the squares The THD is related to the rms value of the waveform as follows:

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

The THD is a very useful quantity for many applications, but its limitations must be realized. It can provide a good idea of how much extra heat will be realized when a distorted voltage is applied across a resistive load. Likewise, it can give an indication of the additional losses caused by the current flowing through a conductor. The THD index is most often used to describe voltage harmonic distortion. Harmonic voltages are almost always referenced to the fundamental value of the waveform at the time of the sample. Because fundamental voltage varies by only a few percent, the voltage THD is nearly always a meaningful.

Total demand distortion

Current distortion levels can be characterized by a THD value, as has been described, but this can often be misleading. A small current may have a high THD but not be a significant threat to the system. For example, many adjustable-speed drives will exhibit high THD values for the input current when they are operating at very light loads. This is not necessarily a significant concern because the magnitude of harmonic current is low, even though its relative current distortion is high. 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. I_L is the peak, or maximum, demand load current at the fundamental frequency component measured at the point of common coupling (PCC). There are two ways to measure I_L. With a load already in the system, it can be calculated as the average of the maximum demand current for the preceding 12 months.

UNIT-V

10. a) Explain the interface of DG with the utility system, including converters and protection schemes.

Ans: Interface to the Utility System

The primary concern here is the impact of DG on the distribution system power quality. While the energy conversion technology may play some role in the power quality, most power quality issues relate to the type of electrical system interface.

The main types of electrical system interfaces are

1. Synchronous machines

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

2. Asynchronous (induction) machines
3. Electronic power inverters

Electronic power inverters: All DG technologies that generate either dc or non-power frequency ac must use an electronic power inverter to interface with the electrical power system. The early thyristor-based, line-commutated inverters quickly developed a reputation for being undesirable on the power system. In fact, the development of much of the harmonics analysis technology was triggered by proposals to install hundreds of rooftop photovoltaic solar arrays with line-commutated inverters. These inverters produced harmonic currents in similar proportion to loads with traditional thyristor-based converters. Besides contributing to the distortion on the feeders, one fear was that this type of DG would produce a significant amount of power at the harmonic frequencies. Such power does little more than heat up wires.

Direct current is supplied on the left side of the diagram either from a conversion technology that produces direct current directly or from the rectification of ac generator output.

The dc voltage is switched at a very high rate with an insulated gate bipolar transistor (IGBT) switch to create a sinusoid voltage or current of power frequency. The switching frequency is typically on the order of 50 to 100 times the power frequency. The filter on the output attenuates these high-frequency components to a degree that they are usually negligible. However, resonant conditions on the power system can sometimes make these high frequencies noticeable.

Asynchronous (induction) machines: In many ways, it is simple to interface induction machines to the utility system. Induction generators are induction motors that are driven slightly faster than synchronous speed. They require another source to provide excitation, which greatly reduces the chances of inadvertent islanding. No special synchronizing equipment is necessary. In fact, if the capacity of the electrical power system permits, induction genera- tors can be started across the line.

The requirements for operating an induction generator are essentially the same as for operating an induction motor of the same size. The chief issue is that a simple induction generator requires reactive power (vars) to excite the machine from the power system to which it is connected. Occasionally, this is an advantage when there are high-voltage problems, but more commonly there will be low-voltage problems in induction generator applications. One of the problems is that the capacitor bank will yield resonances that coincide with harmonics produced in the same facility.

b) Describe the historical development of PQ measuring instruments,

Ans: Historical Perspective of Power Quality Measuring Instruments

Early monitoring devices were bulky, heavy boxes that required a screw- driver to make selections. Data collected were recorded on strip-chart paper. One of the earliest power quality monitoring instruments is a lightning strike recorder developed by General Electric in the 1920s.Significant development on power quality devices was not made until the 1960s when Martzloff developed a surge counter that could capture a voltage waveform of lightning strikes. The device consisted of a high- persistence analog oscilloscope with a logarithmic sweep rate.

Many engineers consider that the first generation of power quality monitors began in the mid-1970s when Dranetz Engineering Laboratories (now Dranetz-BMI) introduced the Series 606 power line disturbance analyzer.

By the mid-1990s, the third-generation power quality instruments emerged. The development of the third-generation power monitors was inspired in part by the EPRI

DPQ project. This generation of monitors was more appropriate as part of a complete power quality monitoring system, and the software systems to collect and manage the data were also developed. Since the conclusion of the project, substantial field experience gained revealed some of the difficulties in managing a large system of power quality monitors[5]:

1. Managing the large volume of raw measurement data that must be collected, analyzed, and archived becomes a serious challenge as the number of monitoring points grows.
2. The data volume collected at each monitoring point can strain communication mechanisms employed to move that data from monitor to analysis point.
3. As understanding of system performance grows through the feed- back provided by the monitoring data, detailed views of certain events, such as normal capacitor switching, become less valuable and would be of more use in a summary or condensed form.
4. The real value of any monitoring system lies in its ability to generate information rather than in collecting and storing volumes of detailed raw data.

OR

11.a) Explain different types of PQ measurement equipment and their functions

Ans: **Types of instruments**

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

- Wiring and grounding test devices
- Multi meters
- Oscilloscopes
- Disturbance analyzers
- Harmonic analyzers and spectrum analyzers
- Combination disturbance and harmonic analyzers
- Flicker meters
- Energy monitors

- Infrared meters can be very valuable in detecting loose connections and overheating conductors. An annual procedure of checking the system in this manner can help prevent power quality problems due to arcing, bad connections, and overloaded conductors.
- Noise problems related to electromagnetic radiation may require measurement of field strengths in the vicinity of affected equipment. Magnetic gauss meters are used to measure magnetic field strengths for inductive coupling concerns. Electric field meters can measure the strength of electric fields for electrostatic coupling concerns.
- Static electricity meters are special-purpose devices used to measure static electricity in

the vicinity of sensitive equipment. Electrostatic discharge (ESD) can be an important cause of power quality problems in some types of electronic equipment.

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

- Number of channels (voltage and/or current)
- Temperature specifications of the instrument
- Ruggedness of the instrument
- Input voltage range (e.g., 0 to 600 V)
- Power requirements

Wiring and grounding testers

Many power quality problems reported by end users are caused by problems with wiring and/or grounding within the facility. These problems can be identified by visual inspection of wiring, connections, and panel boxes and also with special test devices for detecting wiring and grounding problems.

Important capabilities for a wiring and grounding test device include

- Detection of isolated ground shorts and neutral-ground bonds
- Ground impedance and neutral impedance measurement or indication

Multi meters

After initial tests of wiring integrity, it may also be necessary to make quick checks of the voltage and/or current levels within a facility. Overloading of circuits, undervoltage and overvoltage problems, and unbalances between circuits can be detected in this manner. These measurements just require a simple multimeter. Signals used to check for these include

- Phase-to-ground voltages
- Phase-to-neutral voltages
- Neutral-to-ground voltages

Digital cameras

Photographs are extremely useful for documentation purposes. Those conducting the measurements often get distracted trying to get instruments to function properly and tests coordinated

Oscilloscopes

An oscilloscope is valuable when performing real-time tests. Looking at the voltage and current waveforms can provide much information about what is happening, even without performing detailed harmonic analysis on the waveforms. One can get the magnitudes of the voltages and currents, look for obvious distortion, and detect any major variations in the signals.

b) Analyze the operating conflicts between DG and utility systems

Ans: Deploying generation along utility distribution systems naturally creates some conflicts because the design of the system assumes only one source of power.

Utility fault-clearing requirements

The lowest-level component is the lateral fuse, and the other devices (reclosers and breakers) are designed to confirm to the fuse characteristic. There will frequently be two to four feeders off the same substation bus. This design is based mostly on economic concerns. This is the least costly protection scheme that is able to achieve acceptable reliability for distributing the power.

Reclosing

Reclosing utility breakers after a fault is a very common practice, particularly throughout North America. Most of the distribution lines are overhead, and it is common to have temporary faults. Once the current is interrupted and the arc dispersed, the line insulation is restored. Reclosing enables the power to be restored to most of the customers within seconds.

Reclosing presents two special problems with respect to DG:

1. DG must disconnect early in the reclose interval to allow time for the arc to dissipate so that the reclose will be successful.
2. Reclosing on DG, particularly those systems using rotating machine technologies can cause damage to the generator or prime mover.

Interference with relaying

Three of the more common cases where DG can interfere with the over- current protection relaying on distribution feeders will be examined here:

1. Reduction of reach
2. Sympathetic tripping of feeder breakers
3. Defeat of fuse saving

Each over- current relay device has an assigned zone of protection that is determined by its minimum pickup value. Some refer to this generically as the "reach" of the relay.A low-current (high-impedance) fault near the end of the feeder is more likely to go undetected until it does sufficient damage to develop into a major fault. The power quality consequences of this are that voltage sags will be prolonged for some customers and the additional fault damage will eventually lead to more sustained interruptions.

Voltage regulation issues

While there is great concern for various dynamics and transients issues that are difficult to analyze, voltage regulation issues are more likely to occur and cause interconnection problems. One of the voltage regulation problem that can arise when the total DG capacity on a feeder becomes significant. This problem is a consequence of the requirement to disconnect all DG when a fault occurs.