

GOVT. POLY TECHNIC BHUBANESWAR

GOVT. OF ODISHA.

ELECTRICAL AND ELECTRONIC MEASUREMENTS

Semester: 3rd Semester

Branch: Electrical Engineering

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Prepared For: Diploma Students

Unit-1: Fundamentals of Measurements

- 1.1 Measurement: Significance, units, fundamental quantities and standards
- 1.2 Classification of Instrument Systems
- 1.3 Null and deflection type instruments
- 1.4 Absolute and secondary instruments
- 1.5 Analog and digital instruments
- 1.6 Static and dynamic characteristics, types of errors
- 1.7 Calibration: need and procedure
- 1.8 Classification of measuring instruments: indicating, recording and integrating instruments
- 1.9 Essential requirements of an indicating instruments

1.1 Measurement: Significance, Units, Fundamental Quantities and Standards

✦ Measurement

- Measurement is the process of **comparing an unknown quantity** with a known fixed standard of the same kind.
- The result is expressed in a **number with a unit**.
- Example: Measuring current with an ammeter compares it with a standard calibrated current.

✦ Significance of Measurement

Measurement plays a **vital role in science, engineering, and industry**. Without accurate and reliable measurements, no progress in technology would be possible.

✦ 1. Scientific Research & Development

- All scientific laws are based on **measurements** (e.g., Ohm's law, Newton's law).
 - For new discoveries, accurate measurement of quantities like current, voltage, force, temperature, etc., is essential.
 - Example: Discovery of electron charge (Millikan's oil drop experiment).
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✦ 2. Engineering Design & Manufacturing

- Every engineering product (motors, transformers, machines) must be **designed using measured data**.
 - Measurements ensure **components fit properly** and can be replaced (interchangeability).
 - Example: Bolts and nuts manufactured in different factories fit together only because of standardized measurement.
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◆ 3. Quality Control & Standardization

- Ensures that the product **meets specifications** and functions as intended.
 - Measurement allows detection of **defects** and helps in maintaining **tolerances**.
 - Example: Checking dimensions of a car engine cylinder with a micrometer gauge.
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◆ 4. Communication & Trade

- Measurements provide a **common language** in trade and commerce.
 - Standard units (kg, metre, volt) make transactions uniform worldwide.
 - Example: International trading of oil or energy uses standardized units.
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◆ 5. Calibration & Testing

- Instruments and devices **drift over time** and lose accuracy.
 - Regular measurements against standards ensure accuracy.
 - Example: Calibration of energy meters in electricity boards.
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◆ 6. Safety & Reliability

- Measurements ensure safe operation of systems (power plants, airplanes, medical devices).
 - Example: Voltage, current, and temperature monitoring in power stations prevents accidents.
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◆ 7. Automation & Control Systems

- Modern automation is **impossible without measurements**.
 - Sensors continuously measure parameters → feed to controllers → automatic regulation.
 - Example: Automatic temperature control in air conditioners.
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✓ Summary for Exams

The **significance of measurement** can be written as:

1. Basis of scientific research.
2. Foundation for engineering design.
3. Ensures quality control.
4. Provides common standard in trade.
5. Necessary for calibration & testing.
6. Ensures safety and reliability.
7. Backbone of automation.

Fundamental Quantities and Standards

◆ Fundamental Quantities

- Fundamental quantities are those **physical quantities which are independent** of one another and cannot be expressed in terms of any other physical quantities.
- They form the **foundation of the SI system**.
- All other physical quantities (derived quantities) are expressed in terms of these.

Seven SI Fundamental Quantities:

Fundamental Quantity	Unit	Symbol	Definition (SI)
Length	metre	m	Distance travelled by light in vacuum in $1/299,792,458$ seconds.
Mass	kilogram	kg	Mass of the international prototype of platinum-iridium cylinder (now defined in terms of Planck's constant).
Time	second	s	Duration of 9,192,631,770 vibrations of Cesium-133 atom.
Electric Current	ampere	A	Current produced by 1 Coulomb of charge per second.
Temperature	kelvin	K	$1/273.16$ of the thermodynamic temperature of triple point of water.

Fundamental Quantity	Unit	Symbol	Definition (SI)
Luminous Intensity	candela	cd	Intensity of light emitted by a source in a given direction.
Amount of Substance	mole	mol	Number of atoms in 0.012 kg of carbon-12 isotope.

◆ Derived Quantities

- Quantities which can be **expressed in terms of fundamental quantities**.
- Examples:
 - Velocity = Length / Time (m/s).
 - Force = Mass × Acceleration = $\text{kg} \cdot \text{m/s}^2$ = Newton (N).
 - Energy = Force × Distance = Joule (J).
 - Voltage, Resistance, Power are all derived quantities.

◆ Standards of Measurement

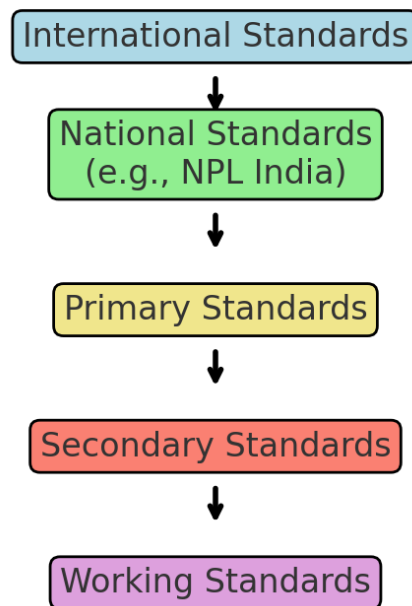
Standards ensure that **measurements are consistent and comparable worldwide**. Without standards, “1 metre” or “1 kg” could mean different values in different places.

Types of Standards:

- International Standards**
 - Maintained at **International Bureau of Weights and Measures (BIPM), Paris**.
 - Serve as the ultimate authority for defining units.
 - Ensure **global uniformity**.
 - Example: Standard definition of metre and kilogram.
- National Standards**
 - Maintained by **National Laboratories** of each country.
 - In India → **National Physical Laboratory (NPL), New Delhi**.
 - Serve as reference for calibration in that country.
- Primary Standards**
 - Maintained in national labs with the **highest precision**.
 - Not used for routine work.
 - Example: Primary resistance standard, primary voltage cell.
- Secondary Standards**
 - Calibrated with primary standards.

- Used in calibration laboratories for routine standardization.
- Example: Secondary volt standards in test labs.
- 5. **Working Standards**
 - Used in industries, colleges, and workshops for daily measurements.
 - Must be checked periodically against secondary standards.
 - Example: Industrial voltmeter, ammeter.
- 6. **Line Standards**
 - Length defined by distance between two engraved lines.
 - Example: Standard metre bar.
- 7. **End Standards**
 - Length defined by distance between two flat surfaces.
 - Example: Slip gauges.
- 8. **Sub-Standards (Tertiary Standards)**
 - Derived from secondary standards.
 - Used for calibration inside industries where accuracy requirements are moderate.

Hierarchy of Standards of Measurement



1.2 Classification of Instrument Systems

Measuring instruments can be classified into **three main systems** depending on their operating principle and construction.

1. Mechanical Instruments

- **Working principle:** Operate with mechanical parts such as levers, springs, gears, and pointers.
- **Examples:** Spring balance, mechanical pressure gauge, mechanical watch.
- **Advantages:**
 1. Simple in construction.
 2. Rugged and durable.
 3. Do not require power supply.
- **Disadvantages:**
 1. Very slow response → not suitable for dynamic measurements.
 2. Limited accuracy due to friction and wear.
 3. Cannot amplify very small signals.

2. Electrical Instruments

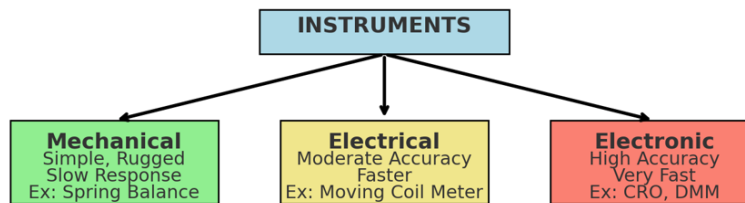
- **Working principle:** Operate on electrical effects – heating, electromagnetic, or electrostatic action.
- **Examples:** Moving coil meter, moving iron instrument, electrodynamometer.
- **Advantages:**
 1. Faster response than mechanical instruments.
 2. Can measure both AC and DC.
 3. Moderate accuracy, suitable for laboratories.
- **Disadvantages:**
 1. Require some power from the system under measurement.
 2. Affected by temperature and frequency variations.

3. Electronic Instruments

- **Working principle:** Use electronic circuits such as amplifiers, oscillators, rectifiers, and microcontrollers.
- **Examples:** Digital Multimeter (DMM), Cathode Ray Oscilloscope (CRO), Digital Storage Oscilloscope (DSO).
- **Advantages:**
 1. Very high sensitivity and accuracy.

- 2. Very fast response – suitable for rapidly varying signals.
- 3. Can measure very small signals (μV , nA).
- 4. Provide digital output for easy processing.
- **Disadvantages:**
 - 1. More expensive.
 - 2. Require external power supply.

Classification of Instrument Systems



✓ Exam Tips

- For **2 marks** → just list: Mechanical, Electrical, Electronic with 1 example.
- For **5 marks** → write principle, 2 advantages, 2 disadvantages, and examples.
- For **10 marks** → expand each + include neat block diagram.

1.3 Null and Deflection Type Instruments

1. Null Type Instruments

- **Definition:**
A null instrument gives measurement when the effect of the measured quantity is balanced (brought to zero/null) by a known value.
Reading is taken when balance (null condition) is achieved.
- **Working Principle:**
Comparison method → Unknown quantity is compared with a standard until the difference (error) is zero.
- **Examples:**
 - Wheatstone bridge (measuring resistance).
 - DC potentiometer (measuring EMF).
 - Kelvin double bridge.
- **Advantages:**
 - Very accurate (no dependence on scale).
 - Error is minimized.
- **Disadvantages:**

- Slower operation.
- Needs skilled operator.

2. Deflection Type Instruments

- **Definition:**
A deflection instrument gives measurement directly by the amount of movement (deflection) of a pointer, needle, or indicator in proportion to the measured quantity.
 - **Working Principle:**
The quantity produces a force/torque → moves the pointer → scale shows value.
 - **Examples:**
 - Ammeter.
 - Voltmeter.
 - Pressure gauge.
 - **Advantages:**
 - Quick and easy to use.
 - Suitable for routine measurements.
 - **Disadvantages:**
 - Less accurate than null type.
 - Errors due to friction, temperature, mechanical wear.
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3. Key Differences

Feature	Null Type Instruments	Deflection Type Instruments
Principle	Balance/Comparison method	Deflection proportional to input
Accuracy	Very high	Moderate
Speed	Slow	Fast
Ease of Use	Requires skilled operator	Easy to operate
Examples	Wheatstone bridge, Potentiometer Ammeter, Voltmeter, Pressure gauge	

✓ Exam tip (SETVT):

- If question asks “What is Null & Deflection type instrument?” → Write **definition + example + 2 advantages/disadvantages**.

- If it says “Differentiate between them” → Draw a **comparison table** (like above).

1.4 Absolute and Secondary Instruments

1. Absolute Instruments

- **Definition:**
Instruments that **give the value of a quantity in terms of physical constants** and instrument dimensions without comparison with another instrument.
- **Principle:** Based on mathematical relations involving constants.
- **Examples:**
 - Tangent galvanometer (measures current using earth’s magnetic field).
 - Rayleigh’s current balance (measures current using force between conductors).
- **Applications:**
 - Rarely used in practice.
 - Mainly used in **standards laboratories** for calibration of secondary instruments.

♦ Advantages

1. Do not require calibration against another instrument.
2. Provide direct relationship with fundamental quantities.
3. Useful as reference instruments.

♦ Disadvantages

1. Complicated construction and use.
2. Time-consuming and bulky.
3. Require skilled operation.
4. Not suitable for routine work.

2. Secondary Instruments

- **Definition:**
Instruments that **give direct reading of the quantity being measured** but must be calibrated using absolute instruments.
- **Principle:** Reading is obtained by **deflection of a pointer** or digital display.
- **Examples:**
 - Ammeter, Voltmeter, Wattmeter, Energy meter.

- **Applications:**
 - Used in **practical work, industries, laboratories, and daily measurements.**

♦ Advantages

1. Easy to use, direct reading.
2. Quick and convenient.
3. Widely available and cheaper.

♦ Disadvantages

1. Need calibration from absolute instruments.
2. Accuracy depends on calibration and environmental factors.

3. Comparison between Absolute and Secondary Instruments

Aspect	Absolute Instruments	Secondary Instruments
Definition	Value obtained in terms of constants	Value obtained by direct reading
Use	For calibration, standards labs	For routine practical measurements
Examples	Tangent galvanometer, Current balance	Ammeter, Voltmeter, Wattmeter
Accuracy	Very accurate (but difficult to use)	Dependent on calibration
Convenience	Complicated, time-consuming	Easy and quick
Need of Calibration	No (self-sufficient)	Yes, must be calibrated

1.4 Absolute and Secondary Instruments

1. Absolute Instruments

- **Definition:** Instruments that give the value of a quantity in terms of physical constants and dimensions of the instrument.
- **Examples:** Tangent galvanometer, Rayleigh's current balance.

- **Use:** Rarely used in practice → mainly in standards laboratories for calibration.

Advantages:

- Do not require calibration against another instrument.
- Provide direct relation with fundamental quantities.

Disadvantages:

- Complicated, bulky, slow, and require skilled operation.
- Not suitable for routine use.

2. Secondary Instruments

- **Definition:** Instruments that indicate the value of the quantity being measured **through deflection of pointer/digital display**, but must be **calibrated using absolute instruments**.
- **Examples:** Ammeter, Voltmeter, Wattmeter, Energy meter.
- **Use:** Widely used in practice → labs, industries, and routine measurements.

♦ Types of Secondary Instruments

1. **Indicating Instruments**
 - Show **instantaneous value**.
 - Example: Ammeter, Voltmeter.
2. **Recording Instruments**
 - Record the variation of a quantity with time.
 - Example: Strip chart recorder, ECG machine.
3. **Integrating Instruments**
 - Measure the **total quantity** of electricity/energy over time.
 - Example: Energy meter, Ampere-hour meter.

Comparison Table

Aspect	Absolute Instruments	Secondary Instruments
Definition	Measure in terms of constants	Measure through calibration against absolute
Examples	Tangent galvanometer, Current balance	Ammeter, Voltmeter, Wattmeter, Energy meter

Aspect	Absolute Instruments	Secondary Instruments
Use	Calibration, standards labs	Routine practical use
Need of Calibration	No (self-sufficient)	Yes, calibrated with absolute
Convenience	Bulky, complicated, slow	Easy, quick, direct reading

✓ Exam Tips

- For **2M** → Definition + one example each.
- For **5M** → Definition + examples + applications.
- For **10M** → Full explanation + types of secondary instruments + comparison table + block diagram.

1.5 Analog and Digital Instruments

1. Analog Instruments

- **Definition:**
Instruments that give a **continuous output** which varies smoothly as the input changes.
Output is usually shown by the **deflection of a pointer** on a dial/scale.
- **Examples:**
 - Analog ammeter
 - Analog voltmeter
 - Mercury thermometer
 - Pressure gauge
- **Advantages:**
 - Simple construction.
 - Cheap and easy to use.
 - Can show small variations (smooth changes).
- **Disadvantages:**
 - Less accurate (parallax error).
 - Hard to read precisely.
 - No storage of data possible.

2. Digital Instruments

- **Definition:**
Instruments that give output in **numeric/digital form** (discrete values).
Reading is displayed directly as numbers on an LED/LCD screen.
- **Examples:**
 - Digital multimeter
 - Digital thermometer
 - Digital energy meter
 - Digital oscilloscope
- **Advantages:**
 - High accuracy.
 - Easy to read (direct numbers).
 - Data storage & processing possible.
 - Free from parallax error.
- **Disadvantages:**
 - More expensive.
 - Require external power/battery.
 - Sensitive to electrical noise/interference.

3. Key Differences

Feature	Analog Instruments	Digital Instruments
Output	Continuous (pointer on scale)	Discrete (numerical display)
Accuracy	Moderate, parallax error possible	High, no parallax error
Ease of Reading	Difficult, needs careful observation	Very easy, direct numbers
Cost	Cheaper	More expensive
Examples	Analog voltmeter, pressure gauge	Digital multimeter, digital thermometer

✓ Exam Tip (SETVT):

- If the question asks “**Explain analog and digital instruments with examples**”
→ write **definition + 2 examples + 2 advantages + 2 disadvantages**.
- If asked “**Differentiate**”, draw the **table above**.

1.6 Static and Dynamic Characteristics, Types of Errors

A. Static Characteristics of Instruments

Static characteristics describe the **performance of instruments under steady (constant) input conditions**.

◆ Main Static Characteristics:

1. **Accuracy**
 - Closeness of measured value to the true value.
 - Example: If true voltage = 100 V, and instrument reads 99.5 V → high accuracy.
2. **Precision**
 - Degree of **repeatability** of measurements (closeness among repeated readings).
 - Example: Readings: 99.8 V, 99.9 V, 100.0 V → high precision.
3. **Sensitivity**
 - Ratio of change in output to change in input.
 - High sensitivity → small input change produces large output deflection.
4. **Resolution**
 - The **smallest change in input** that can be detected by the instrument.
 - Example: Digital meter with resolution 0.01 V can detect 1/100th of a volt.
5. **Linearity**
 - Degree to which input-output relation follows a **straight line**.
 - Example: In ideal voltmeter → deflection $\propto$ voltage.
6. **Range (Span)**
 - The maximum and minimum values of input that can be measured.
7. **Reproducibility**
 - Ability to produce the same output repeatedly under same input over a long time.

B. Dynamic Characteristics of Instruments

Dynamic characteristics describe how instruments **respond to time-varying inputs**.

◆ Main Dynamic Characteristics:

1. **Speed of Response**
 - Time taken by the instrument to respond to a change in input.
 - Faster → better.

2. **Lag**

- Delay in response of instrument output w.r.t. input.
- Example: Mercury thermometer takes time to show body temperature.

3. **Fidelity**

- Ability of instrument to **faithfully reproduce the input signal** without distortion.
- Example: CRO reproduces waveform of input signal.

4. **Dynamic Error (Measurement Lag)**

- The difference between true value and measured value during input change.

C. Types of Errors in Measurement

Errors cause deviation of the measured value from the true value.

◆ 1. Gross Errors

- Due to **human mistakes**.
- Example: Misreading scale, careless recording, wrong instrument handling.
- Can be reduced by careful operation.

◆ 2. Systematic Errors

- Occur consistently due to **instrument defects, environment, or method**.
- Types:
 1. **Instrumental errors:** Imperfections in instruments (friction, hysteresis, calibration error).
 2. **Environmental errors:** Temperature, humidity, dust, stray magnetic/electric fields.
 3. **Observational errors:** Parallax error, incorrect reading.
- Can be minimized by calibration, proper shielding, good design.

◆ 3. Random Errors

- Small, unpredictable variations due to noise, vibrations, or unknown causes.
- Example: Fluctuations in digital meter display.
- Can be minimized by statistical averaging.

✓ Exam Tips

- For **2M** → Write definitions (Accuracy, Precision, Gross error, etc.).

- For **5M** → Write static or dynamic characteristics with 3–4 points each.
- For **10M** → Full explanation + examples + diagram of error classification

1.7 Calibration: Need and Procedure

A. Calibration – Definition

- **Calibration** is the process of **comparing an instrument's reading with a known standard** of higher accuracy to detect errors and make corrections.
- It ensures that the instrument provides **accurate and reliable results**.

B. Need for Calibration

1. **Accuracy**
 - Instruments drift due to ageing, wear, temperature, and mechanical stress.
 - Calibration restores accuracy.
2. **Traceability**
 - Calibration links instrument readings to **national/international standards** (NPL, BIPM).
 - Ensures uniformity worldwide.
3. **Reliability**
 - Regular calibration ensures confidence in measurement results.
 - Very important in industries, labs, and research.
4. **Safety**
 - Incorrect readings may lead to **accidents** (in power plants, medical devices).
 - Calibration prevents such risks.
5. **Legal & Commercial Requirement**
 - Many industries (energy meters, weighing scales) require calibration as per **government rules**.

C. Procedure of Calibration

Step 1: Preparation

- Select an appropriate **standard instrument** (with much higher accuracy).
- Ensure environmental conditions (temperature, humidity) are controlled.

Step 2: Connection

- Connect the **instrument under test (IUT)** and the **standard instrument** to the same input (voltage, current, pressure, etc.).

Step 3: Application of Input

- Apply known input values step by step (e.g., 0V, 20V, 40V... for a voltmeter).

Step 4: Recording

- Record the readings of both the **standard** and the **IUT** at each step.

Step 5: Comparison

- Compare the instrument's reading with the standard.
- Calculate **error** = (**IUT reading** – **Standard reading**).

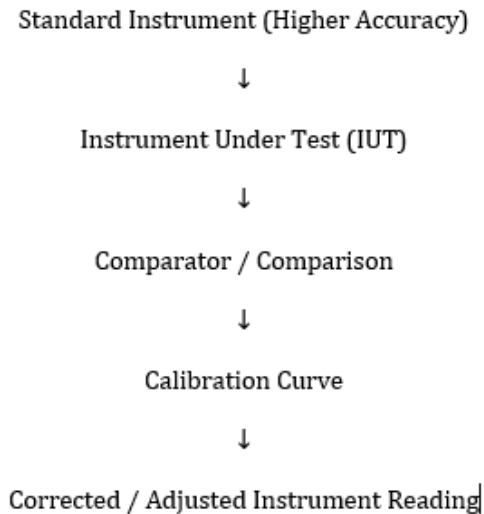
Step 6: Calibration Curve

- Plot a graph of **Standard Reading vs IUT Reading** to visualize the error.

Step 7: Adjustment / Correction

- If error is within tolerance → instrument is **acceptable**.
- If error is large → **adjust instrument** (mechanical/electronic adjustment) or apply correction factor.

Calibration Process



✓ Exam Tips

- For **2M**: Write definition of calibration.
- For **5M**: Write need (at least 3 points) + short procedure.
- For **10M**: Write full need + stepwise procedure + block diagram.

1.8 Classification of Measuring Instruments

Measuring instruments are broadly classified into **three categories**:

1. Indicating Instruments

- **Definition:**
Instruments that **indicate the instantaneous value** of a quantity by means of a **pointer moving on a scale** (in analog type) or a **digital display** (in digital type).
- **Examples:** Ammeter, Voltmeter, Pressure gauge, Digital Multimeter (DMM).

♦ Characteristics

- Show present value only.

- Do not keep a record.
- Used for quick observations.

◆ Applications

- Widely used in labs, industries, electrical circuits for monitoring current, voltage, etc.
-

2. Recording Instruments

- **Definition:**
Instruments that **continuously record the variation** of a quantity with respect to **time**.
- **Working:** Recordings are done on **paper charts**, tapes, or digital memory.
- **Examples:**
 - ECG recorder (medical).
 - Strip chart recorder (lab).
 - Oscillograph.

◆ Characteristics

- Provide a continuous history of measured values.
- Useful for analyzing trends and fluctuations.

◆ Applications

- Medical diagnosis (ECG, EEG).
 - Industrial monitoring (temperature, pressure).
 - Scientific experiments.
-

3. Integrating Instruments

- **Definition:**
Instruments that **measure the total quantity of electricity, energy, or power consumed** over a period of time.
- **Examples:**
 - Energy meter (kWh meter).
 - Ampere-hour meter (used in battery charging).

✦ Characteristics

- Do not show instantaneous value.
- Measure accumulated quantity over time.

✦ Applications

- Domestic energy billing (electricity meters).
- Battery charging/discharging monitoring.

✓ Exam Tips

- For **2M** → Just list three types with examples.
- For **5M** → Definition + example + application for each.
- For **10M** → Full classification + neat diagram.

1.9 Essential Requirements of an Indicating Instrument

. Working Principle

- Indicating instruments consist of a **moving system pivoted in jewel bearings**.
- A **pointer** is attached to the moving system which indicates on a graduated scale the value of the electrical quantity.

2. Torques Required

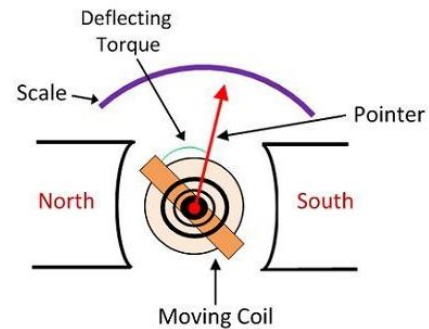
For proper operation, three torques are essential:

1. **Deflecting Torque (T_d)** or Operating Torque
2. **Controlling Torque (T_c)** or Restoring Torque
3. **Damping Torque**

i) Deflecting Torque (T_d)

Definition

- When there is **no input signal**, the pointer stays at **zero position**.
- To move the pointer from zero, a **force/torque** is needed → called **Deflecting Force (or Deflecting Torque)**.
- The system that produces this force is called a **Deflecting System**.



Function

- Converts the **electrical signal** (current or voltage) into a **mechanical force**.
- This mechanical force moves the **pointer** over the scale.
- $T_d \propto I$, where I = current flowing in operating coil.
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ii) Controlling Torque (T_c)

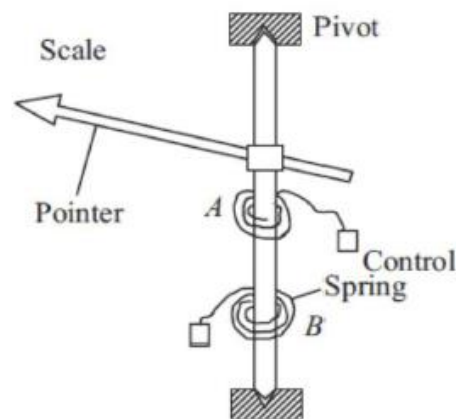
Need of Controlling Torque

- When a current is supplied, **deflecting torque (T_d)** moves the pointer.
- To balance this and bring the pointer to a steady position, a **controlling torque (T_c)** is required.
- Without controlling torque, the pointer would keep moving indefinitely.

Methods of Providing Controlling Torque:

Spring Control System

1. Two **phosphor bronze springs** are attached at either end of the spindle.
2. The spindle is mounted in **jewelled bearings** to reduce friction.
3. The springs are wound in **opposite directions** to compensate for **temperature errors**.
4. When the pointer moves, the spindle rotates → the springs twist → producing **controlling torque (T_c)**.
5. This torque is **directly proportional to the deflection angle (θ)**.
6. $T_c \propto \theta$, where θ = deflection angle



iii) Damping Torque

Why Damping is Needed?

- In measuring instruments, two torques act:
 - **Deflecting Torque (T_d)**: Moves the pointer from zero position.
 - **Controlling Torque (T_c)**: Opposes T_d and brings the pointer to steady position.
- Due to **inertia**, the pointer oscillates about the final position before coming to rest.
- This makes the measurement **slow**.
- To make the pointer settle quickly without oscillations, a **damping torque** is required.

Definition

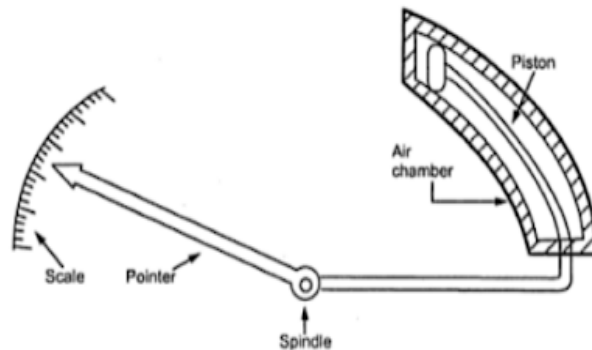
Damping Torque:

The torque which **opposes the oscillations of the moving system** and allows the pointer to come to rest quickly at its final position.

Methods of Providing Damping Torque:

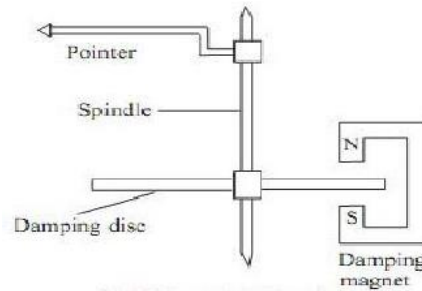
1. Air Friction Damping

- A **piston** is mechanically connected to the spindle by a rod.
- Pointer is fixed to the spindle and moves over a calibrated scale.
- When the pointer moves clockwise → piston compresses air in the cylinder → air pressure pushes piston upward → torque acts in the opposite direction (anticlockwise).
- When the pointer moves anticlockwise → piston moves out → pressure inside reduces → external air pressure pushes piston downward → torque acts in opposite direction (clockwise).
- Thus, **air pressure difference produces damping torque**.



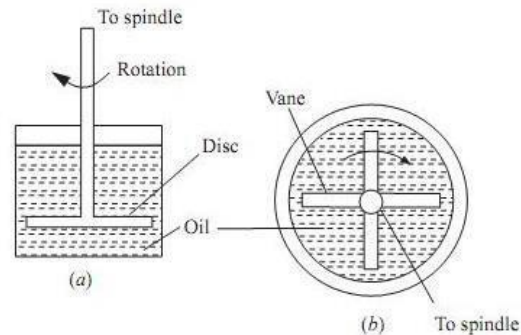
2. Eddy Current Damping

- An **aluminum disc** is fixed to the spindle.
- The disc moves in the magnetic field of a **permanent magnet**.
- When the disc oscillates, it **cuts magnetic flux** → emf induced → eddy currents flow.
- By **Lenz's Law**, eddy currents produce torque in a direction **opposite to the oscillation**.
- Damping torque can be varied by **changing the projection of the magnet** over the disc.
- This method is **very effective** and is used in **PMMC instruments**.



3. Fluid Friction Damping

- Similar to air friction damping, but uses **mineral oil** instead of air.
- Since oil viscosity > air viscosity, **damping torque is stronger**.
- A **disc or vanes** attached to the spindle are submerged in oil.
- When the system moves, frictional drag of oil produces damping torque.
- Two arrangements:
 - (a) Disc immersed in oil.
 - (b) Several vanes attached to spindle, moving in oil vertically → provides greater damping.



✓ Exam Tips

- **For 2M** → Just list the three torques: Deflecting torque, Controlling torque, Damping torque.
- **For 5M** → Definition + function (purpose) of each torque. Mention one example/method (e.g., spring control, air friction damping).
- **For 10M** → Full explanation of all three torques with formulas + neat diagrams (spring control, air damping, eddy current damping).

UNIT II

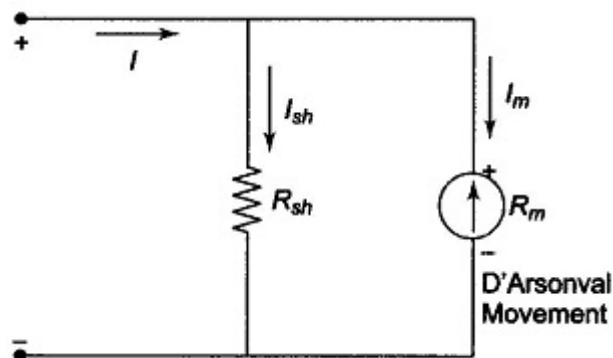
2.1 DC Ammeter: Basic, Multi range, Universal shunt,

Introduction

- A **DC Ammeter** is an instrument used to measure the magnitude of **direct current** in a circuit.
- The most common construction is based on the **Permanent Magnet Moving Coil (PMMC) instrument**
- The ammeter is always connected **in series** with the circuit whose current is to be measured. For accuracy, the ammeter should have **very low internal resistance**.

1. Basic DC Ammeter

- Consists of a **PMMC galvanometer** connected in parallel with a **fixed shunt resistor**.
- It can measure current in only **one range** (decided by the shunt value).



In the above fig.

- R_m = internal resistance of the moving coil
- I_m = full-scale deflection current of the movement (galvanometer current)
- I = total full-scale current of the ammeter (current to be measured)
- I_{sh} = shunt current (current through shunt)

Derivation of Shunt Resistance

Step 1:

Total current = Current through movement + Current through shunt

$$I = I_m + I_{sh}$$

Step 2:

Voltage across movement = Voltage across shunt

$$I_m R_m = I_{sh} R_{sh}$$

Step 3:

Substitute $I_{sh} = I - I_m$

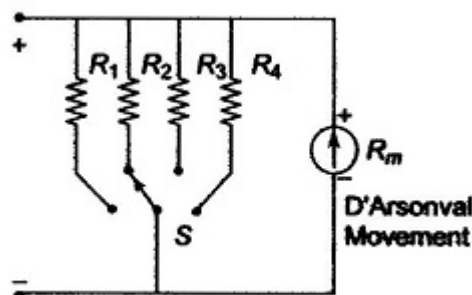
Step 4:

Rearrange for shunt resistance

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

Multi-Range DC Ammeter

The current range of a DC ammeter can be extended further by using **a number of shunts**, which are selected by means of a **range switch**.



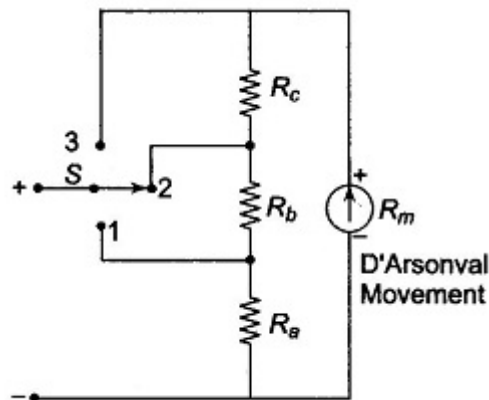
Working Principle

- The basic moving-coil movement can carry only a small current I_m (its full-scale deflection current).
- By connecting **different shunt resistors** (R_1, R_2, R_3, R_4 , etc.) in parallel with the movement, the meter can be used to measure different values of total current I .
- A **range selector switch** connects the galvanometer across one of the shunts at a time.
- Thus, the same meter can be used for multiple ranges (e.g. 0–1 A, 0–5 A, 0–10 A, 0–20 A).

3. Universal Shunt DC Ammeter

- To overcome drawbacks of multi-range ammeter, a **universal shunt arrangement** is used.
- In this method, only **one special shunt** with several **taps** is designed.

-
- The galvanometer is connected across different tapping points of the universal shunt for different ranges.
- No need for switching large shunt resistors in and out.



Working Operation

- **Switch at Position 1:**
 - Resistance R_a is in parallel with series $(R_b + R_c + R_m)$.
 - Most current flows through R_a (shunt), less through meter → **low sensitivity** (large current range).
- **Switch at Position 2:**
 - $R_a + R_b$ in parallel with $(R_c + R_m)$.
 - Current division changes, meter carries more current → **medium sensitivity**.
- **Switch at Position 3:**
 - $R_a + R_b + R_c$ in parallel with meter movement.
 - More current flows through meter, less through shunt → **high sensitivity** (small current range).

Feature	Basic Ammeter	Multi-Range Ammeter	Universal Shunt Ammeter
Shunt used	One fixed shunt	Several shunts + switch	One specially designed universal shunt
Ranges	Single	Multiple (by selector switch)	Multiple (by tapping points)
Accuracy	Good	May reduce due to switch contacts	High, no switching error
Use	Single range measurements	General lab/field work	Precision instruments

2.2 DC Voltmeter: Basic, Multi-range, concept of loading effect and sensitivity

DC Voltmeter

- A **DC voltmeter** is an instrument used to measure the potential difference (voltage) across two points in a DC circuit.
- It is always connected **in parallel** with the component across which the voltage is to be measured.

Basic DC Voltmeter

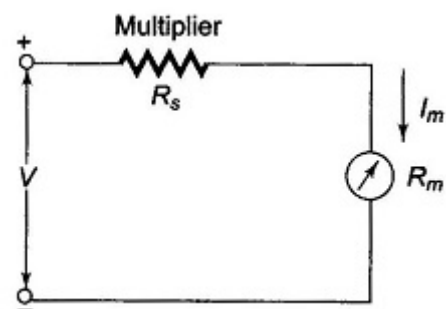
- Constructed from a **PMMC movement** (galvanometer).
- Since galvanometer current I_m is very small, a **high resistance (multiplier)** is connected in series with the movement.
- This ensures that only a small current flows through the meter.

Formula for Series Resistance (R_s):

$$R_s = \frac{V}{I_m} - R_m$$

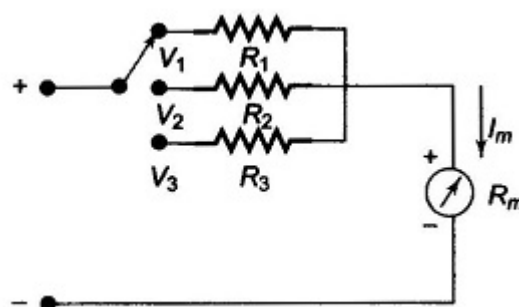
where:

- V = desired voltage range
- I_m = full-scale deflection current of movement
- R_m = Internal resistance of movement



Multi-Range DC Voltmeter

- To measure different voltage ranges, multiple **series resistors** are used.
- A **range selector switch** connects the meter movement with one of these resistors.
- This allows the voltmeter to be used for 0–10 V, 0–50 V, 0–100 V, etc.



Circuit Description

- The voltmeter has **three multipliers**: R_1, R_2, R_3 .
- A **three-position switch** is used to connect one multiplier at a time in series with the meter movement.

- Depending on the switch position:
 - **Position 1:** Multiplier = R1 → range = V1.
 - **Position 2:** Multiplier = R2 → range = V2.
 - **Position 3:** Multiplier = R3 → range = V3.

Thus, the same meter can be used as a 0–10 V, 0–50 V, 0–100 V voltmeter (example ranges).

Loading Effect

- Since a voltmeter is connected in **parallel**, its resistance should be **very high** compared to the circuit resistance.
- If voltmeter resistance is low, it **draws significant current** from the circuit, reducing the actual voltage to be measured.
- This error is called the **loading effect**.

Sensitivity of a DC Voltmeter

- The **sensitivity (S)** of a voltmeter is defined as the **resistance of the voltmeter per volt of its range**.

$$S = \frac{R_t}{V} \text{ } (\Omega/V)$$

where

- R_t = total resistance of voltmeter (series multiplier + meter resistance)
- V = full-scale voltage range

Relation with Meter Current

- Sensitivity is the reciprocal of the full-scale deflection current (I_{fsd}) of the meter movement:

$$S = \frac{1}{I_{fsd}} \text{ } (\Omega/V)$$

Application of Sensitivity

- Sensitivity makes calculation of series multiplier resistors (R_s) easier.

Since

$$R_t = R_s + R_m$$

and

$$R_t = S \cdot V$$

Therefore,

$$R_s = (S \cdot V) - R_m$$

where:

- R_s = required series resistance (multiplier)
- R_m = internal resistance of the movement
- V = desired voltage range

Key Points

Higher sensitivity → higher internal resistance → less loading effect on the circuit.

2.3 AC Voltmeter: Rectifier Type(Half wave and Full Wave)

Definition:

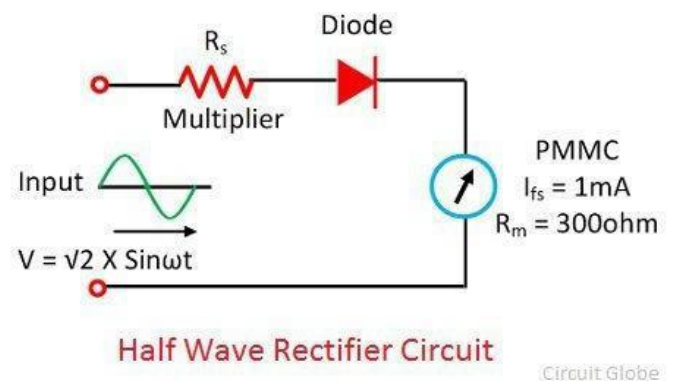
The instruments which use a **rectifying element** (such as a semiconductor diode) for measuring **AC voltage or AC current** are called **Rectifying Instruments**.

- The rectifier converts the alternating current (AC) into direct current (DC).
- The converted DC is then measured by a **DC responsive meter** (usually a **PMMC movement**).
- Thus, rectifying instruments are widely used as **AC voltmeters** and **AC ammeters**.

(i) Half-Wave Rectifier Type AC Voltmeter

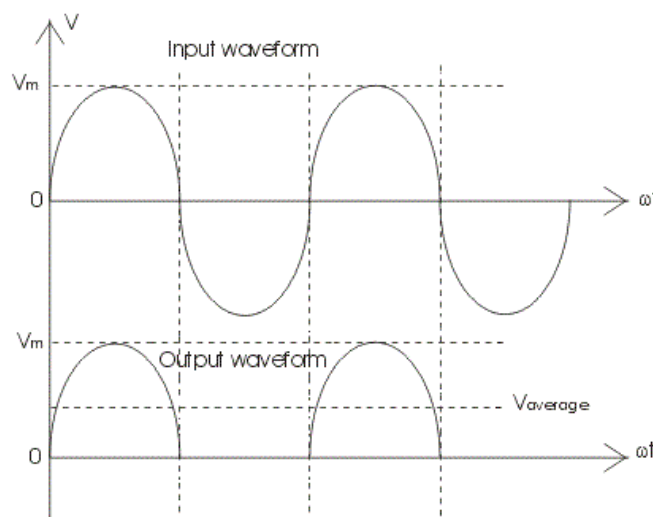
Construction

- Consists of:
 - AC source to be measured
 - Series resistance (multiplier)
 - Single rectifier diode
 - PMMC movement



Working

- During the **positive half cycle**, the diode conducts → current flows through PMMC → pointer deflects.
- During the **negative half cycle**, the diode blocks → no current flows.
- Hence, the meter uses only **half the input waveform**.
- Reading corresponds to the average value of half-wave rectified voltage, but scale is marked in RMS.



Average Value of Voltage

$$V_{av} = \frac{1}{2\pi} \int_0^{\pi} V_m \sin \omega t d(\omega t) = \frac{1}{\pi} V_m$$

$$V_{av} = 0.318 V_m$$

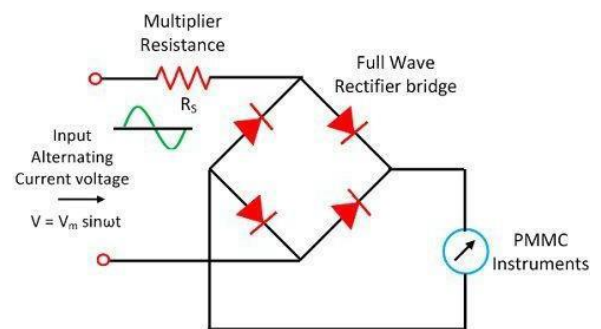
$$V_{av} = 0.318 \times \sqrt{2V} = 0.45V$$

The above calculation shows that the sensitivity of the instrument through AC is 0.45 times the current through the sensitivity of DC.

Full Wave Rectifier Instrument:

Construction

- Consists of:
 - AC source
 - Bridge rectifier (or two diodes)
 - Series resistance
 - PMMC movement

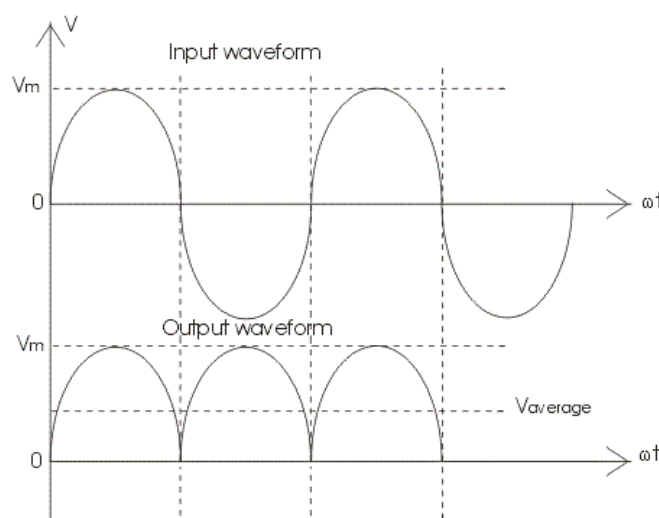


Full Wave Rectifier Circuit

Circuit Globe

Working

- In **positive half cycle**, one pair of diodes conduct.
- In **negative half cycle**, the other pair conduct.
- In both cases, current flows through the meter in the **same direction**.
- Thus, the meter responds to both half cycles → higher sensitivity and accuracy.
- Scale calibrated in terms of RMS voltage.



The DC voltage applied to the circuit causes the full-scale deflection of the PMMC meter. The sinusoidal voltage applied to the meter expressed as

$$V_{av} = \frac{1}{\pi} \int_0^{\pi} V_m \sin \omega t d(\omega t) = \frac{2}{\pi} V_m$$

$$V_{av} = 0.636 V_m$$

$$V_{av} = 0.9V$$

Relation Between AC and DC Sensitivity

- For the same RMS value of voltage:

Average Value of AC (full-wave) = 0.9 × DC Value

- Hence, the sensitivity of the instrument on AC is about **90% of its sensitivity on DC.**

Exam Tip:

Write it like this in short:

- “The average value of AC is 0.9 times the DC value for the same voltage. Hence, the sensitivity of rectifier-type instruments on AC is **90% of that on DC.**”

Feature	Half-Wave Rectifier Voltmeter	Full-Wave Rectifier Voltmeter
Diodes used	1	2 (center-tap) or 4 (bridge)
Waveform used	Only positive half cycle	Both positive & negative half cycles
Sensitivity	Low	High
Accuracy	Poor for non-sinusoidal inputs	Better accuracy

2.4 CT and PT: construction, working and applications

Instrument transformers are special-purpose transformers used to extend the range of AC measuring instruments.

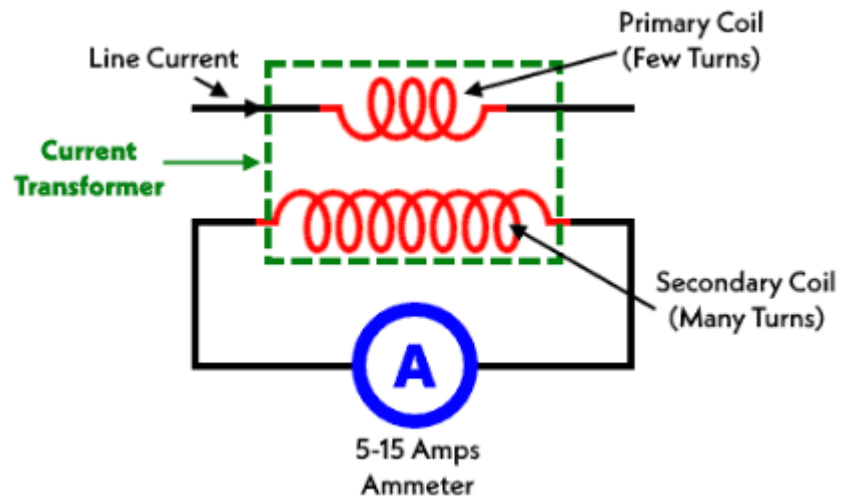
- Current Transformer (CT)** – steps down high current to a standard low value.
- Potential Transformer (PT)** – steps down high voltage to a standard low value.

They make it possible to measure **large currents and high voltages** safely with ordinary ammeters and voltmeters.

1. Current Transformer (CT)

Construction

- Primary winding: very few turns (even 1 turn, a bar conductor) connected **in series** with the load.
- Secondary winding: many turns, connected to a low-range AC ammeter.
- Core: laminated silicon steel core to reduce eddy current losses.
- Entire unit enclosed in an insulated casing.



Working

- Operates on transformer principle:

$$I_p N_p = I_s N_s$$

- Primary carries the line current.
- Secondary delivers a proportionally reduced current (standard: **5 A or 15A**).
- Ammeter connected to the secondary reads this safe current → actual line current = CT ratio × meter reading.

$$\text{CT Ratio} = \frac{I_p}{I_s}$$

where

- I_p = primary (line) current
- I_s = secondary current (standard, usually 5 A or 15 A)

Applications of Current Transformer (CT)

1. **Measurement of Large AC Currents**

- CT steps down high line currents (hundreds or thousands of amperes) to a standard 5 A or 1 A, which can be safely measured by ordinary ammeters.

2. Protection

- CTs supply current to protective relays used in circuit breakers.
- They provide isolation and scaled current for **over-current**, **earth fault**, and **differential protection** schemes.

3. Energy Metering

- Used with energy meters for measuring power and energy consumption in high-current circuits.

4. Monitoring and Control

- Widely used in power substations and industries for continuous monitoring of load current.

5. Testing

- Employed in testing laboratories for calibration of AC ammeters and other instruments.

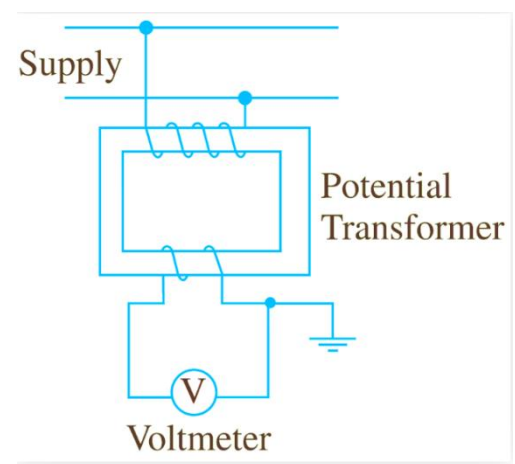
✓ Exam Tip:

Write 3–4 applications briefly (Measurement, Protection, Energy metering, Monitoring). That's enough for 2 marks.

2. Potential Transformer (PT)

Construction

- Primary winding: many turns, connected **in parallel** with the high-voltage line.
- Secondary winding: fewer turns, connected to a low-range AC voltmeter.
- Designed for high insulation strength, since primary is connected to HV system.
- Standard secondary voltage: **110 V**.



Working

- Operates on transformer principle:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

- Primary measures high voltage, secondary delivers reduced voltage (e.g., 110 V).
- Voltmeter reads secondary → actual line voltage = PT ratio × meter reading.

$$\text{PT Ratio} = \frac{V_p}{V_s}$$

where

- V_p = primary (line) voltage
- V_s = secondary voltage (standard, usually 110 V)

Applications of Potential Transformer (PT)

1. **Measurement of High AC Voltage**
 - PT steps down very high voltages (kV level) to a safe standard value (e.g., 110 V) which can be read by ordinary voltmeters.
2. **Energy Metering**
 - Used with wattmeters and energy meters to measure power and energy in high-voltage circuits.
3. **Protection**
 - Supplies voltage signals to protective relays (over-voltage, under-voltage, distance protection).
4. **Synchronizing**
 - Provides reduced voltage for synchronizing lamps and synchronizing instruments in power stations.
5. **Monitoring and Control**
 - Used in substations and industries for continuous monitoring of line voltage.

UNIT-3

Measurement of Electric Power

Syllabus

- 3.1 Analog meters: Permanent magnet moving coil (PMMC) and Permanent magnet moving iron (PMMI) meter, their construction, working, salient features, merits and demerits
- 3.2 Dynamometer type wattmeter: Construction and working
- 3.3 Errors and compensations of PMMI, PMMC and Dynamometer type wattmeter
- 3.4 Active and reactive power measurement: One, two and three wattmeter method
- 3.5 Effect of Power factor on wattmeter reading in two wattmeter method
- 3.6 Maximum Demand indicator(Definition only)

Permanent magnet moving coil (PMMC)

PMMC instruments are widely used for measuring **DC current and voltage**.

Construction

They consist of the following main components:

1. Moving Coil

- Made of fine copper wire, wound with many turns on a **rectangular aluminium former**.
- The aluminium former is **pivoted on jewelled bearings** → allows free movement.
- The coil moves in the magnetic field of a permanent magnet when current flows

2. Magnet System

- A **U-shaped permanent magnet** made of Alnico or Alcomax (materials with high coercive force).
- Produces a strong magnetic field of about **0.1 to 1 Wb/m²**.
- A **soft iron cylinder** is placed between the poles to make the field **radial and uniform**.

3. Control Spring

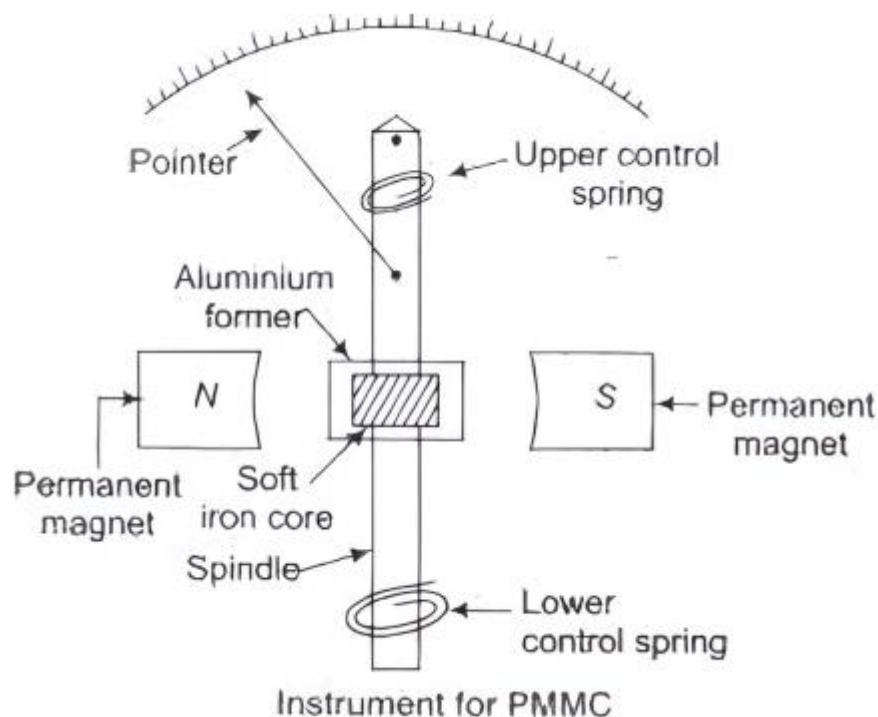
- Two **phosphor bronze hair springs** (spiral/helical type) mounted on jewelled bearings.
- Provide **controlling torque** to balance the deflecting torque.
- Also act as **current leads** (carry current in and out of the moving coil).

4. Damping

- **Eddy current damping** is provided by the aluminium former of the coil.
- It helps to bring the pointer quickly to its steady position without oscillations.

5. Pointer and Scale

- A **lightweight pointer** is attached to the spindle.
- Moves over a **uniformly graduated scale**.
- The pointer tip is **twisted into a fine blade** to reduce **parallax error** in reading.



Principle

☞ “When a current-carrying conductor (or coil) is placed in a magnetic field, it experiences a mechanical force (torque).”

Working of PMMC Instrument:

When the instrument is connected in the circuit to measure current or voltage, then operating current flows through the coil. When a current carrying coil is placed in a magnetic field, it will experience a force.

As a result, the pointer attached to the moving system moves in a clockwise direction over the scale to indicate the value of current or voltage being measured.

- If the current in the coil is reversed, then deflecting torque will also be reversed.
- Since the deflecting torque reverses with the reversal of current in the coil, such instruments can be used to measure **D.C. only**.

Torque Equation of PMMC Instruments

1. Deflecting Torque (T_d)

When current (I) flows through the coil:

$$\text{Deflecting Torque } (T_d) = NBLdI$$

Where:

- N = Number of turns of the moving coil
- B = Flux density of magnetic field
- L = Length of coil
- d = Breadth of coil

Let, $G = NBLd$ (instrument constant)

So,

$$T_d = GI$$

2. Controlling Torque (T_c)

Provided by spring:

$$T_c = K\theta$$

Where:

- K = Spring constant
- θ = Angular deflection

3. Equilibrium Condition

At steady state,

$$T_d = T_c$$

So,

$$GI = K\theta$$

$$\theta = \frac{G}{K} I$$

Conclusion

- Deflection $\theta \propto$ Current (I).
- Hence, the **scale of PMMC instrument is uniform (linear)**.

Salient Features of Permanent Magnet Moving Coil (PMMC) Instruments

1. High Accuracy

- PMMC gives very correct and reliable readings.

2. Uniform Scale

- The scale has equal divisions.
- Reading is very easy and clear.

3. High Sensitivity

- It can detect very small current or voltage.

4. Low Power Consumption

- It takes very little power from the circuit.

5. Quick Damping

- Pointer stops quickly, no vibration or oscillation.

6. No Hysteresis Error

- Uses permanent magnet $\rightarrow$ no magnetic loss.

7. Good Torque-to-Weight Ratio

- Pointer moves smoothly with less weight.

8. Used Only for DC

- PMMC can measure only **DC** (Direct Current).
- Not suitable for AC without converter.

Merits of PMMC Instruments

1. **Low Power Consumption** – Very little power required.
2. **Uniform (Linear) Scale** – Easy to read.
3. **High Torque/Weight Ratio** – Very sensitive instrument.
4. **No Hysteresis Loss** – Accurate readings.
5. **Effective Eddy Current Damping** – Pointer comes to rest quickly.
6. **Less Affected by Stray Magnetic Field** – Good stability and accuracy.

Demerits of PMMC Instruments

1. **Costly** – Delicate construction, requires precision machining.
2. **Aging Effect** – Magnet and springs may weaken with time.
3. **DC Only** – Cannot be used for AC measurements.

Permanent magnet moving iron (PMMI) meter

Definition

The instruments in which a **soft iron piece (moving iron)** is used for measuring current or voltage are called **Moving Iron Instruments**.

Principle:

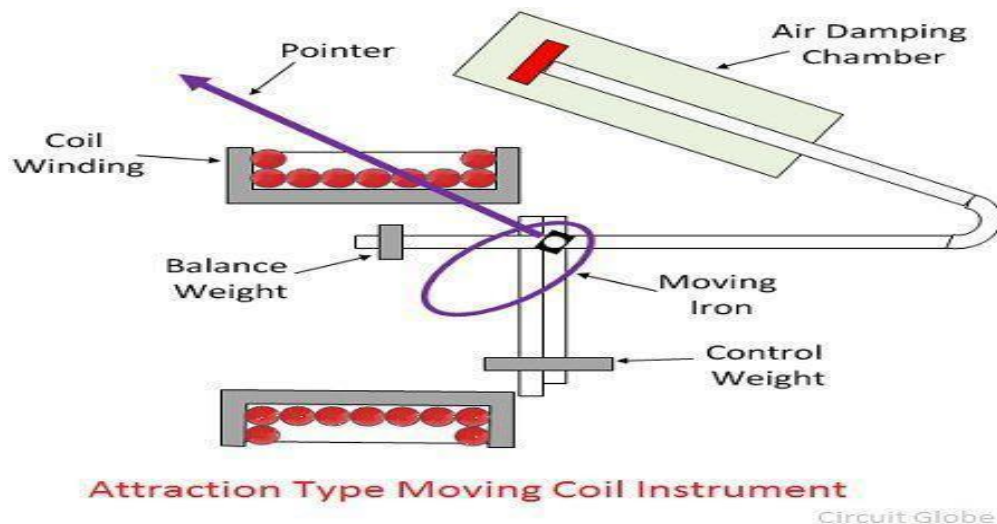
They work on the principle of **magnetizing a soft iron piece by the current in a coil**. The deflecting torque produced is proportional to the **square of the current (I^2)**, hence MI instruments can be used for **both AC and DC** measurements.

Classification of Moving Iron Instruments

1. Attraction Type
 2. Repulsion Type
1. Attraction Type

Construction

1. **Stationary Coil** – Flat coil with a narrow opening, carries the current to be measured.
2. **Moving Element** – A flat soft iron disc/vane placed near the coil.
3. **Control Spring** – Provides controlling torque.
4. **Air Damping Chamber** – Aluminium piston provides damping to reduce oscillations.
5. **Pointer & Scale** – Pointer attached to spindle moves over a **non-linear scale**.



Working (Attraction Type Moving Iron Instrument):

When operating current flows through the coil, a magnetic field is produced in the coil. This field attracts the soft-iron piece towards the coil.

As a result, the pointer attached to the moving system moves from zero position.

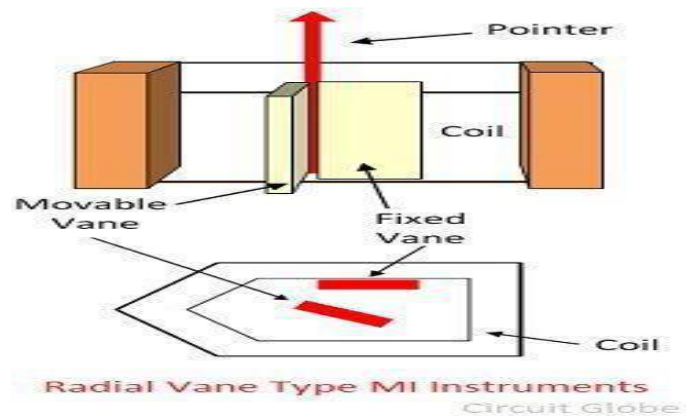
- If the current is reversed, then the magnetic field also reverses, and so does the magnetism produced in the soft-iron piece.
- The direction of deflecting torque remains unchanged.
- For this reason, such instruments are used for both **AC and DC**.

2. Repulsion Type

Construction

- **Stationary Coil** – A hollow cylindrical coil carries the current to be measured.
- **Fixed Iron Vane** – One soft iron piece fixed inside the coil.
- **Moving Iron Vane** – Another soft iron piece attached to a spindle with pointer.
- **Control Spring** – Provides controlling torque to balance deflection.
- **Damping** – Air friction (or eddy current) damping is used to steady the pointer.

- **Pointer & Scale** – Pointer attached to spindle moves over a **non-linear scale**.



Working (Repulsion Type Moving Iron Instrument):

When current flows through the coil, a magnetic field is produced by the coil. This field magnetizes the two iron pieces in the same direction.

As a result, the two iron pieces **repel** each other. Since the fixed iron piece cannot move, the movable iron piece deflects and causes the pointer to move from zero position.

- If the current in the coil is reversed, the direction of deflecting torque remains unchanged.
- This is because reversal of the field of the coil also reverses the magnetization of the two iron pieces, so they continue to repel each other.
- For this reason, such instruments are used for both **AC and DC**.

Salient Features of PMMI (Permanent Magnet Moving Iron) Instruments

1. **Works on AC and DC** – Since $\text{torque} \propto I^2$, deflection is independent of current direction.
2. **Non-linear Scale** – Scale is crowded at the beginning and spread out at higher values.
3. **Simple & Robust Construction** – Strong and durable, less chance of damage.
4. **Moderate Accuracy** – Accuracy is less than PMMC but good enough for general use.
5. **Less Sensitive** – Requires more current for deflection compared to PMMC.
6. **Low Cost** – Cheaper than PMMC instruments.
7. **Errors Possible** – Affected by hysteresis and stray magnetic fields.
8. **Permanent Magnet Support** – Permanent magnet improves field strength and reduces errors.

Merits of PMMI Instruments

1. **Can measure both AC and DC** quantities.
2. **Simple and robust** in construction → durable.
3. **Cheaper** compared to PMMC instruments.
4. **Not easily damaged** by overloads.

5. **Moderate accuracy** – sufficient for general measurements.

Demerits of PMMI Instruments

1. **Scale is non-linear** (crowded at the beginning).
2. **Less sensitive** – requires more current for deflection.
3. **Accuracy is lower** compared to PMMC instruments.
4. **Errors due to hysteresis** (in iron parts).
5. **Affected by stray magnetic fields**.

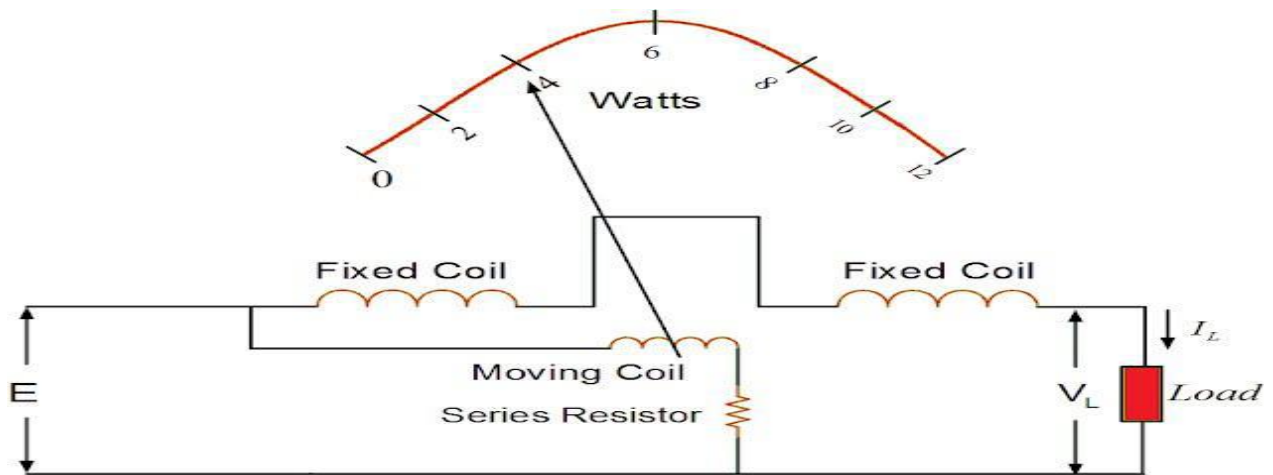
3.2 Dynamometer type wattmeter: Construction and working

Definition:

A wattmeter is an instrument used to measure the **power in an electric circuit in watts**. The most common type is the **dynamometer wattmeter**, which works on the interaction between the magnetic fields of two coils – the **current coil** and the **potential coil**.

Construction

1. **Fixed Coil (Current Coil)**
 - Split into two equal halves and placed parallel.
 - Connected in series with the load → carries the **load current**.
 - Air-cored to avoid hysteresis effects on AC.
2. **Moving Coil (Potential Coil)**
 - Mounted on a spindle, placed between fixed coils.
 - Connected in parallel with the load through a **high resistance**.
 - Carries current proportional to the **load voltage**.
3. **Series Resistance**
 - High resistance in series with moving coil → limits current, makes coil lightweight, increases sensitivity.
4. **Pointer & Scale**
 - Pointer fixed to spindle → moves over a uniform scale to indicate power.
5. **Control Springs**
 - Provide controlling torque.
 - Also carry current in/out of the moving coil.
6. **Damping**
 - Air friction damping is used.



Working Principle

- Current coil produces magnetic field **F_m** (proportional to load current).
- Potential coil produces magnetic field **F_r** (proportional to load voltage).
- Interaction between F_m and F_r produces **deflecting torque**.
- The torque is proportional to $V \times I \times \cos\Phi$, i.e., the real power.
- Pointer deflects over the scale → measures power directly in watts.

Advantages

1. Can be used for **both AC and DC** circuits.
2. Scale is **uniform and linear**.
3. High accuracy possible with careful design.

Disadvantages

1. At **low power factor**, the inductance of the potential coil causes serious errors.
2. Affected by **stray magnetic fields**, so the instrument must be shielded inside an iron case.
3. Errors due to frequency and temperature variations.

3.3 Errors and compensations of PMMI, PMMC and Dynamometer type wattmeter

Errors in Permanent Magnet Moving Iron (PMMI) Instruments

Moving Iron (MI) instruments suffer from two types of errors:

1. **Errors with both AC and DC**
2. **Errors with AC only**

Errors due to both AC and DC and Their Compensation

1. Error due to Hysteresis

- **Cause:** Iron parts retain residual magnetism (hysteresis).
- **Effect:** Reading is **higher for descending values** and **lower for ascending values**.
- **Compensation:** Use **mumetal or permalloy** (special alloys with very low hysteresis loss).

2. Error due to Stray Magnetic Fields

- **Cause:** Weak operating field of MI is disturbed by **external magnetic fields**.
- **Effect:** Causes **serious errors** in measurement.
- **Compensation:** Enclose the instrument in an **iron case or magnetic shielding**.

3. Error due to Temperature

- **Cause:** Temperature changes affect the **spring stiffness** and resistance of coil.
- **Effect:** Variation in readings (either higher or lower depending on change).
- **Compensation:**
 - Use **springs with low temperature coefficient**.
 - In voltmeters, resistance error may balance spring error.

4. Error due to Frequency (AC Only)

- **Cause:** On AC, frequency change → changes **coil impedance** and **eddy currents**.
- **Effect:** Causes **serious errors in voltmeters**.
- **Compensation:** Connect a **capacitor (condenser)** across the **swamp resistance** to neutralize frequency effect.

Exam Tips for SCTEVT Students

- **2 Marks:** Write **one error + its compensation**.
- **5 Marks:** Write **three errors with compensation**.

Errors in PMMC Instruments and Their Compensation

1. Error due to Magnetism (Magnet Aging)

- **Cause:** Permanent magnets lose magnetism with time (heat, vibration).
- **Effect:** Reduction in magnetic strength → smaller deflection → lower reading.
- **Compensation:** Use **Alnico or Alcomax magnets** (high coercivity, stable over time). Instruments are also **periodically recalibrated**.

2. Error due to Temperature

- **Cause:** Copper coil resistance increases with rise in temperature ($\alpha \approx 0.004/^\circ\text{C}$).
- **Effect:** Current decreases → deflection reduces → reading error.
- **Compensation:** Use **swamping resistors** (manganin wire in series with the coil, having very low temp. coefficient). This minimizes overall temperature effect.

3. Error due to Spring Aging

- **Cause:** Control springs weaken with age.
- **Effect:** Deflection increases → higher reading.
- **Compensation:** Proper **calibration** at regular intervals balances this error. In practice, spring aging and magnet aging **partially cancel** each other.

Exam Tips for SCTEVT Students

- **2 Marks:** Write **error + one compensation** (e.g., “Temperature error → compensated by manganin swamping resistance”).
- **5 Marks:** Write **two errors with their compensation**.

Errors in Dynamometer Type Wattmeter and Their Correction

1. Error due to Potential Coil Inductance

- **Cause:** Inductance of potential (voltage) coil introduces phase difference.
- **Effect:** Wattmeter shows **high reading at lagging p.f.** and **low reading at leading p.f.**
- **Correction:** Connect a **high non-inductive resistance** in series with the potential coil → swamps the inductive effect.

2. Error due to Power Loss in Potential or Current Coil

- **Cause:**
 - Voltage drop in current coil.
 - Current taken by potential coil.
- **Effect:** Error in indicated power reading.
- **Correction:** Use an **additional compensating winding** in series with the potential coil → produces field opposite to current coil.

3. Error due to Eddy Currents

- **Cause:** Alternating field of current coil induces eddy currents in nearby solid metal parts.
- **Effect:** Eddy currents set up opposing fields → cause wrong deflection.
- **Correction:** Keep **solid metal parts away from current coil** or use **laminated parts**.

4. Error due to Stray Magnetic Fields

- **Cause:** Wattmeter has weak operating field → affected by stray external fields.
- **Effect:** Causes serious errors in readings.
- **Correction:** Use **magnetic shielding** (iron case or thin iron shields over working parts).

Exam Tips for SCTEVT Students

- **2 Marks:** Write **any one error + correction** (e.g., “Stray field error → corrected by iron shielding”).
- **5 Marks:** Write **two errors with corrections**.

3.4 Active and reactive power measurement: One, two and three-wattmeter method

One-Wattmeter Method

Principle

- Only **one wattmeter** is used.
- The **current coil (CC)** is connected **in series with any one line** (say Line R).
- The **pressure (voltage) coil (PC)** is connected:
 - Between **line R and line Y** (switch in position-1). → Wattmeter reads W_1 .
 - Between **line R and line B** (switch in position-2). → Wattmeter reads W_2 .

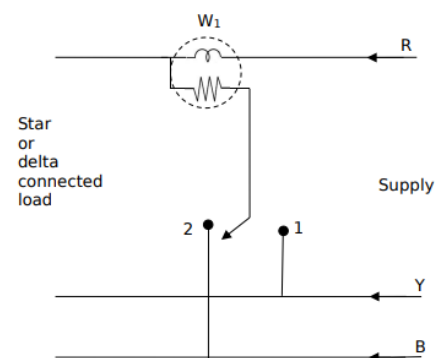


Fig. Power measurement by one wattmeter method

Measurement

- Take two readings by changing the switch.
- **Total Power in 3-phase balanced load:**

$$P = W_1 + W_2$$

Conditions

- Applicable only for **balanced loads** (since power in all phases is equally shared).
- For unbalanced loads → **two-wattmeter method** is required.
- Rarely used in practice, since the **two-wattmeter method is more general**.

Two-Wattmeter Method

Applicability

- Works for both **balanced and unbalanced 3-phase loads**.
- Commonly used in **3-phase, 3-wire systems** (no neutral).

Connection

- Two wattmeters are connected as:
 - Current coils** in any two lines (say Line R and Line Y).
 - Pressure coils** connected between those lines and the third line (say Line B).
- This gives two wattmeter readings: W1 and W2.

Balanced Star-Connected System

- Phase voltages:

$$V_{RN} = V_{YN} = V_{BN} = V_{ph}$$

- Line voltages:

$$V_{RY}, V_{YB}, V_{BR} = \sqrt{3}V_{ph}$$

- Line currents:

$$I_R = I_Y = I_B = I$$

Wattmeter Readings

From phasor diagram:

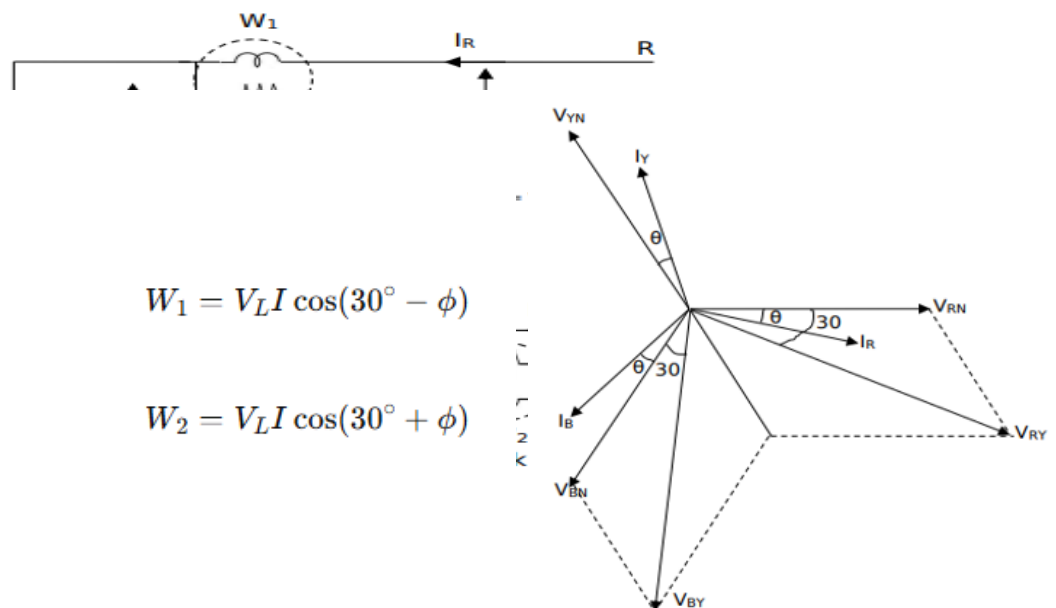
- First Wattmeter (W1):
- Second Wattmeter (W2):

$$W_1 = V_L I \cos(30^\circ - \phi)$$

$$W_2 = V_L I \cos(30^\circ + \phi)$$

where

- V_L = line voltage
- I = line current
- ϕ = load power factor angle



Total Power

$$P = W_1 + W_2 = \sqrt{3}V_{ph}I \cos \phi$$

This is the **active (true) power** in the system.

Reactive Power (for balanced load)

$$Q = \sqrt{3}(W_1 - W_2)$$

Two-Wattmeter Method – Delta Connected Load

Applicability

- Works for **balanced or unbalanced loads** in a 3-phase, 3-wire system.
- Same method as in star connection — the difference is in the relation between line and phase values.

1. Relations in Delta Connection

- Line voltage = Phase voltage:

$$V_L = V_{ph}$$

- Line current = $\sqrt{3} \times$ Phase current:

$$I_L = \sqrt{3}I_{ph}$$

2. Wattmeter Connections

- Current coils of wattmeters are connected in **two lines** (say Line R and Line Y).
- Voltage coils are connected between those lines and the **third line** (Line B).
- This gives readings W1 and W2.

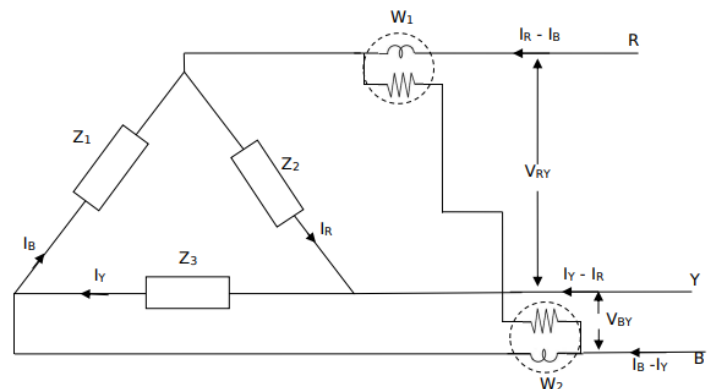


Fig. Two wattmeter method in delta connected network

3. Wattmeter Readings

From phasor diagram (similar to star, but different current relation):

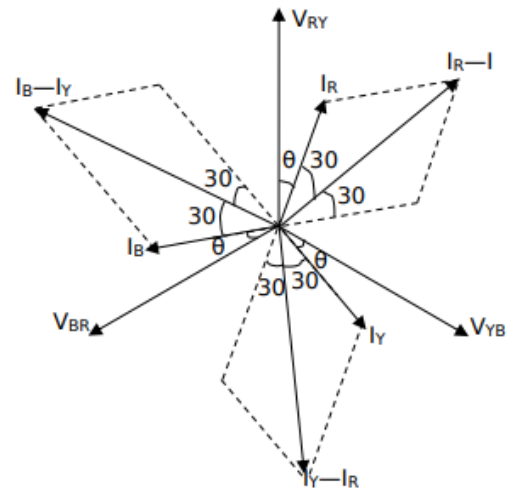


Fig. Phasor diagram for delta connected system

- First Wattmeter (W1):

$$W_1 = V_L I_L \cos(30^\circ - \phi)$$

- Second Wattmeter (W2):

$$W_2 = V_L I_L \cos(30^\circ + \phi)$$

5. Reactive Power (for balanced load)

$$Q = \sqrt{3}(W_1 - W_2)$$

Three-Wattmeter Method

(3-Phase, 4-Wire Star Connected System)

Principle

- Used for **measuring total power** in a 3-phase, 4-wire system.

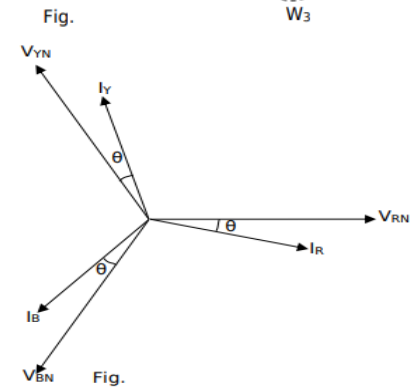
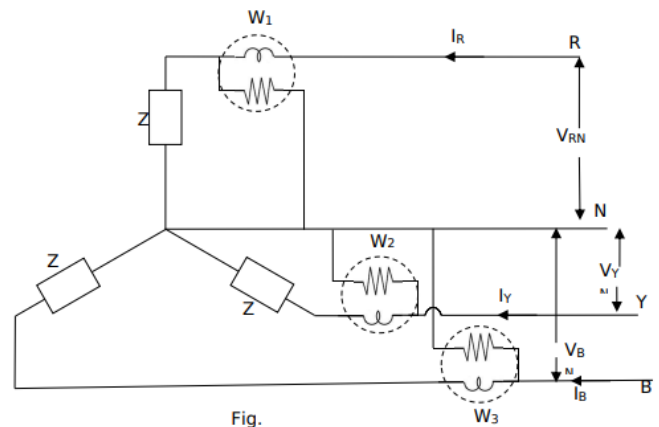
- Suitable for both **balanced and unbalanced loads**.

Connections

- **Three wattmeters** are used.
- Current coil of each wattmeter is connected **in series with each line** (R, Y, B).
- Potential coil of each wattmeter is connected **between the respective line and the neutral (N)**.

So:

- Wattmeter **W1** → current = I_R , voltage = V_{RN}
- Wattmeter **W2** → current = I_Y , voltage = V_{YN}
- Wattmeter **W3** → current = I_B , voltage = V_{BN}



Wattmeter Readings

$$W_1 = V_{RN} I_R \cos \phi_R$$

$$W_2 = V_{YN} I_Y \cos \phi_Y$$

$$W_3 = V_{BN} I_B \cos \phi_B$$

Total Power

$$P = W_1 + W_2 + W_3$$

This gives the **total active power** of the system.

Balanced Load Case

For a balanced system:

- $V_{RN} = V_{YN} = V_{BN} = V_{ph}$
- $I_R = I_Y = I_B = I$
- $\phi_R = \phi_Y = \phi_B = \phi$

So:

$$W_1 = W_2 = W_3 = V_{ph} I \cos \phi$$

$$P = W_1 + W_2 + W_3 = 3V_{ph} I \cos \phi$$

This is the **total 3-phase power**.

Reactive Power (for

balanced loads):

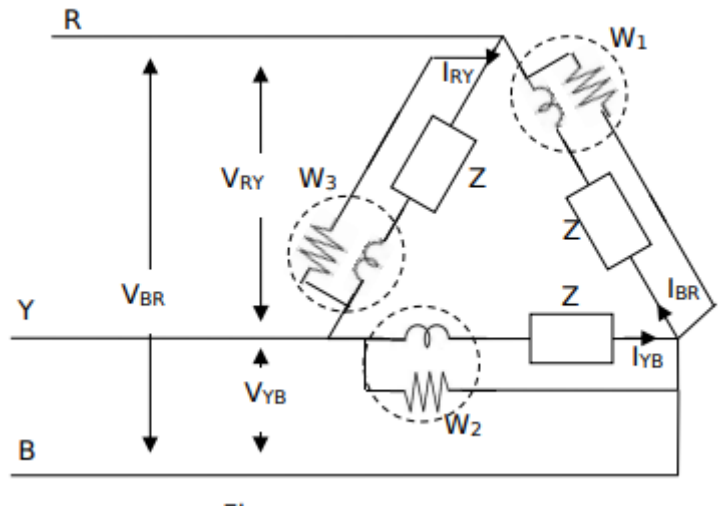
$$Q = \sqrt{3}(W_1 + aW_2 + a^2W_3)$$

- (complex form, but practically → measured using 2-wattmeter method instead).
- **Advantage:** Can measure **active power in unbalanced 4-wire systems** accurately.

Three-Wattmeter Method (Delta-Connected Load)

Connections

- System: **3-phase, 3-wire Delta connected load.**
- **Three wattmeters** are used:
 - Current coil of each wattmeter in **each line conductor (R, Y, B).**
 - Voltage (pressure) coil of each wattmeter is connected **between the line and another line** (since no neutral in delta).
- Each wattmeter therefore measures the power of one branch of the delta load



Wattmeter Readings

If:

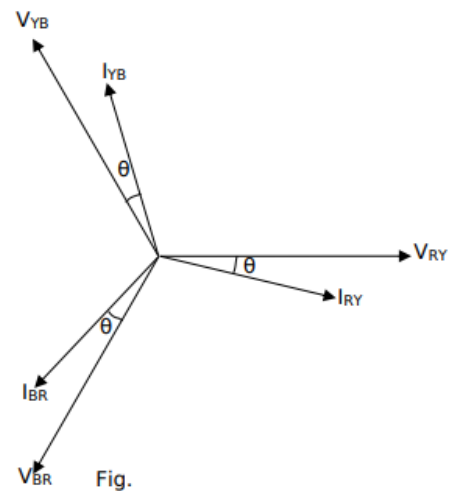
- V_{RY}, V_{YB}, V_{BR} = line (and phase) voltages in delta
- I_R, I_Y, I_B = line currents
- ϕ_R, ϕ_Y, ϕ_B = power factor angles of each phase branch

Then,

$$W_1 = V_{RY} I_R \cos \phi_R$$

$$W_2 = V_{YB} I_Y \cos \phi_Y$$

$$W_3 = V_{BR} I_B \cos \phi_B$$



Total Power

$$P = W_1 + W_2 + W_3$$

Balanced Load Condition

For a balanced delta load:

- $V_{RY} = V_{YB} = V_{BR} = V_{ph}$
- $I_R = I_Y = I_B = I_{ph}$
- $\phi_R = \phi_Y = \phi_B = \phi$

So each wattmeter reads:

$$W_1 = W_2 = W_3 = V_{ph} I_{ph} \cos \phi$$

$$P = W_1 + W_2 + W_3 = 3V_{ph} I_{ph} \cos \phi$$

Since in delta, $V_{ph} = V_L$ and $I_{ph} = \frac{I_L}{\sqrt{3}}$,

$$P = \sqrt{3} V_L I_L \cos \phi$$

✔ Summary Table

Method	System	Active Power (P)	Reactive Power (Q)
One Wattmeter	Single-phase / Balanced	$P = VI \cos \phi$	Not possible
Two Wattmeter	3-phase, 3-wire system	$P = W_1 + W_2$	$Q = \sqrt{3}(W_1 - W_2)$ (balanced)
Three Wattmeter	3-phase, 4-wire system	$P = W_1 + W_2 + W_3$	Complicated, rarely used

★ Quick Student-Friendly Revision

- **2 marks** → Definitions / formulas / small facts.
- **5 marks** → Diagram + short derivation OR special case explanation.
- **10 marks** → Full derivation + diagram + phasor OR numerical problem.
- **Balanced system** → All wattmeters read the same.
- **Unbalanced system** → Wattmeter readings differ, but total is always correct.
- **Final formula (Star or Delta):**

$$P = \sqrt{3} V_L I_L \cos \phi$$

3.5 Effect of Power factor on wattmeter reading in two wattmeter method

General Formulas

For a 3-phase, 3-wire system (balanced load):

$$W_1 = V_L I_L \cos(30^\circ - \phi)$$

$$W_2 = V_L I_L \cos(30^\circ + \phi)$$

- V_L = line voltage
- I_L = line current
- ϕ = load power factor angle

Cases of Power Factor

1. Unity Power Factor ($\phi = 0^\circ$)

- $W_1 = V_L I_L \cos 30^\circ$
- $W_2 = V_L I_L \cos 30^\circ$
- Both wattmeters read **equal and positive**.
- **Total Power:**

$$P = W_1 + W_2 = \sqrt{3} V_L I_L$$

2. Lagging Power Factor, $0 < \phi < 60^\circ$

- Both wattmeters show **positive readings**.
 - $W_1 > W_2$.
-

3. Power Factor = 0.5 Lag ($\phi = 60^\circ$)

- $W_1 = V_L I_L \cos(30^\circ - 60^\circ) = V_L I_L \cos(-30^\circ) = V_L I_L \cos 30^\circ$
 - $W_2 = V_L I_L \cos(30^\circ + 60^\circ) = V_L I_L \cos 90^\circ = 0$
 - So, **one wattmeter reads zero**.
-

4. Low Power Factor, $\phi > 60^\circ$

- One wattmeter shows **negative reading**.
 - The pointer may deflect backward → need to **reverse connections** to get upscale deflection.
-

5. Zero Power Factor ($\phi = 90^\circ$, purely reactive load)

- $W_1 = V_L I_L \cos(30^\circ - 90^\circ) = V_L I_L \cos(-60^\circ) = V_L I_L \times 0.5$
- $W_2 = V_L I_L \cos(30^\circ + 90^\circ) = V_L I_L \cos 120^\circ = -0.5 V_L I_L$
- Readings are equal and opposite → **Total Active Power = 0**.

Summary Table

Power Factor ($\cos\phi$)	W1 Reading	W2 Reading	Observation
1.0 (unity)	Equal positive	Equal positive	Both positive, equal
0.5 ($\phi = 60^\circ$)	Positive	Zero	One reads zero
< 0.5 ($\phi > 60^\circ$ lag)	Positive	Negative	One reads negative
0 ($\phi = 90^\circ$)	+0.5 VLI	-0.5 VLI	Equal & opposite → P = 0

3.6 Maximum Demand indicator(Definition only)

A **Maximum Demand Indicator (MDI)** is an instrument used in electrical power systems to record the **maximum load (or demand) on the system during a specific period of time**.

It helps utilities and industries monitor the **highest power demand** reached, so that tariff charges and proper sizing of equipment (transformers, cables, etc.) can be determined.

UNIT-4

Measurement of Electric Energy

4.1 Single and three phase electronic energy meter:

Constructional features and working principle

4.2 Errors and their compensations

4.3 Calibration of single-phase electronic energy meter using direct loading.

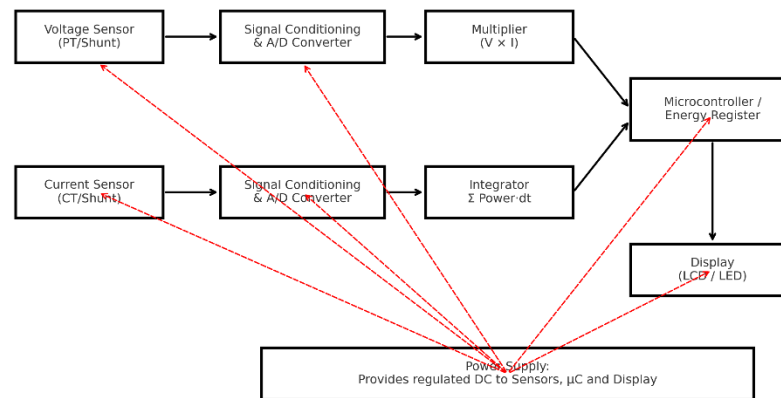
Single phase electronic energy meter

Constructional Features

A **digital/electronic energy meter** has no moving parts (unlike electromechanical meters). It consists of the following blocks:

1. **Voltage Sensor (Potential Transformer – PT):**
 - Steps down line voltage.
 - Provides proportional low-voltage signal.
2. **Current Sensor (CT / Shunt):**
 - Measures line current.
 - Provides proportional signal.
3. **Analog Signal Conditioning & A/D Conversion:**
 - Filters, amplifies, and converts analog signals (V, I) into digital signals.
4. **Multiplier (Instantaneous Power Calculator):**
 - Multiplies digitized voltage and current signals.
 - Gives **instantaneous power** = $V \times I$.
5. **Integrator (Energy Register):**
 - Integrates instantaneous power over time.
 - Gives **Energy** = $\int P \, dt$ (kWh).
6. **Microcontroller / Processing Unit:**
 - Stores readings, performs correction, and controls display.
 - Can detect tampering, overload, etc.
7. **Display Unit (LCD/LED):**
 - Shows kWh, kVAh, instantaneous power, PF, demand, etc.
8. **Power Supply Circuit:**
 - Provides low-voltage DC to all internal circuits.

Block Diagram of Digital Energy Meter



Working Principle

- **Sensing:**

- The meter takes the **voltage** using a PT (Potential Transformer).
- The meter takes the **current** using a CT (Current Transformer) or shunt.

- **Signal Processing:**

- These signals are made small and clean.
- Then converted into **digital signals** by A/D converter.

- **Power Calculation:**

- The meter multiplies **Voltage × Current**.
- This gives the **instantaneous power**.

- **Energy Calculation:**

- The meter adds power with respect to time.
- This gives the **energy used (kWh)**.

- **Microcontroller:**

- It controls the calculation.
- Stores readings, checks tamper, calculates power factor.

- **Display:**

- The result (energy consumed) is shown on the **LCD/LED display**.

- **Power Supply:**

- A small circuit inside changes AC to DC.
- This runs all parts of the meter.

Advantages

- High accuracy (class 0.5 or better).
- Can measure **kWh, kVAh, kVARh** simultaneously.
- Provides **tamper detection & data storage**.
- No wear and tear (solid-state).
- Communication capability (Smart Metering).

⚡ Three-Phase Digital Energy Meter

Constructional Features

Similar to single-phase, but adapted for **3-phase, 3-wire or 4-wire systems**.

Main Components:

1. **Voltage Sensors (PTs):**
 - 3 PTs (one for each phase R, Y, B) step down line voltages.
2. **Current Sensors (CTs/Shunts):**
 - 3 CTs measure line currents (IR, IY, IB).
3. **Signal Conditioning & A/D Conversion:**
 - Each voltage and current channel is filtered, amplified, digitized.
4. **Multipliers (Instantaneous Power):**
 - For each phase:

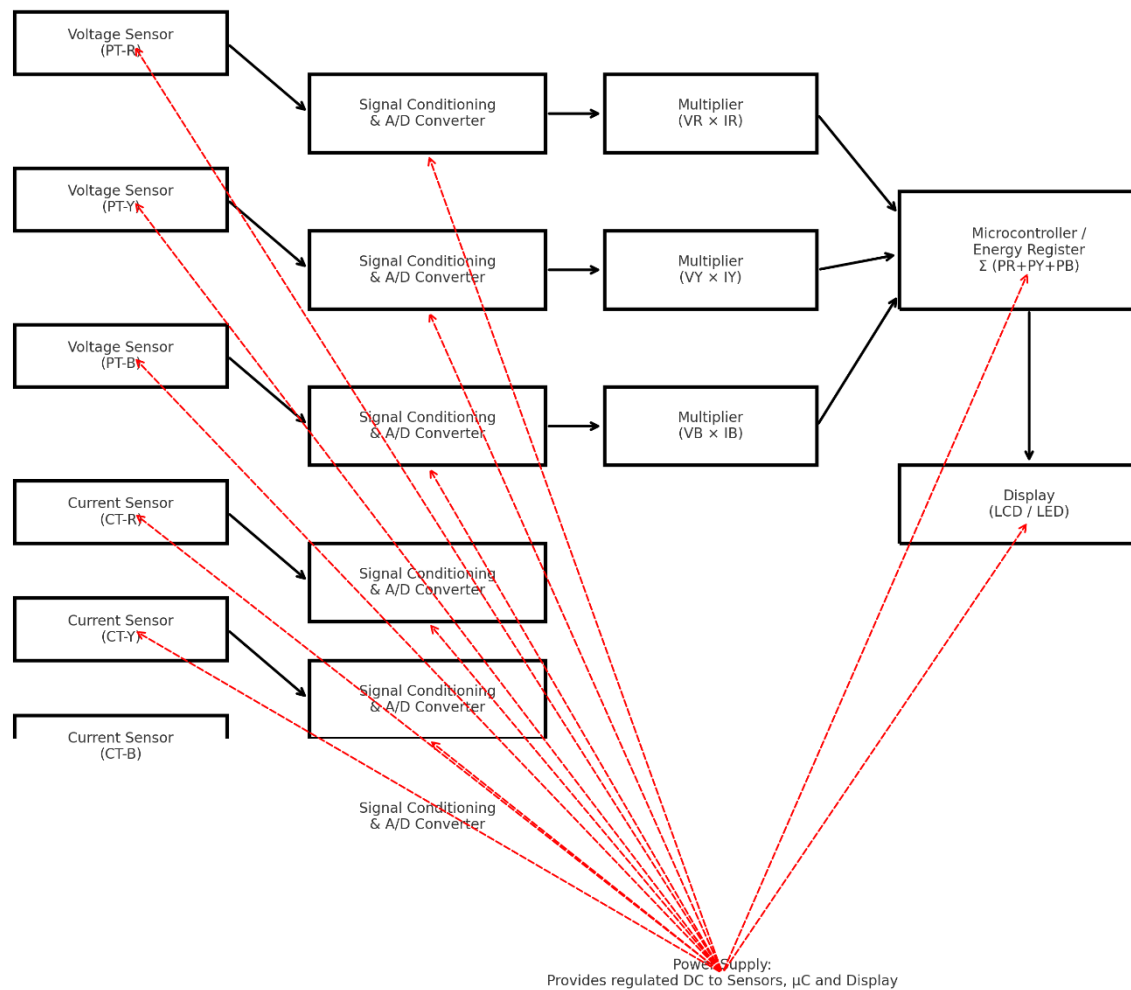
$$p_R = v_R \cdot i_R, \quad p_Y = v_Y \cdot i_Y, \quad p_B = v_B \cdot i_B$$

5. **Integrator (Energy Calculation):**
 - Integrates instantaneous power for each phase → energy in kWh.
6. **Microcontroller / DSP Processor:**
 - Adds energies of all phases:

$$E_{total} = E_R + E_Y + E_B$$

- Stores data, detects tamper/load unbalance.
7. **Display (LCD/LED):**
 - Shows kWh, kVAh, kVARh, PF, max demand, etc.
8. **Power Supply Block:**
 - Provides regulated DC to all internal blocks.

Block Diagram of Three-Phase Digital Energy Meter



Working Principle

- **Sensing:**

- The meter takes the **voltage** from PT (Potential Transformer).
- The meter takes the **current** from CT (Current Transformer).

- **Signal Processing:**

- These signals are made small and clean by **filters and amplifiers**.
- Then they are changed into **digital form** (A/D conversion).

- **Power Calculation:**

- The meter multiplies **Voltage × Current** in each phase.
- This gives **instant power** of R, Y, and B phases.

- **Energy Calculation:**
 - Power is added continuously with time.
 - This gives **energy (kWh)** used by the load.
- **Microcontroller:**
 - It controls the whole process.
 - Stores data, checks for faults, and calculates PF, kVAh, kVArh.
- **Display:**
 - The result (energy used) is shown on **LCD/LED screen**.
- **Power Supply:**
 - The meter has a small power supply inside.
 - It converts AC to DC to run all parts of the meter.

4.2 Errors and their compensations

⚡ Errors in Single-Phase Digital Energy Meter and Their Compensation

1. Phase Angle Error

- **Cause:**
Small phase difference between the voltage signal (from PT) and current signal (from CT/shunt).
- **Effect:**
Leads to incorrect power calculation (especially at low power factor).
- **Compensation:**
 - Use precision CTs and PTs with minimum phase error.
 - Software correction in the microcontroller.

2. Creep (Unwanted Rotation / Pulses at No-Load)

- **Cause:**
Meter shows slow movement (or extra pulses) even when no load is connected.
Due to stray magnetic fields, leakage currents, or vibrations.
- **Effect:**
False energy registration at no load.
- **Compensation:**
 - Anti-creep circuits.
 - Use of small electronic compensation circuits.

3. Temperature Error

- **Cause:**
Electronic components (resistors, sensors, ICs) change behaviour with temperature.
- **Effect:**
Wrong readings when ambient temperature is too high/low.
- **Compensation:**
 - Temperature-compensating circuits.
 - High-quality resistors and ICs with low temperature coefficient.

4. Supply Voltage Fluctuation Error

- **Cause:**
Change in supply voltage affects the sensing and power supply circuits.
- **Effect:**
Meter may register incorrectly during under-voltage/over-voltage.
- **Compensation:**
 - Use regulated DC supply inside the meter.
 - Digital sampling technique reduces this error.

5. Frequency Error

- **Cause:**
Variation of supply frequency (not exactly 50 Hz).
- **Effect:**
Sampling may be slightly off → causes calculation error.
- **Compensation:**
 - Use crystal oscillator for timing reference.
 - Proper digital signal processing.

6. Harmonic Distortion Error

- **Cause:**
Non-linear loads (like SMPS, computers, motors) create harmonics.
- **Effect:**
Distorted V and I waveforms cause wrong multiplication.
- **Compensation:**
 - Use digital signal processing (DSP) to filter harmonics.
 - True RMS measurement technique.

⚡ Errors in Three-Phase Digital Energy Meter and Their Compensation

1. Phase Angle Error

- **Cause:**
 - Phase shift between CTs/PTs and the actual supply signals.
 - More critical in 3-phase because three different sets of CTs/PTs are used.

- **Effect:**
 - Incorrect power factor measurement.
 - Wrong total energy calculation.
- **Compensation:**
 - Use precision CTs and PTs with low phase error.
 - Software-based phase correction in microcontroller.

2. Creep (Unwanted Pulses at No Load)

- **Cause:**
 - Spurious pulses in electronic circuits, leakage currents, stray fields.
- **Effect:**
 - Meter registers small energy even at no load.
- **Compensation:**
 - Anti-creep circuits.
 - Improved shielding and electronic filters.

3. Temperature Error

- **Cause:**
 - Variation in component characteristics with temperature (resistors, ICs, CT/PT windings).
- **Effect:**
 - Reading may drift at high or low ambient temperatures.
- **Compensation:**
 - Use temperature-compensated components.
 - Microcontroller applies correction factors.

4. Supply Voltage Fluctuation Error

- **Cause:**
 - Fluctuating mains voltage affects sensing circuits and power supply unit.
- **Effect:**
 - Wrong measurement, especially at low voltages.
- **Compensation:**
 - Internal regulated DC supply.
 - Auto-ranging ADCs and DSP corrections.

5. Frequency Error

- **Cause:**
 - If supply frequency deviates from 50 Hz, sampling and calculation may be inaccurate.
- **Effect:**
 - Wrong kWh, kVAh, PF readings.
- **Compensation:**
 - Use of crystal oscillator for time reference.
 - DSP algorithms correct for frequency changes.

6. Harmonic Distortion Error

- **Cause:**
 - Non-linear loads (drives, SMPS, inverters) create harmonics in V & I waveforms.
- **Effect:**
 - Wrong energy measurement if meter only measures fundamental.
- **Compensation:**
 - True RMS technique.
 - Digital filters (DSP) to account for harmonics.

7. CT / PT Ratio Error

- **Cause:**
 - Inaccurate CT/PT ratio setting or drift.
- **Effect:**
 - Overall scaling error in energy calculation.
- **Compensation:**
 - Calibration with standard meters.
 - Digital correction factors stored in microcontroller.

4.3 Calibration of single-phase electronic energy meter using direct loading

Definition

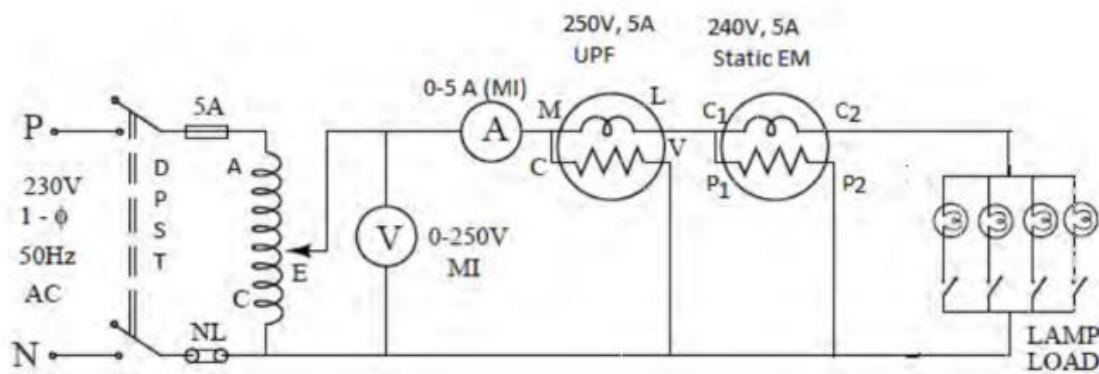
Calibration means **comparing the reading of the energy meter under test (MUT)** with the reading of a **standard energy meter or wattmeter**, when both are connected to the same load.

- If there is a difference, the error is calculated and corrected.

Apparatus Required

- Single-phase **Electronic Energy Meter (MUT)**
- **Standard Wattmeter / Energy Meter**
- Variable **Resistive Load** (lamps, heaters)
- AC Supply (230 V, 50 Hz)
- Stop-watch (for time measurement, if required)

Circuit Diagram



Procedure

1. **Connections:**
 - Connect the MUT and Standard Meter in series with the load.
 - Ensure voltage and current circuits are properly connected.
2. **Apply Load:**
 - Switch ON a known resistive load (bulb or heater).
 - Keep the load constant during the test.
3. **Take Readings:**
 - Note down:
 - Energy recorded by the Standard Meter (E_s).
 - Energy recorded by the MUT (E_m).
 - Or, time taken for a certain number of disc revolutions (in electromechanical type) / pulses (in digital type).
4. **Calculate Error:**
 - % Error is given by:

$$\% \text{ Error} = \frac{E_m - E_s}{E_s} \times 100$$

5. **Adjust Calibration:**
 - If error is beyond the permissible limit ($\pm 1\%$), adjust calibration constant of the MUT.
6. **Repeat:**
 - Repeat the process for different load values (light load, half load, full load).

Advantages of Direct Loading

- Simple and accurate method.
- Actual load is used → real operating conditions.

⚡ Disadvantages of Direct Loading Calibration

- High power loss (wastage of energy).
- Excessive heating of load and equipment.
- Bulky setup → needs large space.
- Limited to small load ranges.
- Time-consuming.
- Not suitable for mass/continuous testing.

✓ Perfect for **2 marks (any one)** or **5 marks (list 4–5 points)**.

UNIT-5

Circuit Parameter Measurement, CRO and Other Meters

5.1 Measurement of resistance

5.1.1 Low resistance: Kelvin's double bridge,

5.1.2 Medium Resistance: Voltmeter and ammeter method

5.1.3 High resistance: Megger and Ohm meter: Series and shunt

5.2 Measurement of inductance using Anderson bridge (no derivation and phasor diagram)

5.3 Measurement of capacitance using Schering bridge (no derivation and phasor diagram)

5.4 Single beam/single trace CRO (Working principle and block diagram only)

5.5 Digital storage Oscilloscope: Basic block diagram, working, Cathode ray tube, electrostatic deflection, vertical amplifier, time base generator, horizontal amplifier, measurement of voltage/ amplitude/ time period/ frequency/ phase angle delay line, specifications.

5.6 Other meters: Earth tester, Digital Multimeter; L-C-R meter, Frequency meter (ferromagnetic and Weston type), Phase sequence indicator, power factor meter (single phase and three phase dynamometer type), Synchro scope, Tri-vector meter

5.7 Signal generator: need, working and basic block diagram.

5.1 Measurement of resistance

Classification of resistance:-

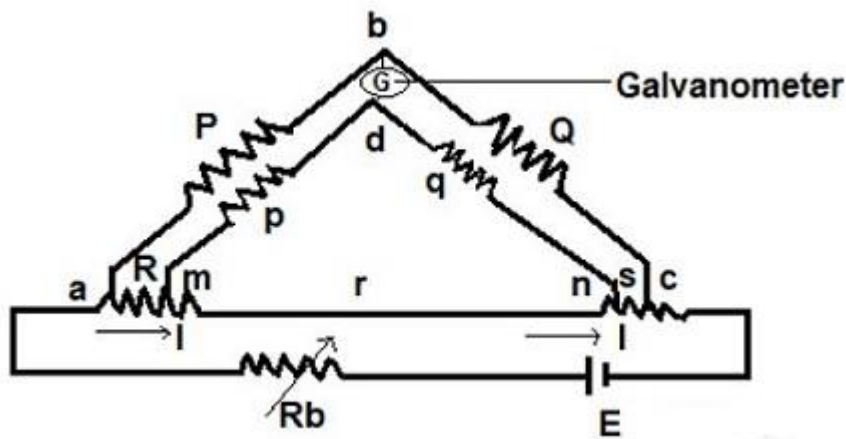
We categorize the resistance into three classes-



1. Measurement of Low Resistance ($<1\Omega$)
2. Measurement of Medium Resistance ($1\Omega - 100k\Omega$)
3. Measurement of High Resistance ($>100k\Omega$)

5.1.1 Low resistance: Kelvin's double bridge

⚡ Construction of Kelvin's Double Bridge



- The **construction** of Kelvin's Double Bridge is similar to a **Wheatstone bridge**, with one main difference:
 - It has **two sets of ratio arms**:
 - **P & Q** (main ratio arms).
 - **p & q** (auxiliary ratio arms).
- The **auxiliary arms (p & q)** are connected to one end of the galvanometer at point **d**.
- The **main arms (P & Q)** are connected to the other end of the galvanometer at point **b**.

☞ This arrangement **minimizes the effect of connecting lead resistance**.

- The **unknown resistance (R)** is placed between points **a and m**.
- The **standard resistance (S)** is placed between points **n and c**.
- A **battery (E)** supplies DC power, and a **galvanometer (G)** is used to detect balance.

Derivation of Balance Condition in Kelvin's Double Bridge

Step 1: Potential Divider Relation

From ratio arms **P & Q**:

$$E_{ab} = \frac{P}{P + Q} E_{ac}$$

Step 2: Voltage across arms (with lead resistance included)

Considering current I:

$$E_{ac} = I \left[R + S + \frac{(p+q)r}{p+q+r} \right]$$

$$E_{amd} = I \left[R + \frac{p}{p+q} \cdot \frac{(p+q)r}{p+q+r} \right]$$

$$E_{nc} = I \cdot \frac{qr}{p+q+r}$$

Step 3: Balance Condition (No Current in Galvanometer)

At balance, potential difference at galvanometer = 0.

$$\frac{P}{P+Q} E_{ac} = E_{amd}$$

Step 4: Simplification

After simplification:

$$R = \frac{P}{Q} \cdot S - \frac{pr}{p+q+r} \left(\frac{P}{Q} - \frac{p}{q} \right)$$

Step 5: Elimination of Lead Resistance

If ratio arms are chosen such that:

$$\frac{P}{Q} = \frac{p}{q}$$

Final Balance Equation:

$$R = \frac{P}{Q} \cdot S$$

Key Point

- The term due to **lead resistance r** vanishes because of the **auxiliary arms (p & q)**.
- Hence, Kelvin's Double Bridge gives **accurate measurement of low resistance**.

5.1.2 Medium Resistance: Voltmeter and ammeter method

Principle

The resistance of a medium-value resistor can be found using **Ohm's law**:

$$R = \frac{V}{I}$$

where

- V = potential difference across the resistor,
- I = current through the resistor.

This method is used for resistances from **1 Ω to a few hundred Ω** .

Circuit Arrangements

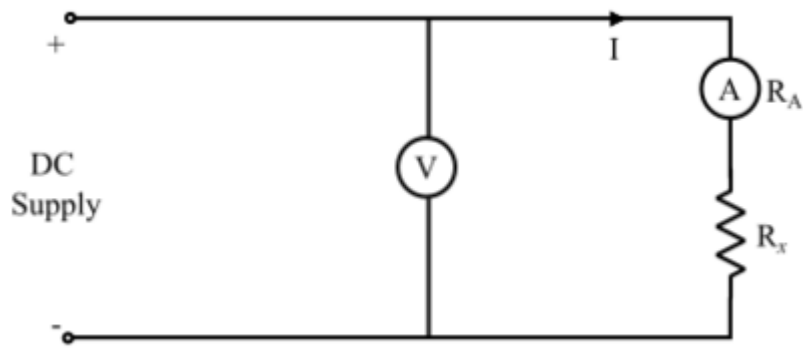
There are two possible connections of voltmeter and ammeter:

(a) Voltmeter across resistor (Ammeter in series)

- Ammeter in series with resistor.
- Voltmeter across resistor.
- Error: voltmeter also includes small drop across ammeter $\rightarrow$ measured resistance **higher** than actual.

$$R_{\text{measured}} > R_{\text{true}}$$

When the ammeter is connected such that it measures only the current flowing through the unknown resistor (R_x), then the voltmeter measures voltage drop across the ammeter and R_x .



$$V = IR_A + IR_X = I(R_A + R_X) \quad (1)$$

From (1):

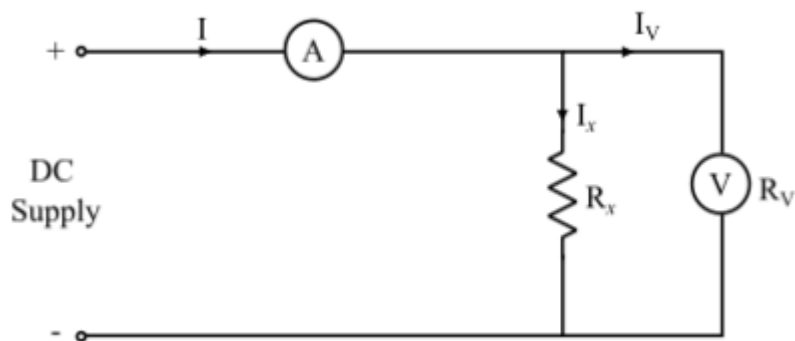
$$R_X = \frac{V}{I} - R_A \quad (2)$$

(b) Voltmeter across supply (Ammeter before resistor)

- Voltmeter connected across supply terminals.
- Ammeter measures current through resistor + **voltmeter current**.
- Error: resistance appears **lower** than actual.

$$R_{measured} < R_{true}$$

When voltmeter is directly connected across the resistor, then the ammeter measures current flowing through the unknown resistance (R_x) and the voltmeter.



Step-by-Step Derivation

1. Total current through ammeter:

$$I = I_{Rx} + I_V$$

2. Current through unknown resistor:

$$I_{Rx} = I - I_V$$

3. Current through voltmeter:

$$I_V = \frac{V}{R_V}$$

4. Substitute in (2):

$$I_{Rx} = I - \frac{V}{R_V}$$

5. Resistance of unknown:

$$R_X = \frac{V}{I_{Rx}}$$

$$R_X = \frac{V}{I - \frac{V}{R_V}}$$

5.1.3 High resistance: Megger and Ohm meter: Series and shunt

Megger

Definition

A **Megger** is an instrument used for measuring **high insulation resistances** (in the order of MΩ) such as those of cables, winding insulation, and electrical installations.

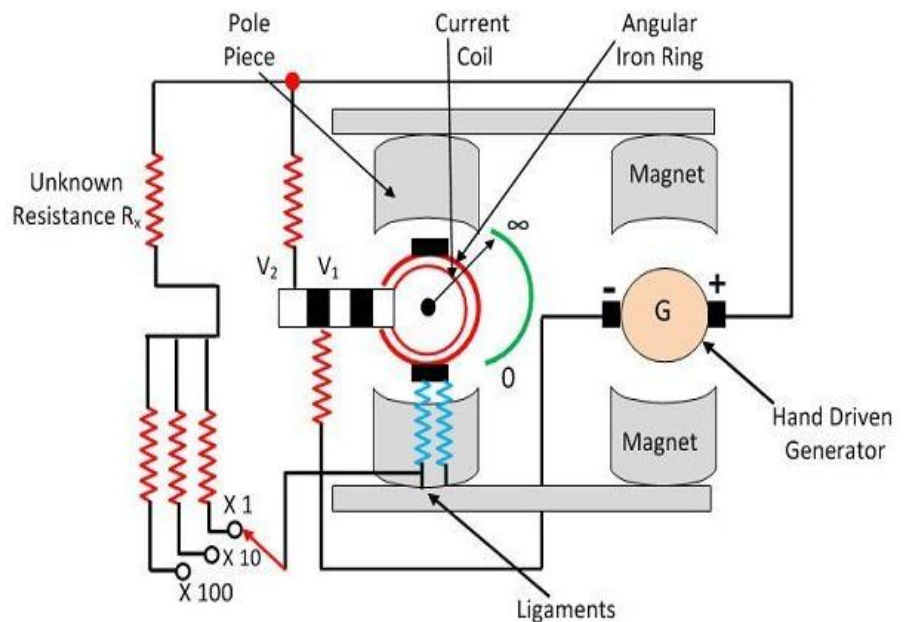
It works on the **principle of comparison**, i.e., the resistance of the insulation is compared with a known resistance using the deflection of a moving-coil system.

- If insulation resistance is **high** → pointer deflects towards ∞ (**infinity**).
- If insulation resistance is **low** → pointer deflects towards **0 (zero)**.
- **Accuracy** is high compared to ordinary ohmmeters because it uses a **high DC test voltage** (500V to 2.5kV).

Construction of Megger

The main parts are:

1. **DC Generator (Hand-driven or motor-driven):** Provides test voltage ($\approx 500\text{V}$ to 2.5kV).
2. **Permanent Magnet Moving Coil (PMMC) system:** Acts as the indicator.
3. **Current Coil (C):** Connected in series with the test circuit, carries current proportional to insulation leakage.
4. **Voltage Coils (V1 and V2):**
 - **V1:** Mounted across a weak magnetic field region. Controls pointer deflection.
 - **V2:** Mounted in strong magnetic field region. Provides controlling torque.
5. **Pointer and Scale:** Calibrated directly in $\text{M}\Omega$.
6. **Test Terminals:** To connect insulation under test.



Principle of Operation

- The deflection of the pointer depends on the **torques produced by current coil and voltage coils**.
- **When insulation resistance is high:**
 - Current through current coil is almost zero.
 - Torque due to voltage coil dominates $\rightarrow$ pointer moves towards ∞ .
- **When insulation resistance is low:**
 - Large current flows through current coil.
 - Torque due to current coil dominates $\rightarrow$ pointer moves towards **0**.
- Thus, balance of torques gives a direct reading of insulation resistance.

Applications of Megger

- Measurement of **cable insulation resistance**.
- Testing **motor and transformer windings**.
- Checking **electrical installations and house wiring** for leakage.

Shortcut Revision

- **2 Marks:** Key word / fact.
- **5 Marks:** Short note with diagram.
- **10 Marks:** Full essay answer with headings + neat labelled diagram.

Ohm meter

Definition

An **ohmmeter** is an instrument used to measure resistance directly in ohms. It consists of a battery, a moving-coil meter, and resistors arranged so that the scale is calibrated in ohms.

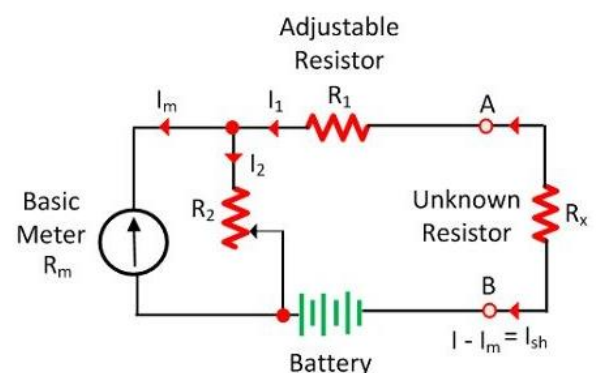
Two types:

1. **Series type** – used for **high resistances**.
2. **Shunt type** – used for **medium resistances**.

Series Ohmmeter

Construction

1. It consists of a **DC battery**, resistors R_1 and R_2 , a **d'Arsonval movement (PMMC meter)**, and terminals A and B for connecting the unknown resistance R_x .
2. The **d'Arsonval movement** is connected in parallel with a shunt resistance R_2 .
3. This parallel combination (meter + shunt R_2) is connected in series with another resistance R_1 , the battery, and the unknown resistance R_x .
4. The entire circuit is enclosed in a portable instrument with a scale calibrated in ohms.



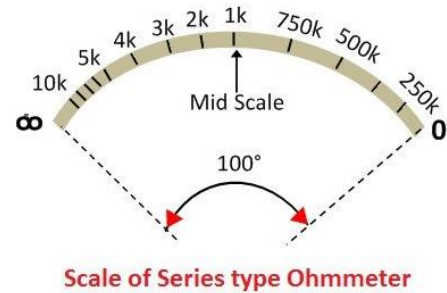
Series Type Ohmmeter

Working / Principle of Operation

1. **When $R_x = 0\Omega$:**
 - Maximum current flows through the meter.
 - The shunt resistance R_2 is adjusted so that the meter gives **full-scale deflection**.
 - Pointer shows **0 ohms**.
2. **When $R_x = \infty\Omega$:**
 - Open circuit condition, no current flows through the meter.
 - Pointer shows ∞ (**infinity**).
3. **For intermediate values of R_x :**
 - If R_x is **small**, pointer deflects towards **right (low resistance)**.
 - If R_x is **large**, pointer deflects towards **left (high resistance)**.

Scale

- The scale of a series ohmmeter is **non-linear**.
- It reads **0 Ω** at full-scale deflection (right side) and **$\infty \Omega$** at zero deflection (left side).



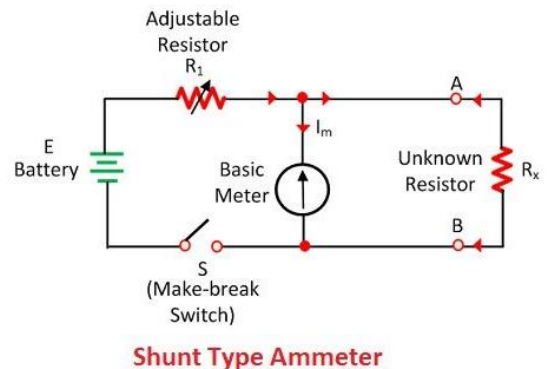
Applications

- Used to measure **high resistances** (from $k\Omega$ up to $M\Omega$).
- Common in portable insulation testers and laboratory instruments.

Shunt Ohmmeter

Construction

1. The **battery (E)**, a **basic PMMC meter (R_m)**, and an **adjustable resistor** form the main circuit.
2. The **unknown resistance R_x** is connected in **parallel (shunt)** with the meter movement.
3. Terminals **A and B** are provided for connecting the unknown resistance.
4. The adjustable resistance is used to calibrate the meter for full-scale deflection.
5. The scale is calibrated in ohms, but **non-linear**.

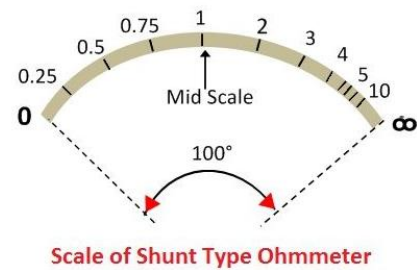


Working / Principle of Operation

1. **When $R_x = 0\Omega$:**
 - All the current bypasses the meter through R_x .
 - No current flows through the meter $\rightarrow$ pointer shows **0 Ω** (left side of scale).
2. **When $R_x = \infty\Omega$ (open circuit):**
 - No current flows through the shunt path.
 - Entire battery current flows through the meter $\rightarrow$ **full-scale deflection (right side)**.
 - Pointer shows **$\infty \Omega$** .
3. **For intermediate values of R_x :**
 - Moderate current divides between meter and shunt.
 - Pointer shows a resistance value between **0 and ∞** depending on division of current.

Scale

- Scale is **reverse of series type ohmmeter**.
- $0\ \Omega \rightarrow$ at **zero deflection (left side)**.
- $\infty\ \Omega \rightarrow$ at **full-scale deflection (right side)**.



Applications

- Suitable for measuring **medium resistances** (few ohms up to kilo-ohms).
- Used where sensitivity at **lower values** of resistance is important.

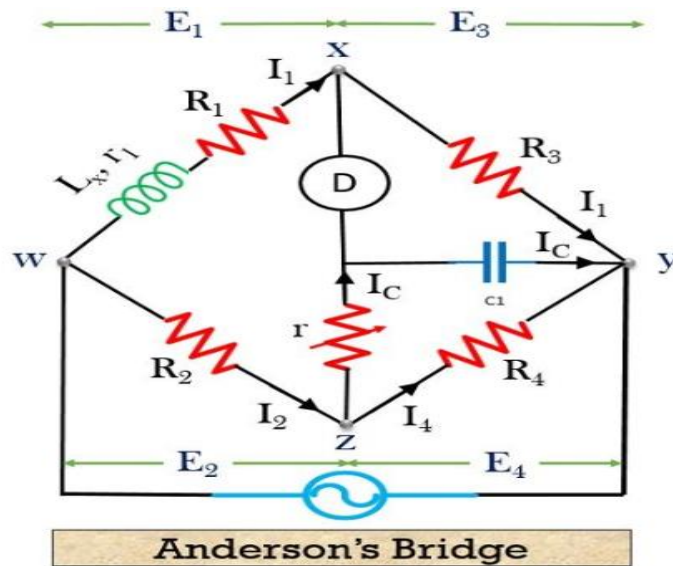
5.2 Measurement of inductance using Anderson bridge (no derivation and phasor diagram)

Introduction

- The **Anderson Bridge** is an AC bridge used for the **precise measurement of self-inductance** of a coil.
- It is a **modification of the Maxwell's Bridge**, with one additional resistor connected to form a bridge balance more conveniently.
- Widely used in laboratories due to its **accuracy and versatility**.

Construction

- It is a **six-arm bridge circuit** consisting of:
 1. Four ratio arms (resistances).
 2. A standard capacitor C_1 .
 3. An additional resistor connected to the junction of the capacitor and one arm (distinguishing feature from Maxwell's Bridge).
 4. The unknown inductance coil L_x (with its resistance r_1).
- A source of AC supply is connected across one diagonal.
- A sensitive detector (headphone or vibration galvanometer) is connected across the other diagonal.



$$L_x = \frac{CR_3}{R_4} [r(R_4 + R_2) + R_2R_4]$$

Working Principle

- The bridge works on the **null deflection principle**:
 - At balance, no current flows through the detector.
 - Under balance conditions, the unknown inductance can be expressed in terms of known resistances and capacitance.
- The additional resistor in the Anderson bridge allows the balance equations to be obtained without using variable inductors.

Advantages

1. Provides **accurate measurement** of self-inductance.
2. More **convenient and versatile** than Maxwell's Bridge.
3. Can measure a wide range of inductances with fixed standard capacitor.

Disadvantages

1. Circuit is more **complex** (uses six arms).
2. Requires more connections → difficult to set up in practical labs.

Applications

- Widely used in **electrical labs** for measuring inductance of:
 - Coils,
 - Transformers,
 - Chokes.

✓ **Exam Tips (SCTEVT)**

- **2 Marks:** Define Anderson bridge / state its use.
- **5 Marks:** Draw the circuit diagram of Anderson bridge and explain its working (no derivation).
- **10 Marks:** Explain construction, working, advantages, and applications of Anderson bridge with neat circuit diagram.

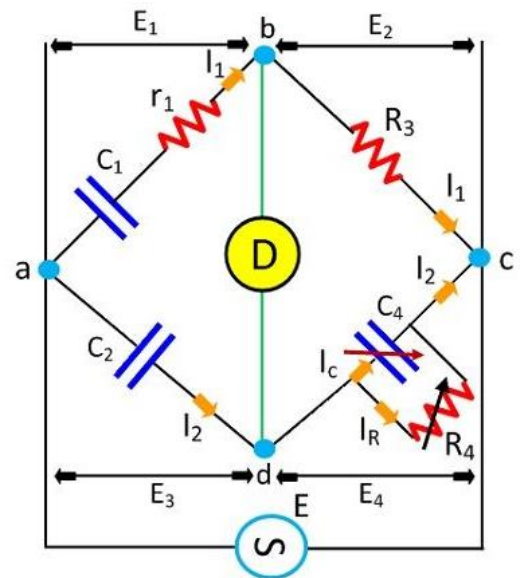
5.3 Measurement of capacitance using Schering bridge (no derivation and phasor diagram)

Introduction

- The **Schering Bridge** is an AC bridge used for the **measurement of unknown capacitance, dielectric loss, and power factor** of a capacitor.
- It is widely used because of its **accuracy** in measuring both pure and imperfect (lossy) capacitors.

Construction

- It is a four-arm AC bridge consisting of:
 1. **Unknown capacitor C_1** (with dielectric loss resistance in parallel or series).
 2. **r_1 – a series resistance, representing the loss of the capacitor C_1 .**
 3. **Standard capacitor C_2** with negligible loss.
 4. **Non-inductive resistors R_3** used as ratio arms.
 5. **A variable resistor (R_4) and capacitor (C_4)** for balancing the bridge.
- AC supply is applied across one diagonal.
- A **detector** (headphone, vibration galvanometer, or null detector) is connected across the other diagonal.



$$C_1 = C_2 \left(\frac{R_4}{R_3} \right)$$

Working Principle

- The bridge works on the **balance condition**: when adjusted properly, no current flows through the detector.
- At balance, the unknown capacitance C_1 and its dielectric loss are expressed in terms of known standard capacitor and resistances.
- This allows accurate measurement of:
 - Capacitance,
 - Dissipation factor ($\tan \delta$),
 - Dielectric loss.

Advantages

1. Measures both **capacitance and dielectric loss**.
2. Provides **accurate results** for high-voltage capacitors.
3. Simple and reliable in laboratory use.

Disadvantages

1. Not suitable for measurement at **very high frequencies**.
2. Circuit is more complex compared to a simple capacitance bridge.

Applications

- Used for measurement of:
 - Capacitance of unknown capacitors.
 - Dielectric loss and power factor of cables, insulators, and capacitor banks.
 - Quality factor of capacitor materials.

Exam Tips (SCTEVT)

- **2 Marks:** Define Schering bridge / state its use.
- **5 Marks:** Draw the circuit of Schering bridge and explain its working (no derivation).
- **10 Marks:** Explain construction, working, advantages, and applications of Schering bridge with a neat diagram.

5.4 Single beam/single trace CRO (Working principle and block diagram only)

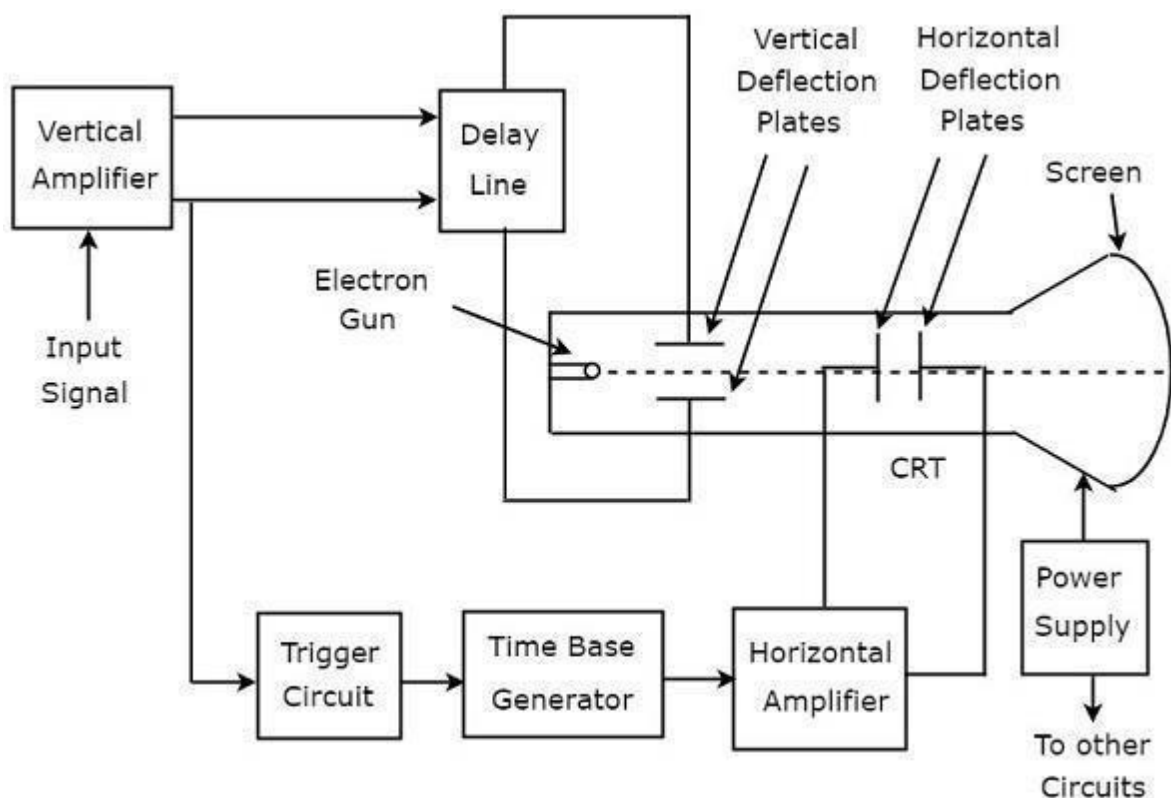
Working Principle

- A CRO works on the principle of **deflection of an electron beam** inside a CRT (Cathode Ray Tube).
- The input signal is applied to **vertical deflection plates**, producing vertical movement (Y-axis).
- A **sawtooth signal** from the time base is applied to **horizontal plates**, producing horizontal sweep (X-axis).
- Thus, the CRO converts the input signal (voltage vs. time) into a **visible waveform** on the fluorescent screen.

Block Diagram & Functions

1. **Vertical Amplifier**
 - Amplifies the input signal before applying it to the vertical plates.
2. **Delay Line**
 - Provides a small delay to the amplified signal so that the horizontal sweep (time base) starts in time, ensuring the waveform is not cut at the left side of the screen.
3. **Trigger Circuit**

- Produces a trigger pulse to synchronize the horizontal sweep with the input signal, giving a stable display.
- 4. **Time Base Generator**
 - Generates a **sawtooth waveform** to move the electron beam horizontally at a uniform speed (time axis).
- 5. **Horizontal Amplifier**
 - Amplifies the sawtooth signal and applies it to the horizontal deflection plates.
- 6. **Power Supply**
 - Provides both **high voltage** (for CRT anode, to accelerate the electron beam) and **low voltages** (for amplifiers and circuits).
- 7. **Cathode Ray Tube (CRT)**
 - Contains electron gun, deflection plates, and fluorescent screen.
 - Displays the waveform of the input signal.



Exam Tips (SCTEVT):

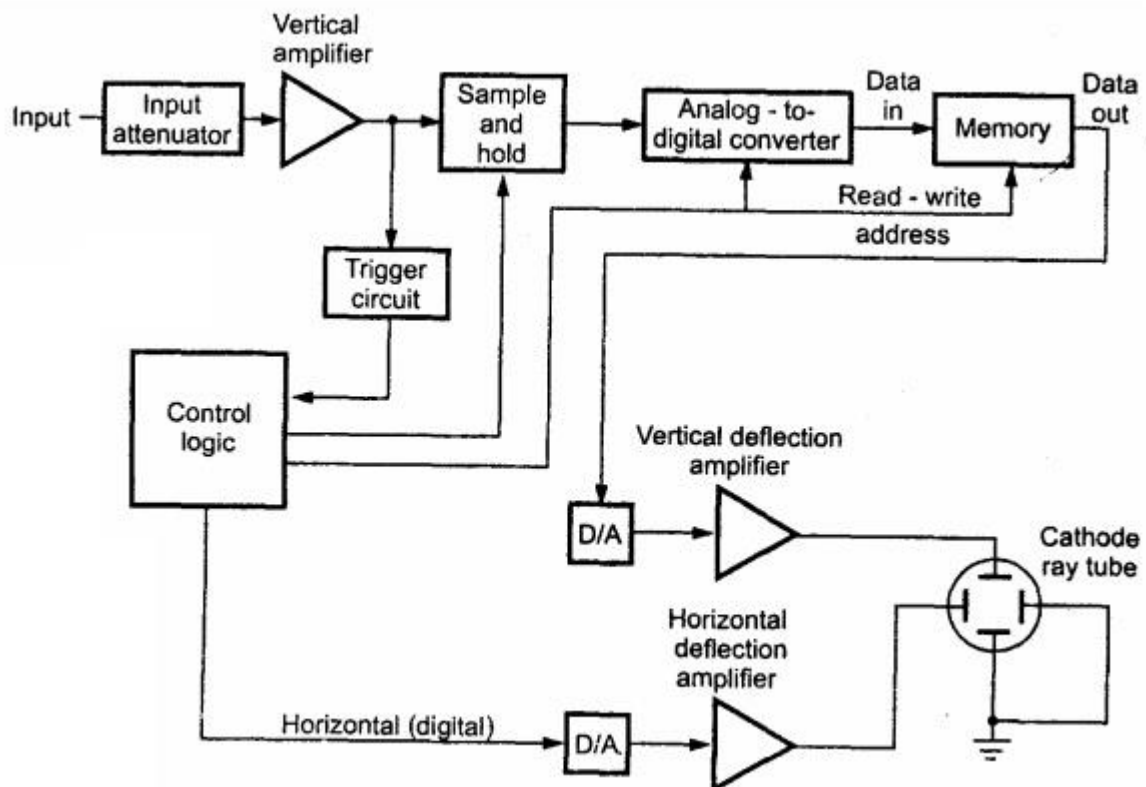
- **2M:** State working principle of CRO.
- **5M:** List the blocks of CRO and mention their functions.
- **10M:** Explain working principle with block diagram of single-beam CRO.

5.5 Digital storage Oscilloscope: Basic block diagram, working, Cathode ray tube, electrostatic deflection, vertical amplifier, time base generator, horizontal amplifier, measurement of voltage/ amplitude/ time period/ frequency/ phase angle delay line, specifications.

Introduction

- A **Digital Storage Oscilloscope (DSO)** is an electronic instrument used to capture, store, and analyze waveforms digitally.
- Unlike a conventional CRO, it converts the input analog signal into **digital data** using an ADC (Analog-to-Digital Converter).
- Stored waveforms can be displayed, measured, and analyzed later.

Blockdiagram



Main blocks of a DSO:

1. **Vertical Amplifier**
2. **Delay Line**
3. **ADC (Analog-to-Digital Converter)**
4. **Digital Memory (Storage)**
5. **Time Base Generator**
6. **Horizontal Amplifier**
7. **Trigger Circuit**
8. **Display System (CRT/LCD)**
9. **Power Supply**

Working

1. **Input Section (Amplifier + Attenuator)**

- The input signal first passes through an **attenuator** and a **preamplifier** to adjust the signal amplitude.
- Same circuitry as in conventional CROs.
- 2. **Vertical Amplifier**
 - Amplifies the conditioned signal to a suitable level.
- 3. **Analog-to-Digital Converter (ADC)**
 - Converts the amplified analog signal into **digital data** (binary).
 - **Speed is the most important requirement** of the ADC in DSOs (not resolution as in digital voltmeters).
 - The most commonly used ADC is the **Successive Approximation type** because it is fast and efficient.
- 4. **Memory (Storage)**
 - The digitized data set is stored in digital memory for later processing and display.
- 5. **Microprocessor Section**
 - Processes the stored digital data.
 - Controls measurement functions and formatting of the waveform for display.
- 6. **Display Section**
 - The processed waveform is displayed on CRT or modern LCD/LED screens.
 - Waveforms can be stored, recalled, and analyzed.

Modes of Operation of DSO

1. **Roll Mode**
 - Used for **very fast-varying signals**.
 - Displays them on screen as if they are changing slowly.
 - In this mode, the input signal is **not triggered**.
2. **Store Mode**
 - Stores a signal waveform in memory so that it can be displayed **continuously** on the screen even after the signal disappears.
 - Useful for **transient or one-time events**.
3. **Hold / Save Mode**
 - Freezes the displayed waveform at any instant.
 - Useful for detailed analysis of a captured signal.

Cathode ray tube

Definition

- A **Cathode Ray Tube (CRT)** is a **vacuum tube display device** used in oscilloscopes, televisions, and radar displays.
- It works by producing images when a **high-speed electron beam** emitted from an electron gun strikes a **phosphorescent (fluorescent) screen**.

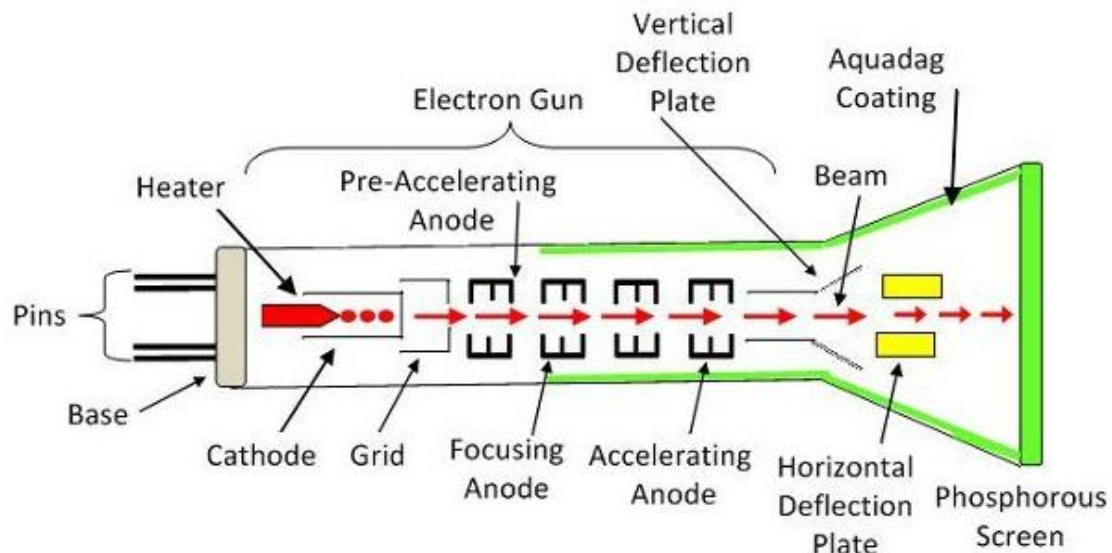
Working Principle

1. The **electron gun** generates a narrow, sharply focused beam of electrons.

2. These electrons are accelerated by applying a **high voltage**.
3. The **electron beam** passes through **deflection plates** (electrostatic or magnetic).
 - **Vertical plates (Y-plates):** Deflect the beam up or down.
 - **Horizontal plates (X-plates):** Deflect the beam left or right.
4. When the beam finally strikes the **phosphorescent screen**, it produces a **bright luminous spot**.
5. By continuously deflecting the beam in a controlled manner, the required image or waveform is displayed.

Main Parts of CRT

1. **Electron Gun Assembly** – Produces and accelerates electron beam.
2. **Deflection Plates** – Control the position of beam on the screen.
3. **Phosphorescent Screen** – Converts electron beam into visible light.
4. **Glass Envelope** – Provides vacuum and mechanical support.
5. **Aquadag Coating** – Collects secondary electrons and maintains potential.



Cathode Ray Tube

Circuit Globe

Electrostatic Deflection

- In CRT-based DSOs, beam deflection is achieved by applying voltages to **electrostatic deflection plates**:
 - Vertical plates → Y deflection (input signal).
 - Horizontal plates → X deflection (time base).

Vertical Amplifier

- Amplifies the input signal.
- Has selectable sensitivity (mV/div to V/div).
- Ensures that the input signal is scaled correctly before digitization.

Time Base Generator

- Generates a **sawtooth waveform** or digital clock pulses.
- Provides uniform horizontal sweep for time-axis representation.
- Controls the sampling rate of ADC.

Horizontal Amplifier

- Amplifies the sawtooth/time-base signal.
- Applies it to the horizontal deflection system (X-axis movement).

Delay Line

- Introduces a small delay to the vertical signal.
- Ensures that the trigger event and the starting portion of the waveform are visible on the screen.

measurement of voltage/ amplitude/ time period/ frequency

. Voltage / Amplitude Measurement

- On the screen, the **vertical axis (Y)** represents **voltage**.
- The CRO/DSO scale is calibrated in **volts/division (V/div)**.
- **Peak Voltage (V_p)**:

$$V_p = (\text{Number of vertical divisions}) \times (\text{Volts/div})$$

- **Peak-to-Peak Voltage (V_{pp})**:

RMS Voltage (for sine wave):

$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

2. Time Period Measurement

- On the screen, the **horizontal axis (X)** represents **time**.
- The CRO/DSO scale is calibrated in **time/division (s/div or ms/div or μs/div)**.
- **Time Period (T)**:

$$T = (\text{Number of horizontal divisions for one cycle}) \times (\text{Time/div})$$

3. Frequency Measurement

- Frequency is the reciprocal of time period.
- Formula:

$$f = \frac{1}{T}$$

4. Amplitude (General Case)

- Amplitude means **maximum displacement from mean value** (same as V_p for voltage waveform).
- Measured in **vertical divisions × Volts/div.**

Key Specifications

1. **Bandwidth**
 - The maximum frequency range up to which signals can be displayed and measured **accurately**.
 - Typically in **MHz or GHz**.
2. **Sampling Rate**
 - Number of times the input signal is sampled per second.
 - Expressed in **MS/s (Mega Samples per second)** or **GS/s (Giga Samples per second)**.
 - Must be at least **2× the signal frequency** (Nyquist criterion).
3. **Memory Depth**
 - Number of **data points stored** in memory for each waveform.
 - Determines how long a signal can be captured at full sampling rate.
4. **Vertical Sensitivity**
 - Smallest and largest voltages measurable per division on vertical scale.
 - Typically ranges from **mV/div to V/div**.
5. **Time Base Range**
 - Horizontal sweep speed per division.
 - From **ns/div (fast events)** to **s/div (slow events)**.
6. **Input Impedance**
 - Typical value: **1 MΩ in parallel with 10–30 pF**.
 - Ensures proper loading of the circuit under test.
7. **Accuracy**
 - Percentage error in measurement.
 - Usually specified as **±(percentage of reading ± least count)**.

5.6 Other meters: Earth tester, Digital Multimeter; L-C-R meter, Frequency meter (ferromagnetic and Weston type), Phase sequence indicator, power factor meter (single phase and three phase dynamometer type), Synchro scope, Tri-vector meter

Earth tester

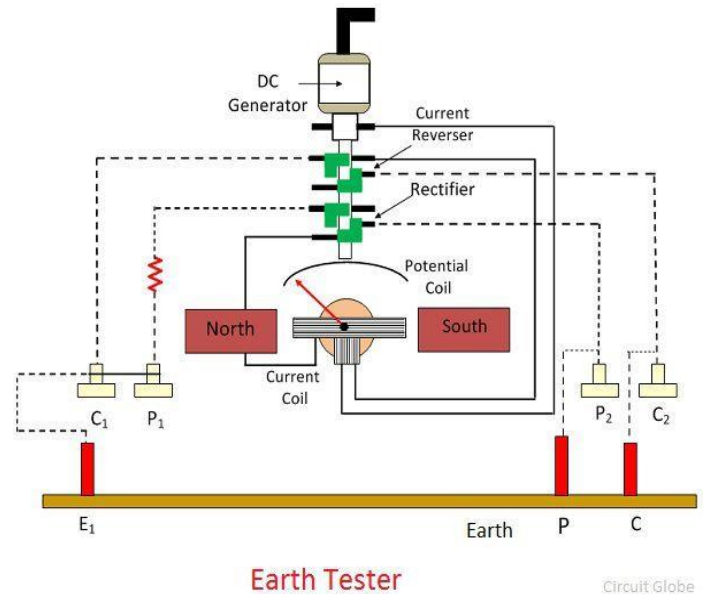
Definition

- An **Earth Tester** is an instrument used to measure the **earth resistance** of grounding systems and earth electrodes.
- It ensures safety in electrical installations by checking effective earthing.

Construction

The earth tester mainly consists of:

1. **Hand-driven DC Generator**
 - Provides the required supply.
 - Fitted with a **current reverser** and a **rectifier** mounted on its shaft.
 - Works with **DC supply**, but through rectifier and current reverser it produces **alternating test current** for measurement.
2. **Commutators and Brushes**
 - Two commutators are mounted with the current reverser and rectifier.
 - Each commutator has four fixed brushes.
 - Function: Convert direction of current and transfer power from rotating armature to external circuit.
3. **Current Coils and Pressure Coils**
 - Placed across a **permanent magnet**.
 - **Current coils** connected to auxiliary electrodes (to pass current through soil).
 - **Pressure coils** connected to the rectifier and earth electrode (to measure voltage drop).
4. **Potential Coil & Pointer System**
 - Potential coil connected directly to the generator.
 - Pointer mounted on calibrated scale shows earth resistance in ohms.
 - Deflection depends on the **ratio of voltage across pressure coil to current in current coil**.



Working Principle

- The generator produces DC, which through **rectifier + current reverser** is converted into **alternating test current**.
- This alternating current is passed into the soil through the **earth electrode** and **auxiliary electrodes**.
- Pressure coils measure potential drop, and current coils measure current.
- The ratio $V/IV / IV/I$ is indicated by the pointer as the value of **earth resistance**.
- The use of **AC test current** avoids **electrolytic effects and back EMF** in soil.

Applications

- Measurement of earth resistance of:
 - Earth electrodes.
 - Earth pits and grounding systems.
 - Lightning arresters and transformer earthing.

Exam Tips (SCTEVT)

- **2M:** Define earth tester.
- **5M:** Draw neat diagram and explain construction.
- **10M:** Explain construction and working of earth tester with neat diagram, mention its applications.

◆ Digital Multimeter (DMM)

Definition

A **Digital Multimeter (DMM)** is an electronic test instrument used to measure **electrical quantities** such as voltage, current, and resistance. Unlike analog multimeters, it displays the measured values in **numerical (digital) form** on an **LCD or LED display**.

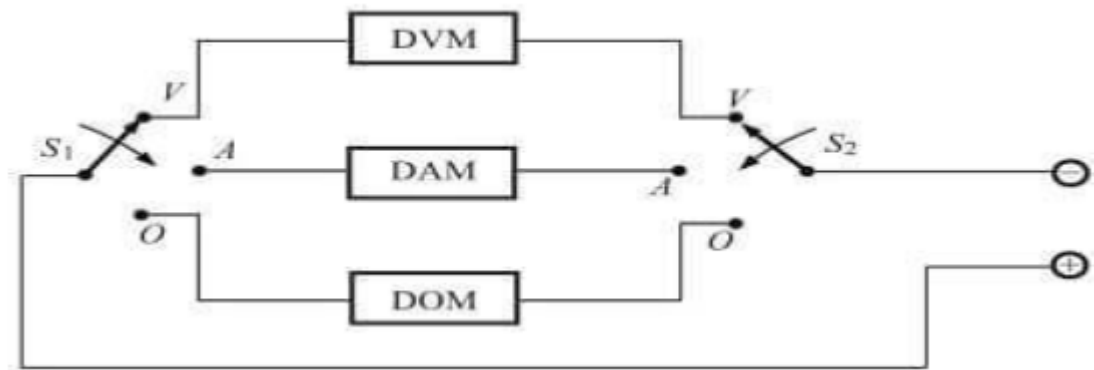


(DIGITAL MULTIMETER)

A **Digital Multimeter (DMM)** integrates three main measuring instruments:

- **Digital Voltmeter (DVM)**
- **Digital Ammeter (DAM)**

- **Digital Ohmmeter (DOM)**



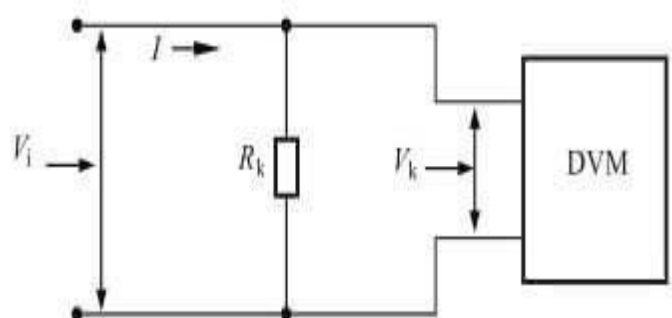
Working of Each Mode

(i) Digital Voltmeter (DVM)

- Input voltage is passed through an **attenuator** (if required).
- The voltage is fed to an **ADC (Analog-to-Digital Converter)**.
- Output displayed as numerical digits on LCD/LED.
- **Key principle:** Conversion of analog voltage → digital form.

(ii) Digital Ammeter (DAM)

- Current is first passed through a **shunt resistor (R_k)**.
- This produces a small **voltage drop proportional to current**.
- The voltage is measured by ADC and calibrated to display current.
- **Key principle:** Current is converted to equivalent voltage

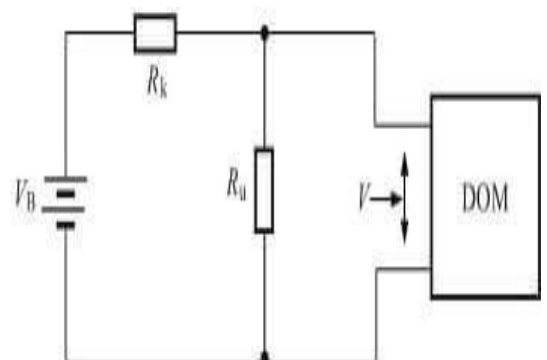


(iii) Digital Ohmmeter (DOM)

- A small DC source (battery voltage V_B) is applied to a **resistance network** consisting of:
 - Known resistance (R_K)
 - Unknown resistance (R_u)
- Voltage developed across R_u :

$$V = \frac{V_B \cdot R_u}{R_K + R_u}$$

- This voltage is fed to ADC → display shows resistance value.
- **Key principle:** Measurement based on voltage divider rule.



◆ Working Principle of Digital Multimeter (DMM)

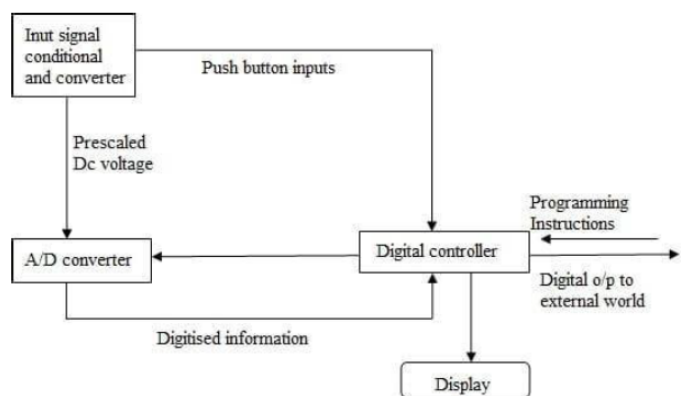
Basic Principle

- The input signal (AC/DC voltage, current, resistance, temperature, etc.) is first **converted into a proportional DC voltage** within the safe operating range of the **ADC (Analog-to-Digital Converter)**.
- The **ADC** converts this analog voltage into an equivalent **digital number**.
- The digital number is processed and displayed on the **LCD/LED screen** as a precise numerical value.

◆ Main Parts of a Digital Multimeter

(i) Display

- Usually an **LCD screen** (sometimes LED in older models).
- Shows the measured value in digits (typically $3\frac{1}{2}$ to $4\frac{1}{2}$ digits).
- Can also display a **negative sign** if required.
- Some modern DMMs have **backlit displays** for visibility in low light.



(ii) Selection Dial / Rotary Switch

- Located at the center of the multimeter.
- Allows the user to **select the measurement function**:
 - Voltage (AC/DC)
 - Current (mA, A)
 - Resistance (Ω)
 - Capacitance, frequency, diode check, continuity (in advanced DMMs).
- The dial “pre-scales” the input signal into the range suitable for ADC.

(iii) Ports

Most DMMs have **3 ports** (some advanced ones have 4):

1. **COM (Common)**
 - Connected to circuit ground (–ve terminal).
 - Black probe is always inserted here.
2. **mAV Ω Port**
 - Used for most measurements: **Voltage, Resistance, and Low Current (up to 200 mA)**.
 - Red probe usually inserted here.
3. **10A (or A) Port** (optional, in 4-port meters)
 - Special port for measuring **high current (up to 10A)**.

(iv) Test Leads

- **Red Lead** → Positive terminal, connected to measurement port (V/ Ω /mA/A).
- **Black Lead** → Negative terminal, always in COM port.

(v) Probes

- Handles used to grip and test points in the circuit.
- Provide electrical connection between circuit under test and the DMM.

(vi) Tips

- Sharp metallic ends of probes.
- Ensure **direct electrical contact** with test points.

Advantages over Analog Multimeter

- **High accuracy** and **resolution**.
- **Easy readability** (numerical display).
- **Auto-ranging feature** in modern DMMs.
- **Less parallax error** (no needle movement like analog meters).
- **Compact and portable**.

Applications

- Electrical and electronics troubleshooting.
- Testing household wiring, fuses, and appliances.
- Measuring parameters in laboratory experiments.
- Servicing power supplies, motors, and electronic circuits.

✓ Exam tips

- **2M:** Write **definition** / **two points** (keep it short and direct).
- **5M:** Always **draw block diagram** + **explain in 4–5 lines**.
- **10M:** Write **construction** + **working** + **neat block diagram** + **applications**. Use headings to make it neat.

◆ LCR Meter

Definition

An **LCR meter** is a test instrument used to measure the values of **inductance (L)**, **capacitance (C)**, and **resistance (R)** of electronic components. It works by applying an AC test signal to the component and measuring the resulting voltage and current.

◆ Types of LCR Meter

1. Handheld LCR Meter

- **Portable, battery-operated** device.
- Small size, lightweight, easy to carry.
- Measures **basic L, C, R values** with moderate accuracy.
- Suitable for **field work, quick testing, and service applications**.
- Limited frequency range (usually at one or two test frequencies).



Handheld LCR Meter

2. Benchtop LCR Meter

- Larger, **lab-grade instrument** kept on workbenches.
- High accuracy, stable, and reliable.
- Can measure L, C, R at **multiple test frequencies** (up to MHz range).
- Includes advanced functions like:
 - Q-factor (quality factor),
 - D (dissipation factor),
 - ESR (Equivalent Series Resistance).
- Used in **R&D labs, manufacturing, and quality control**.



Benchtop LCR Meter

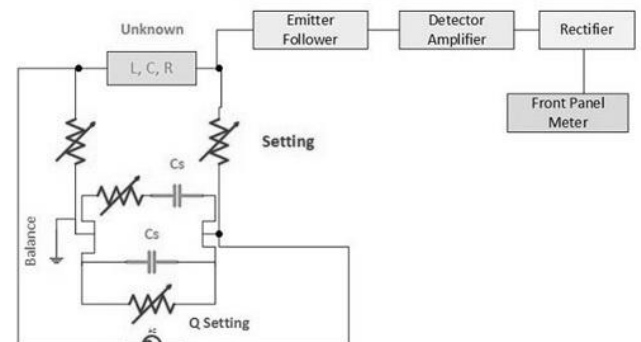
◆ LCR Meter Block Diagram Explanation

1. Unknown Component (L, C, R)

- The device under test (inductor, capacitor, or resistor) is connected here.
- The instrument will measure its parameters.

2. Bridge Network

- Contains variable resistors and standard capacitors (Cs).
- Used to **balance the bridge** for accurate measurement.
- **Balance control** adjusts resistance,
- **Q-setting** adjusts quality factor of measurement.



LCR Meter Block Diagram

3. Emitter Follower

- Acts as a **buffer amplifier**.
- Provides **isolation** between bridge circuit and detector stage.
- Ensures that the measurement circuit does not load the bridge network.

4. Detector Amplifier

- Detects and amplifies the unbalanced signal from bridge.

- Converts small unbalanced voltage into measurable level.
- Sensitive to both **magnitude and phase**

5. Rectifier

- Converts AC output of amplifier into DC voltage.
- This DC is proportional to the unbalanced signal of bridge.

6. Front Panel Meter (Display Unit)

- Calibrated to directly read **Inductance (L)**, **Capacitance (C)**, **Resistance (R)**.
- Shows value digitally in advanced LCR meters.

◆ Working Principle (Stepwise)

1. The unknown component (L, C, or R) is inserted.
2. The bridge circuit is excited and produces an unbalanced output.
3. The **emitter follower** isolates bridge and sends signal to detector.
4. **Detector amplifier** amplifies the signal.
5. The signal is rectified into DC by rectifier.
6. The front panel meter displays the measured value directly.

◆ Comparison: LCR Meter vs Digital Multimeter (DMM)

Feature	LCR Meter	Digital Multimeter (DMM)
Definition	Specialized instrument for measuring inductance (L), capacitance (C), and resistance (R).	General-purpose instrument for measuring voltage, current, resistance (and some extra parameters in advanced models).
Measured Parameters	L, C, R, Q-factor, D (dissipation factor), ESR (in advanced models).	Voltage (AC/DC), Current (AC/DC), Resistance, Continuity, Diode test, sometimes Capacitance & Frequency.
Accuracy	Very high for L, C, R measurement (lab standard).	Moderate, sufficient for routine testing.
Working Principle	Uses AC bridge method + signal conditioning → calculates unknown L, C, or R.	Uses shunt resistor (for current) , voltage divider (for voltage) , ADC (for digital display) .
Display	Digital/Analog scale showing L, C, R values directly.	Digital (LCD/LED) numerical display.
Applications	Used in labs, R&D, and manufacturing to test electronic components (inductors, capacitors, resistors).	Used in field service, electrical troubleshooting, household and industrial circuits.

Feature	LCR Meter	Digital Multimeter (DMM)
Portability	Available in handheld and benchtop models (benchtop gives better accuracy).	Mostly handheld, lightweight, very portable.
Cost	Generally more expensive (especially benchtop models).	Less expensive, widely available.

✓ Quick Answering Strategy

- **2M:** Write definition / principle / one-liner points.
- **5M:** Always include a **diagram + short explanation**.
- **10M:** Structure as:
 1. Definition
 2. Block diagram / circuit
 3. Working principle (stepwise)
 4. Applications & advantages

Frequency Meter

Definition

- A **frequency meter** is an instrument used to measure the frequency of an alternating current (AC) supply.
- It is generally used in **power systems** to monitor frequency variation from the rated value (e.g., 50 Hz).

1. Ferromagnetic Frequency Meter

Construction

- Consists of two **identical soft iron (ferromagnetic) strips**, mounted side by side.
- Strips are fixed at different mechanical positions inside a moving system.
- Connected to two **coils** that are displaced in phase by 90° .

Working Principle

- When AC supply is given, the magnetic flux in each coil **depends on frequency**.
- Due to phase difference, the **deflection of the soft iron strips** changes with frequency.
- At rated frequency (e.g., 50 Hz), both deflections balance and the pointer indicates correct value.

Features

- Scale is usually **narrow (± 3 Hz around rated frequency)**.
- Simple, rugged, but less accurate than Weston type.

2. Weston Frequency Meter

Definition

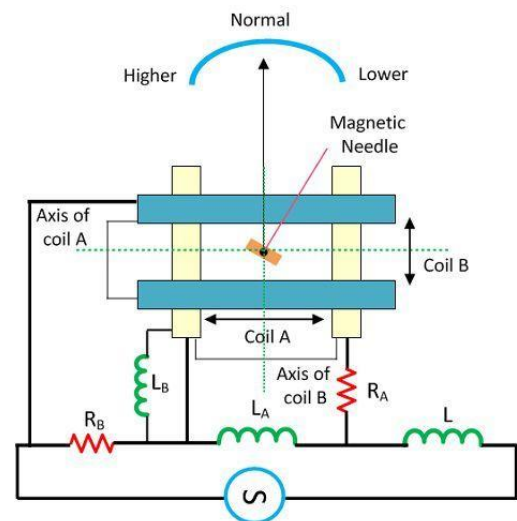
- A **Weston frequency meter** is a moving iron type instrument used for measuring the **unknown frequency** of an AC signal.
- It uses two coils: one **inductive** and one **resistive**.
- Frequency measurement depends on the **current distribution** between these two coils.

Working Principle

- The distribution of current between an **inductive circuit** and a **resistive circuit** changes when supply frequency changes.
- Since inductive reactance $X_L = 2\pi fL$ varies with frequency, current in the inductive path changes with frequency.
- Thus, **relative currents in the two coils change**, producing different magnetic fields → pointer deflects according to supply frequency.

Construction

1. **Two Coils (A & B):**
 - Mounted **perpendicular** to each other.
 - Coil A: in series with resistance R_A , in parallel with inductance L_A .
 - Coil B: in series with inductance L_B , in parallel with resistance R_B .
2. **Soft Iron Pointer + Magnetic Needle:** Mounted at the center, acts as moving element.
3. **Series Inductance (L):** Connected to suppress harmonics, reducing waveform error.
4. **Scale:** Calibrated in frequency (Hz).



Working

- **At normal frequency:**
 - Voltage drops across R_A , R_B , L_A , and L_B are equal → equal currents in both coils.
 - Pointer rests at **mid-scale (45°)**.
- **At high frequency:**
 - Reactance of inductors L_A , L_B increases → current in coil A decreases.
 - Current in coil B increases → stronger magnetic field in coil B.
 - Pointer deflects towards **coil B side**.
- **At low frequency:**
 - Reactance of inductors decreases → current in coil A increases.
 - Current in coil B decreases → pointer deflects towards **coil A side**.

Applications

- Used for **accurate frequency measurement** in laboratories.

- Calibration of supply frequency (50 Hz or 60 Hz systems).

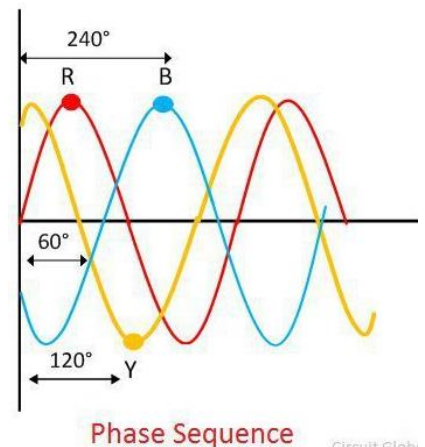
Phase Sequence Indicator

Definition

- A **phase sequence indicator** is an instrument used to determine the **phase sequence (order of rotation of phases: R, Y, B)** in a **3-phase AC supply system**.
- Phase sequence must be checked before connecting **3-phase motors, alternators, or transformers**, to ensure correct rotation.

What is Phase Sequence?

- The **phase sequence** is the order in which the **phases of a polyphase system (R, Y, B)** reach their **maximum values**.
- In a 3-phase system, the three voltages are separated by **120° phase difference**.
- Correct phase sequence (RYB) is essential for proper rotation of 3-phase motors and alternators.

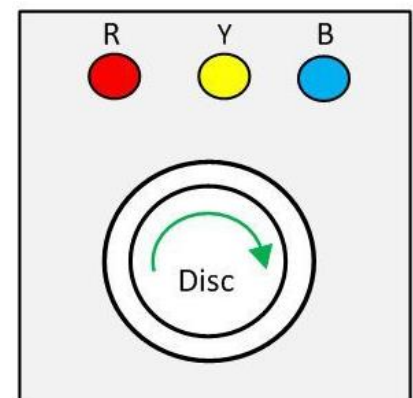


Types of Phase Sequence Indicators

1. Rotating Type
2. Static Type

1. Rotating Type Phase Sequence Indicator

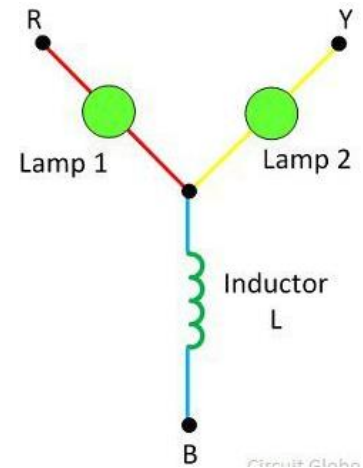
- **Construction:**
 - Contains a small induction motor with a light aluminium disc at its center.
 - Coils of the motor are star-connected to the 3-phase supply terminals.
- **Working Principle:**
 - When supply is applied, the **coils produce a rotating magnetic field**.
 - This induces **eddy currents** in the aluminium disc.
 - Interaction of rotating field and eddy current produces torque → disc rotates.
- **Indication:**
 - If disc rotates **clockwise** → **Phase sequence = RYB**.
 - If disc rotates **anticlockwise** → **Reverse sequence**.



Rotating Type Phase Sequence Indicator

2. Static Type Phase Sequence Indicator

- **Construction:**
 - Consists of **two lamps** and an **inductor** connected across the 3-phase supply.
- **Working Principle:**
 - If **Lamp 1 is dim** and **Lamp 2 is bright** → Phase sequence is **RYB**.
 - If **Lamp 1 is bright** and **Lamp 2 is dim** → Reverse phase sequence.
- **Explanation:**
 - Brightness depends on **voltage drops** across resistor and inductor paths.



Applications

- Ensuring **correct rotation of 3-phase induction motors**.
- Checking phase sequence in **alternators before synchronization**.
- Used in **power plants, substations, and industries**.

✓ Exam Tips (SCTEVT):

- **2M:** Define phase sequence.
- **5M:** Explain rotating type phase sequence indicator.
- **10M:** Explain rotating and static type phase sequence indicators with neat diagrams.

Power Factor Meter (Single Phase & Three Phase, Dynamometer Type)

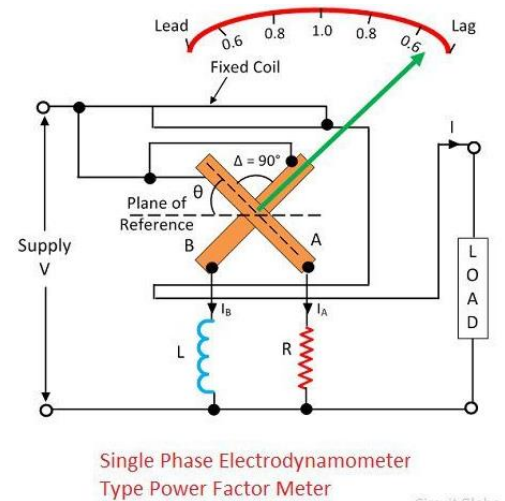
Definition

- A **Power Factor Meter** is an instrument used to measure the **power factor ($\cos \phi$)** of AC circuits directly.
- Power factor = Ratio of **real power (kW)** to **apparent power (kVA)**.
- Dynamometer type is commonly used for both single-phase and three-phase measurement.

1. Single Phase Dynamometer Type Power Factor Meter

Construction

- **Fixed Coil (Current Coil):** Split into two parts, connected in series with the load $\rightarrow$ carries load current.
- **Two Moving Coils (Pressure Coils A & B):**
 - Coil A $\rightarrow$ connected with non-inductive resistance (current in phase with supply voltage).
 - Coil B $\rightarrow$ connected with high inductance (current lags supply voltage by $\sim 90^\circ$).
- **Pointer & Scale:** Pointer attached to moving system, calibrated in **power factor**.
- **Ligaments (silver/gold):** Used for connection $\rightarrow$ minimize controlling torque.



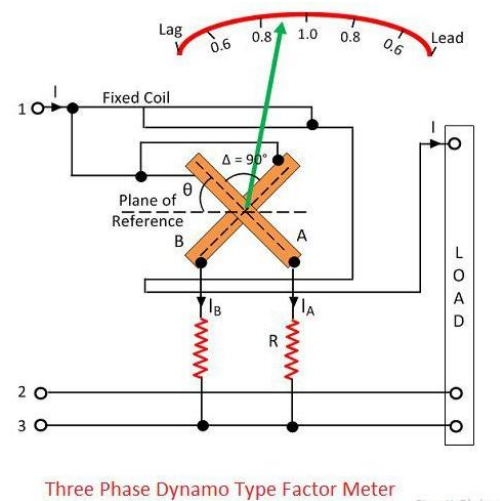
Working Principle

- Coil A produces torque proportional to in-phase component of voltage.
- Coil B produces torque proportional to quadrature component of voltage.
- These torques act in **opposite directions**.
- At balance, the resultant deflection angle θ corresponds to **phase angle ϕ of the circuit**.
- Thus pointer directly reads **power factor ($\cos \phi$)**.

2. Three Phase Electrodynamicometer PF Meter

Construction

- **Fixed Coils:** Two fixed coils connected in two different phases of 3-phase system $\rightarrow$ carry line currents.
- **Two Moving Coils:** Placed at 120° apart, connected across different phase-to-phase voltages through series resistances.
- **Pointer & Scale:** Deflection calibrated in power factor.
- **Condition:** Works correctly only for **balanced loads**.



Working Principle

- Coil A: carries current I_{A1} in phase with voltage V_{12} .
- Coil B: carries current I_{B1} in phase with voltage V_{13} .
- Torques T_A and T_B act in **opposite directions**.
- Resultant torque $\propto$ phase angle ϕ of the load.
- Deflection angle $\theta \propto \phi \rightarrow$ pointer shows **power factor $\cos \phi$** .

Applications

- Used in **power stations, substations, industries** for monitoring PF.
- Helps in **power factor correction** using capacitor banks.

Comparison Table

Feature	Single Phase PF Meter	Three Phase PF Meter
Fixed Coil	Split coil, carries load current	Two fixed coils in two phases
Moving Coils	2 (one resistive, one inductive)	2 (across line voltages)
Condition	Any load	Balanced load only
Use	Single-phase AC circuits	3-phase AC circuits

✓ Exam Tips (SCTEVT):

- **2M:** Define power factor meter.
- **5M:** Explain single-phase electrodynamic PF meter with construction.
- **10M:** Explain three-phase PF meter with working and comparison.

Synchroscope

Definition

- A **synchroscope** is an instrument used to determine whether **two AC systems (generators or alternators)** are in **synchronism** before connecting them in parallel.
- It indicates the **phase difference** and the **frequency difference** between the incoming machine and the busbar supply.

Construction

- It is essentially a **specially designed moving iron or dynamometer instrument**.
- Two windings:
 1. **Reference (fixed) winding:** Connected to the busbar supply.
 2. **Rotating (moving) winding:** Connected to the incoming alternator (machine to be synchronized).
- A pointer attached to the moving system, moving over a circular dial marked:
 - **“Fast”** → **Incoming machine frequency higher**
 - **“Slow”** → **Incoming machine frequency lower**
 - **“In phase / Synch”** → **Synchronism point**

Working Principle

- Based on the principle of **torque produced by interaction of two alternating magnetic fields** (from busbar and incoming machine).
- If the two supplies have the same frequency and are in phase → pointer remains steady at the **12 o'clock position (Synch mark)**.
- If incoming machine frequency is **slightly higher** → pointer rotates in **clockwise direction (Fast)**.
- If incoming machine frequency is **slightly lower** → pointer rotates in **anticlockwise direction (Slow)**.
- When pointer is at **vertical “Synch” position**, the circuit breaker can be closed → machine is safely connected in parallel.



Applications

- Used in **power plants** to synchronize alternators with the busbar.
- Ensures **safe and smooth paralleling** of generators.
- Prevents damage due to out-of-phase switching.

Exam Tips (SCTEVT)

- **2M:** Define synchroscope.
- **5M:** Explain construction and working principle of synchroscope.
- **10M:** Explain with diagram how a synchroscope is used for synchronization of alternators.

Tri-Vector Meter

Definition

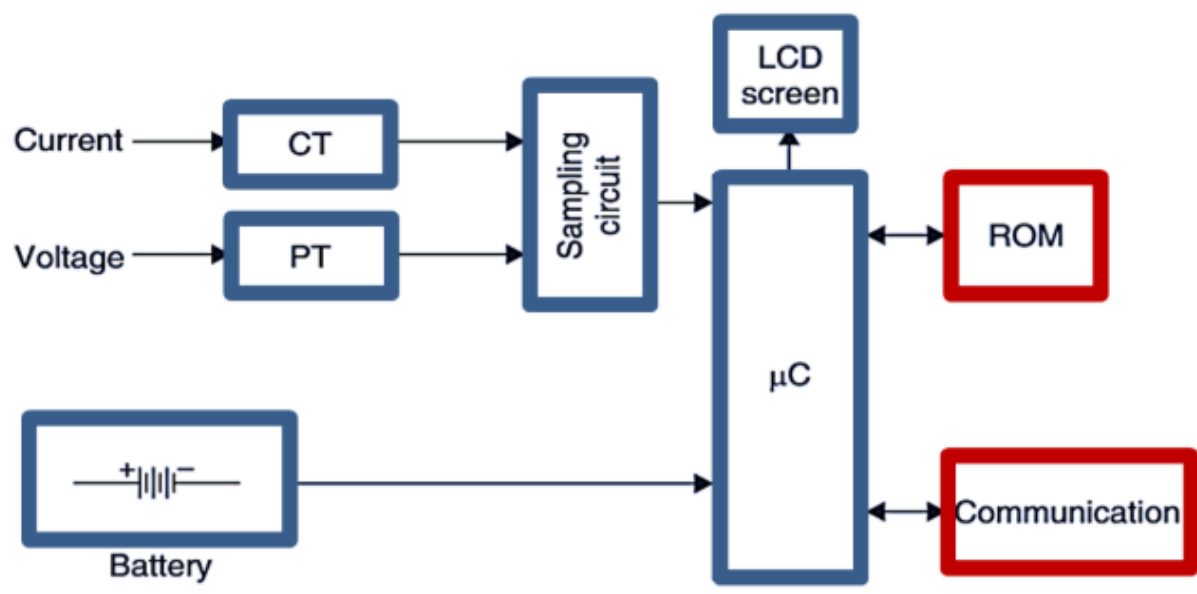
- A **Tri-vector meter** is an energy meter used in **3-phase power systems** to measure and record three types of energy:
 1. **Active energy (kWh)**
 2. **Reactive energy (kVARh)**
 3. **Apparent energy (kVAh)**
- Named “tri-vector” because it combines the three vectors of power: **active, reactive, and apparent**.

Need

- In industries, electricity billing depends not only on energy (kWh) but also on **power factor (PF)**.
- Tri-vector meters help monitor and improve PF, and they provide complete energy accounting.

Block Diagram of Tri-Vector Meter

Main Blocks and Functions



1. **CT (Current Transformer):**
 - Steps down the line current to a safer measurable level.
2. **PT (Potential Transformer):**
 - Steps down the line voltage to a safe level.
3. **Sampling Circuit:**
 - Takes proportional samples of voltage & current signals.
 - Converts them into suitable form for digital processing.
4. **Microcontroller (μC):**
 - Main processing unit.
 - Calculates **kWh, kVARh, and kVAh** from sampled data.
 - Computes **power factor**.
5. **ROM:**
 - Stores calibration data, constants, and meter program.
6. **LCD Screen:**
 - Displays readings: kWh, kVARh, kVAh, PF.
7. **Communication Module:**
 - Provides interface with remote systems for **energy monitoring / billing**.
8. **Battery Backup:**
 - Ensures continuous operation during power interruptions.

Working Principle

- Line **current and voltage** are stepped down by **CT and PT**.
- Signals are sampled and fed into the **microcontroller**.
- μC processes the signals to calculate:
 - **Active energy** ($\text{kWh} = V \cos \phi$)
 - **Reactive energy** ($\text{kVARh} = V \sin \phi$)
 - **Apparent energy** ($\text{kVAh} = \sqrt{(\text{kWh}^2 + \text{kVARh}^2)}$)
- Results are stored in memory and displayed on **LCD screen**.
- **Communication unit** transfers data to remote billing/control centers.

Applications

- Used in **industries, substations, power utilities**.
- Helps in billing based on both **energy consumption and power factor**.
- Essential for **power factor correction monitoring**.

✓ Exam Tips (SCTEVT):

- **2M:** Define tri-vector meter.
- **5M:** List functions of tri-vector meter.
- **10M:** Explain block diagram and working of digital tri-vector meter.

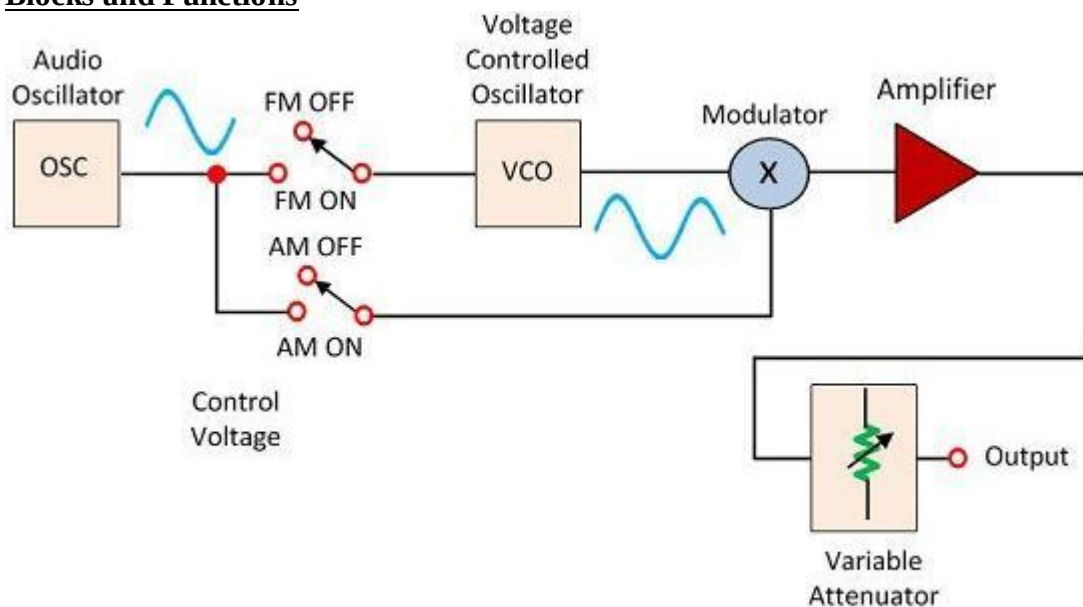
5.7 Signal Generator

Definition

- A **Signal Generator** is an electronic device used to produce **electrical signals of different frequencies, amplitudes, and waveforms** (sine, square, triangular, pulse, etc.).
- It is widely used in testing, designing, and troubleshooting of electronic circuits.

Basic Block Diagram of Signal Generator

Blocks and Functions



Block Diagram of Signal Generator

Circuit Globe

1. **Oscillator:**
 - Generates a sinusoidal signal at a desired frequency.
 - Types: RC oscillator, LC oscillator, Wien bridge oscillator, or crystal oscillator.
2. **Wave Shaping Circuit:**

- Converts the sine wave into other waveforms (square, triangular, pulse).
- Uses clipper, integrator, differentiator circuits.
- 3. **Amplifier:**
 - Amplifies the shaped waveform to required amplitude.
 - Ensures signal is strong enough to drive DUT.
- 4. **Attenuator:**
 - Stepwise reduction of amplitude.
 - Provides accurate control of output level.
- 5. **Output Stage:**
 - Provides signal at output terminal.
 - Ensures impedance matching with DUT.
- 6. **Power Supply:**
 - Provides necessary DC supply to oscillator and amplifier stages.

Working Principle

- The core of a signal generator is an **oscillator** (RC, LC, Wien bridge, or crystal), which produces a stable periodic waveform.
- The **basic process**:
 1. **Oscillator** → Generates raw sinusoidal waveform at a desired frequency.
 2. **Wave Shaping Circuit** → Converts sinusoidal into other waveforms (square, triangular, pulse).
 3. **Amplifier** → Boosts signal strength to required amplitude.
 4. **Attenuator** → Reduces output amplitude in controlled steps.
 5. **Output Control** → Delivers stable waveform to DUT.
- **Frequency selection** is achieved by varying frequency-determining elements (R, L, C or crystals).
- In modern digital signal generators, microcontrollers and DACs are used for precise waveform synthesis

Applications of Signal Generator

1. **Testing amplifiers, receivers, and filters.**
2. **Calibration of voltmeters, frequency meters, and oscilloscopes.**
3. **Checking frequency response of audio and RF circuits.**
4. **Generating AM and FM modulated signals for communication testing.**
5. **Educational experiments and laboratory use.**

Key Points

- Signal generators can be **analog** (using oscillators and wave shaping circuits) or **digital** (DDS – Direct Digital Synthesis).
- Modern digital signal generators provide **higher accuracy, frequency stability, and programmability**.

✓ **Exam Tips (SCTEVT):**

- **2M:** Define signal generator.
- **5M:** Draw and explain block diagram.
- **10M:** Need, working principle, block diagram, and applications.