Wattmeters

Objectives: At the end of this lesson you shall be able to
- **state the advantages of measuring power directly**
- **state the types of single phase wattmeters**
- **explain the construction and working of the induction type single phase wattmeter**

Advantages of measuring power supply

Power in a single phase AC circuit can be calculated by using an ammeter, a voltmeter and a power factor meter with the help of the formula

Power in a single phase circuit = EI Cos ø watts.

In the same way power in a 3-phase balanced circuit can be measured by using one ammeter, one voltmeter and one power factor meter with the help of the formula

Power in a balanced 3 - phase circuit = $3E_P I_P Cos\phi$

$or \sqrt{3}\, E_L I_L Cos\phi$

where $E_P I_P$ are the phase values and

$E_L I_L$ are the line values

This indirect method of measuring power in an AC circuit has the following disadvantages.

- Low accuracy due to a number of meters.
- Reading errors due to a number of meter readings.
- Involves calculation every time the load changes and hence not suitable for changing loads.

To get an on the spot true power reading, a wattmeter is used. The power dissipated in the circuit can be read directly from the scale of the meter. The wattmeter takes the power factor of the circuit into account and always indicates the true power.

Types of wattmeters

There are three types of wattmeters in use as stated below.

- Dynamometer wattmeter
- Induction wattmeter
- Electrostatic wattmeter

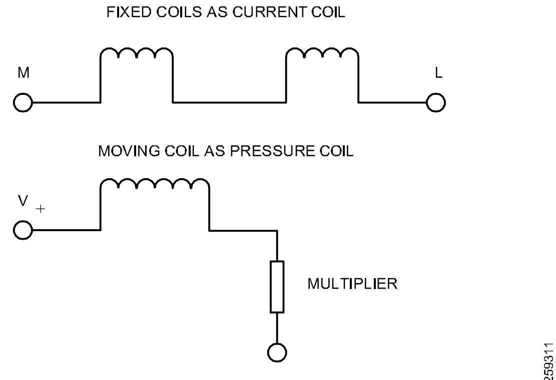
Among the three, the electrostatic type is very rarely used. Information given here is for the other two types only.

Dynamometer type, single phase wattmeter: This type is commonly used as a wattmeter. Construction details and the working of this type of meter have already been discussed . Hence the trainees are advised to read the information before proceeding further.

Dynanometer used as a Wattmeter: The dynamometer is commonly used as a wattmeter to measure power in both AC and DC circuits and will have uniform scale.

When this instrument is used as a wattmeter, the fixed coils are treated as current coil, and the moving coil is made as pressure coil with necessary multiplier resistance (Fig 1).

Fig 1



DYNAMOMETER INSTRUMENT AS A WATT METER

Advantages

- This instrument can be used both in AC and DC.
- As this is an air cored instrument, the hysteresis and eddy current losses are eliminated.
- This instrument has better accuracy.
- When used as wattmeter, the scale is uniform.

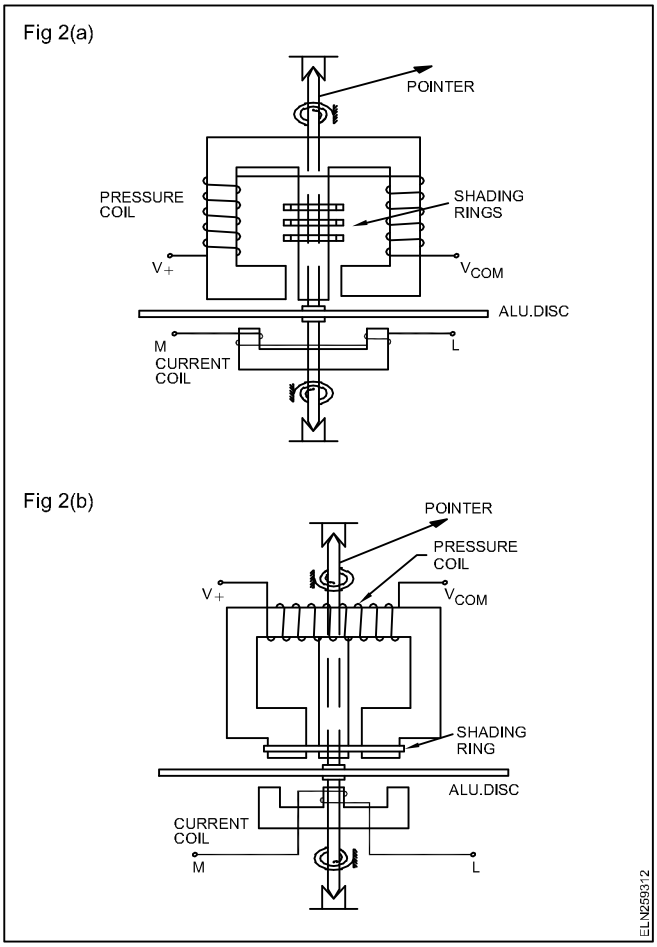
DIsadvantages

- It is more expensive than PMMC and moving iron instruments.
- When used as voltmeter or ammeter the scale will not be uniform.
- It has a low torque/weight ratio-as such has low sensitivity.
- Sensitive for over loads and mechanical impact. Hence careful handling is necessary.
- It consumes more power than PMMC meters.

Induction type single phase wattmeter: This type of wattmeters could be used only in AC circuits whereas a dynamometer type wattmeter could be used in both AC and DC circuits.

Induction type wattmeters are useful only when the supply voltage and frequency are almost constant.

Construction: Induction wattmeters having two different types of magnetic cores (Figs 2a and 2b).



Both the types have one pressure coil magnet and one current coil magnet. The pressure coil carries a current proportional to the voltage whereas the current coil carries the load current.

A thin aluminium disc is mounted on a spindle in between the space of the magnets and its movement is controlled by springs. The spindle carries a weightless pointer at one end.

Working: The alternating magnetic fluxes produced by the pressure and current coils cut the aluminium disc and produce eddy currents in the disc. Due to the interaction between the fluxes and the eddy currents a deflecting torque is produced in the disc and the disc tries to move. Control springs attached to the two ends of the spindle control the deflection and the pointer shows the power in watts on a graduated scale.

Shaded rings provided in the pressure coil (shunt) magnet could be adjusted in order to cause the resultant flux in the magnet to lag in phase by exactly 90° behind the applied voltage.

Method of connecting wattmeter in single phase circuits - pressure coil connection to reduce erroneous measurement.

There are two ways of connecting the pressure coil of the wattmeter (Fig 3).

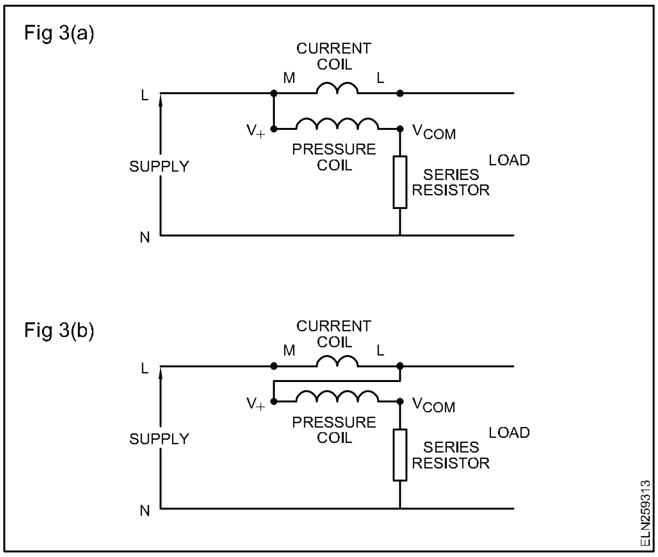
Both the methods shown in Figs 3a & b need correction in power measurement due to the reasons stated below.

In the method of connection shown in Fig 3a, the pressure coil is connected on the 'supply' side of the current coil, and hence, the error in power measurement is due to the fact that the voltage applied to the voltage coil is higher than that of the load on account of the voltage drop in the current coil. As such the wattmeter measures the load power in addition to the power lost in the current coil.

On the other hand, in the method of connection shown in Fig 3b, the current coil carries the small current taken by the voltage coil, in addition to the load current, thereby introducing errors in power measurement. As such the wattmeter measures the load power in addition to the power lost in the pressure coil.

If the load current is small, the voltage drops in the current coill will be small, so that the method of connection, shown in Fig 3a, introduces a very small error and, hence, preferable.

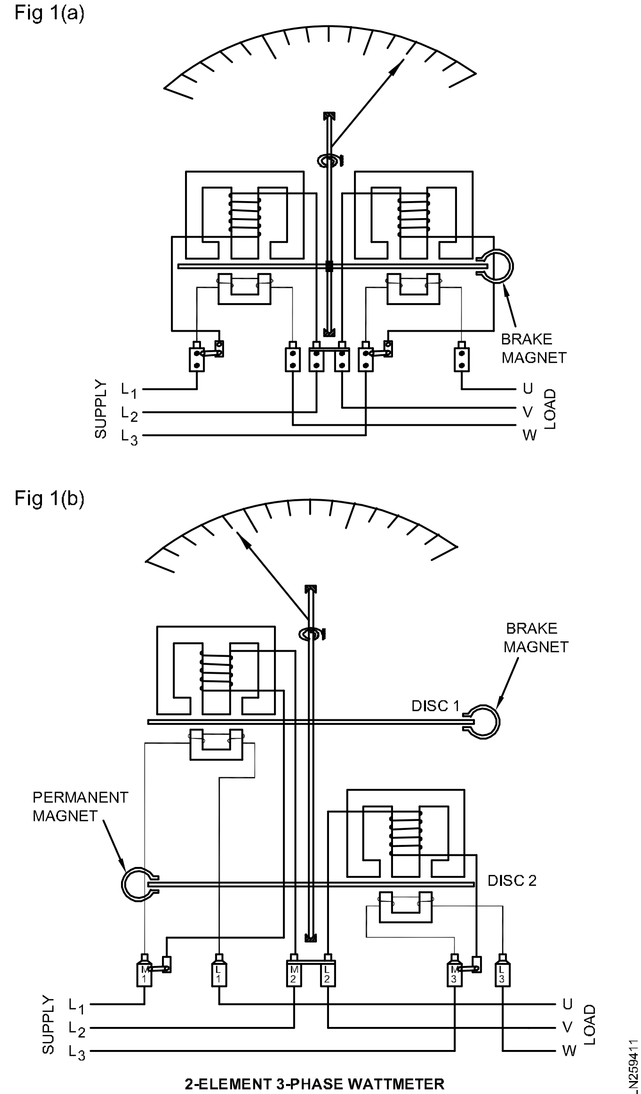
On the other hand, if the load current is large the power lost in the pressure coil will be negligible when compared to the load power in the method of connection shown in Fig 3b, and, hence, a very small error is introduced resulting in the preference of this connection.



3-phase Wattmeter

Objectives: At the end of this lesson you shall be able to
- **describe the various types of 3-phase wattmeters, their connections**
- **state how to connect different types of 3 phase watt meter.**

In single-phase wattmeters there will be one set of pressure and current coils driving a single aluminium disc, whereas in 2-element, three phase wattmeters there will be two sets of pressure and current coils driving a single aluminium disc (Fig 1a) or driving two aluminium discs mounted on the same shaft (Fig 1b) thereby providing a torque proportional to the 3-phase power.



2-ELEMENT 3-PHASE WATTMETER

On the other hand a 3-element, 3-phase wattmeter will have three sets of pressure and current coils kept at 120° to each other but driving a single aluminium disc (Fig 2) or alternatively 3 sets of pressure and current coils driving three discs one over the other but mounted on the same single spindle (Fig 3).

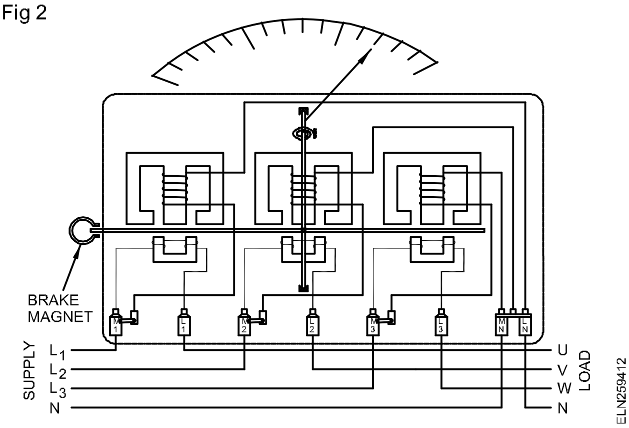
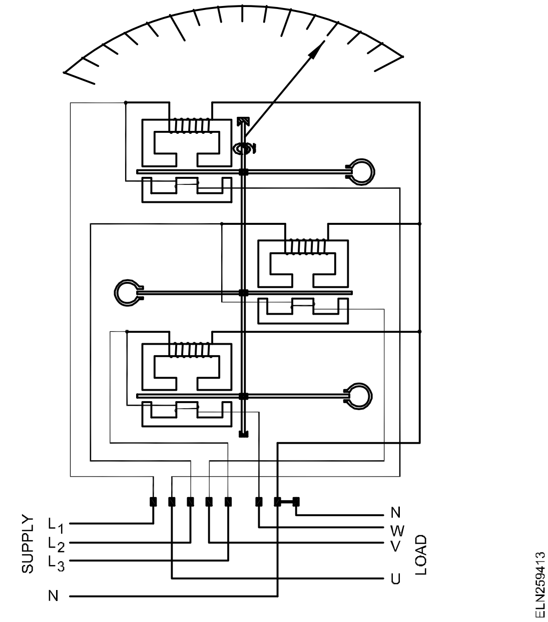
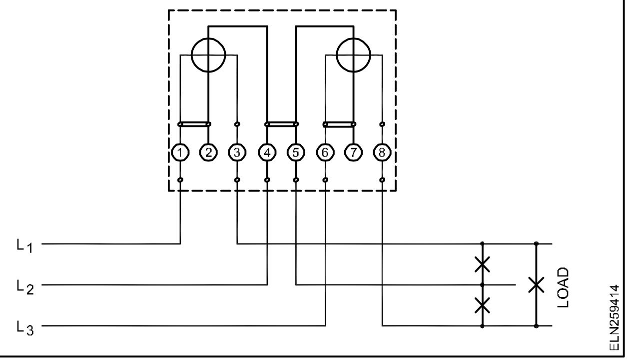
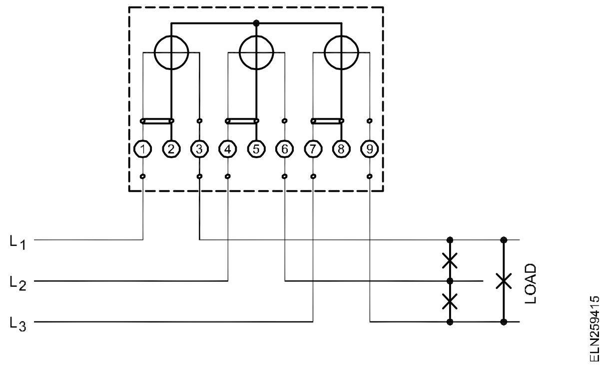
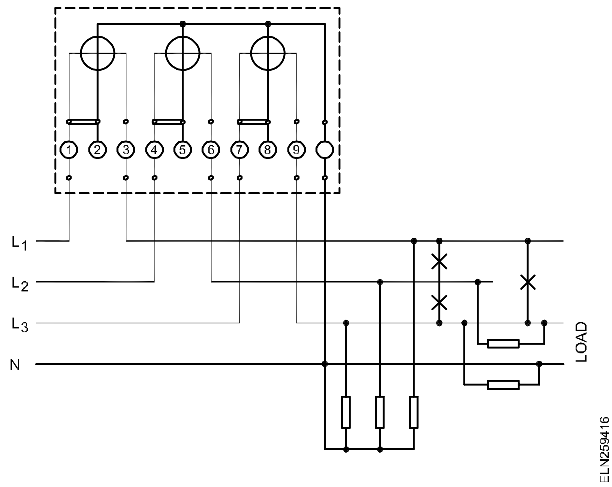
Fig 2


Fig 3


The principle and working of an induction type wattmeter are similar to the induction type energy meter. The only difference in construction between the energy meter and wattmeter is that the spindle of the wattmeter is spring-controlled, has a pointer but no train of gears.

However to summarise what has been learnt earlier the following table 1 is provided with connection diagram of 3-phase wattmeter Fig 4, Fig 5 & Fig 6

Table 1

Sl.No.	Types of 3-phase wattmeter	Circuit diagram	Application
1	2-element 3-wire type	Fig 4 	Balanced and unbalanced loads.
2	3-element 3-wire type	Fig 5 	Balanced loads.
3	3-element 4-wire type	Fig 6 	Un balanced loads.

Digital Wattmeter

Objectives: At the end of this lesson you shall be able to
- **describe the block diagram**
- **compare between analog and digital wattmeter**

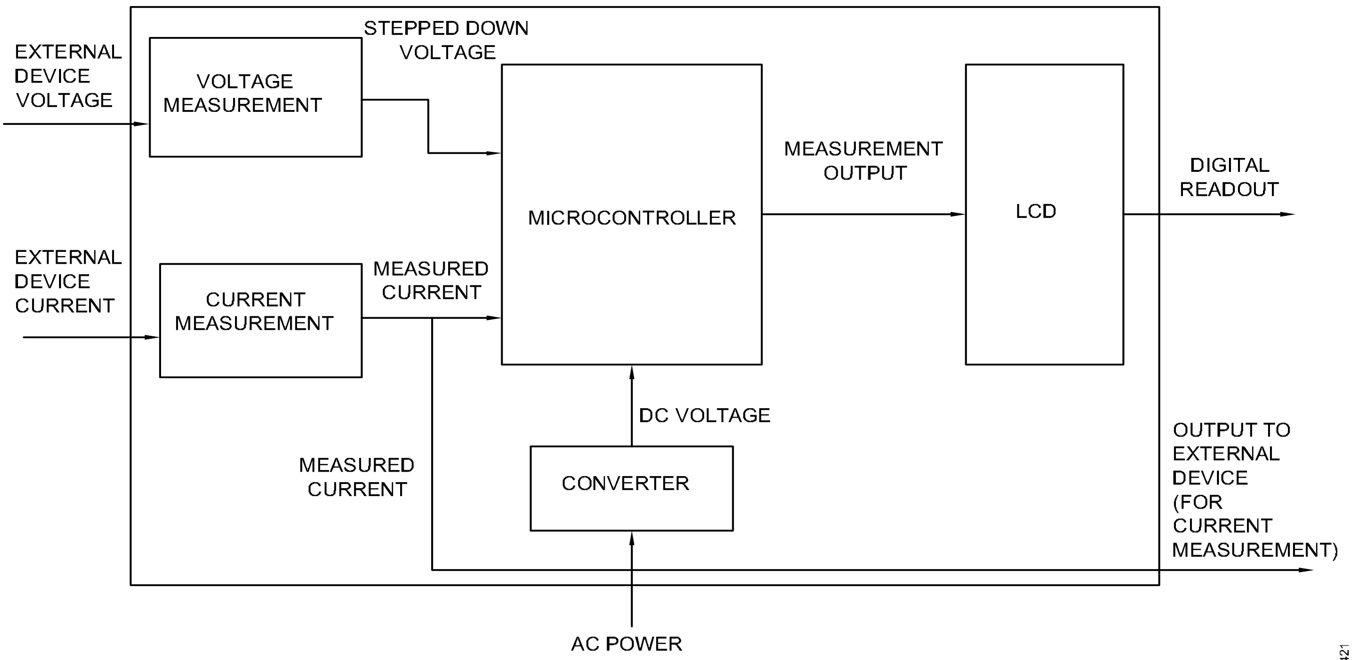
Digital wattmeter

The wattmeter is an instrument for measuring the electric power in watts of any given circuit. Electromagnetic wattmeters are used for measurment of utility frequency and audio frequency and audio frequency power; other types are required for radio frequency.

Fig 1 shows the block diagram of digital wattmeter.

Digital wattmeters measure current and voltage electronically thousands of times a second, multiplying the results in a computer microcontroller chip to determine watts. The computer can also perform statistics such as peak, average, low watts consumed. They can monitor the power line for voltage surges and outages. Digital electronic wattmeter, have become popular for conveniently measuring power consumption in household appliances with saving energy and money.

Fig 1



BLOCK DIAGRAM OF DIGITAL WATTMETER

Comparison between analog wattmeter and digital wattmeter

Analog wattmeter	Digital wattmeter
Due to moving parts there are losses and bearings.	As there are no moving parts,friction at mechanical losses are reduced .
Accuracy is less compared to digital wattmeters.	Accuracy is high as compared to analog.
Error may take place at the time of reading due to its non linearity.	Digital display facilitates to read the scale due power in fraction and in correct fashion.
It does not require any auxillary supply.	It requires auxillary DC supply to work.
More reliable as no complications in design and avoidance of electric components	Reliability is less as compared to analog to work
No effect of supply transients on performance of meter.	Any supply transients may damage the wattmeters.
More stable to vibration and temperature variations.	Considerable effect of vibration and temperature on performance of electric components.

Energy meter (analog and digital)

Objectives: At the end of this lesson you shall be able to
- **describe the construction and working principle of single phase energy meters**
- **state and explain creeping error in energy meter.**

Necessity of energy meter: The electrical energy supplied by the Electricity board should be billed, based on the actual amount of energy consumed. We need a device to measure the energy supplied to a consumer. Electrical energy is measured in kilowatt hours in practice. The meter used for this is an energy meter.

In AC, an induction type of energy meter is universally used for measurement of energy in domestic and industrial circuits.

Principle of a single phase induction type energy meter: The operation of this meter depends on the induction principle. Two alternating magnetic fields produced by two coils induce current in a disc and produce a torque to rotate it (disc). One coil (potential coil) carries current proportional to the voltage of the supply and the other (current coil) carries the load current. (Fig 1) Torque is proportional to the power as in wattmeter.

Fig 1

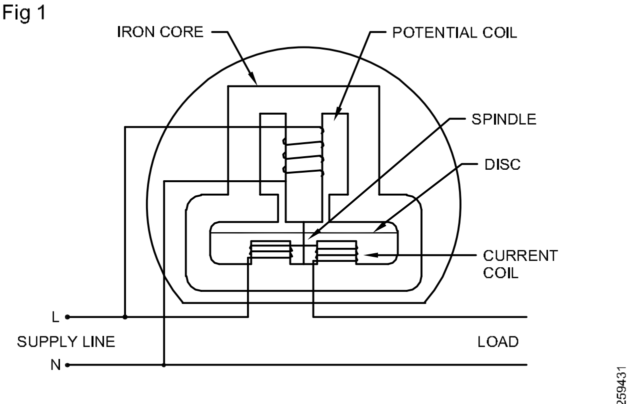


DIAGRAM OF AN INDUCTION TYPE WATT-HOUR METER

The watt-hour meter must take both power and time into consideration. The instantaneous speed is proportional to the power passing through it.

The total number of revolutions in a given time is proportional to the total energy that passes through the meter during that period of time.

Parts and functions of an energy meter: The parts of the induction type single phase energy meter are (Fig 1).

Iron core: It is specially shaped to direct the magnetic flux in the desired path. It directs the magnetic lines of force, reduces leakage flux and also reduces magnetic reluctance.

Potential coil (voltage coil): The potential coil is connected across the load and is wound with many turns of fine wire. It induces eddy current in the aluminium disc.

Current coil: The current coils, connected in series with load, are wound with a few turns of thick wire, since they must carry the full load current.

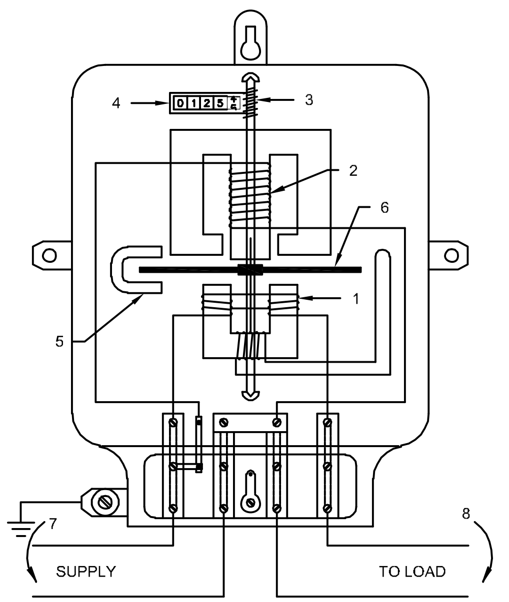
Disc: The disc is the rotating element in the meter, and is mounted on a vertical spindle which has a worm gear at one end. The disc is made of aluminium and is positioned in the air gap between the potential and current coil magnets.

Spindle: The spindle ends have hardened steel pivots. The pivot is supported by a jewel bearing. There is a worm gear at one end of the spindle. As the gear turns the dials, they indicate the amount of energy passing through the meter.

Permanent magnet/brake magnet: The permanent magnet restrains the aluminium disc from racing at a high speed. It produces an opposing torque that acts against the turning torque of the aluminium disc.

Functioning of energy meters: The rotation of the aluminium disc (Fig 2) is accomplished by an electromagnet, which consists of a potential coil and current coils. The potential coil is connected across the load. It induces an eddy current in the aluminium disc. The eddy current produces a magnetic field which reacts with the magnetic field produced by the current coils to produce a driving torque on the disc.

Fig 2



1. CURRENT COIL
2. VOLTAGE COIL
3. WORM GEAR
4. REGISTERING MECHANISM
5. PERMANENT MAGNET
6. ALUMINIUM DISC
7. SUPPLY TERMINALS
8. LOAD TERMINALS

INDUCTION TYPE ENERGY METER

ELN259432

The speed of rotation of the aluminium disc is proportional to the product of the amperes (in the current coils) and the volts (across the potential coil). The total electrical energy that is consumed by the load is proportional to the number of revolutions made by the disc during a given period of time.

A small copper ring(shading ring) or coil (shading coil) is placed in the air gap under the potential coil, to produce a forward torque, large enough to counteract any friction produced by the rotating aluminium disc.

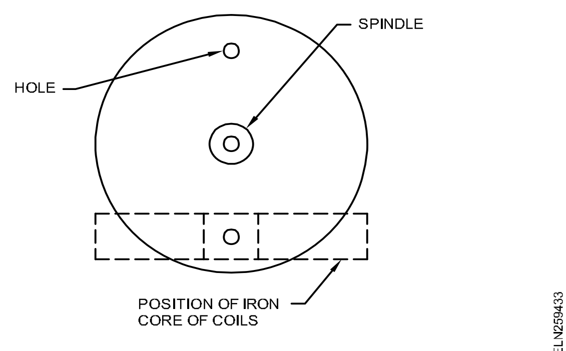
This counter torque is produced when the aluminium disc rotates in the magnetic field established by the permanent magnet. The eddy currents, in turn, produce a magnetic field that reacts with the field of the permanent magnet, causing a restraining action that is proportional to the speed of the disc.

The faster the disc rotates, the greater the induced eddy currents, and greater the restraining action. This restraining action is necessary to make the speed of rotation proportional to the current taken by the load and also to stop the disc from further rotation due to inertia when the supply is disconnected.

Creeping error and adjustment: In some meters the disc rotates continuously even when there is no current flow through the current coil i.e. when only the pressure coil is energised. This is called creeping. The major cause for creeping is over-compensation for friction. The other causes for creeping are excessive voltage across the pressure coil, vibrations and stray magnetic fields.

In order to prevent creeping, two diameterically opposite holes are drilled in the disc (Fig 3). The disc will come to rest with one of the holes under the edge of a pole of the potential coil magnet, the rotation being thus limited to a maximum of half a revolution.

Fig 3



Digital Energy meters

Objectives: At the end of this lesson you shall be able to
- **distinguish the merits of digital type over electromechanical type energy meter**
- **describe the functional operation of digital type energymeter from block diagram.**

Energy meter

An electric meter or energy meter is an essential device enables systematic pricing of energy consumed by individual consumer as it measures the amount of electrical energy consumed by a residence, business or equipment.

Generally, energy meters operate by continuously measuring the instantaneous voltage and current and finding the product of these to give instantaneously electrical power (watts) which is then integrated against time to give energy is used in joules, kWh

The energy meters are classified into two basic categories. They are

- Electromechanical type
- Electronic (digital) type

Electro mechanical type Energy meter

This meter has spinning disc and a mechanical counter display. It operates by counting the revolutions of a metal disc that rotates at a speed proportional to the power drawn through the main switch. Nearby coils spin the disc by inducing eddy currents and a force proportional to the instantaneous current and voltage

A permanent magnet exerts a damping force on the disc, stopping its spin after power has been removed

This type meter has these limitations

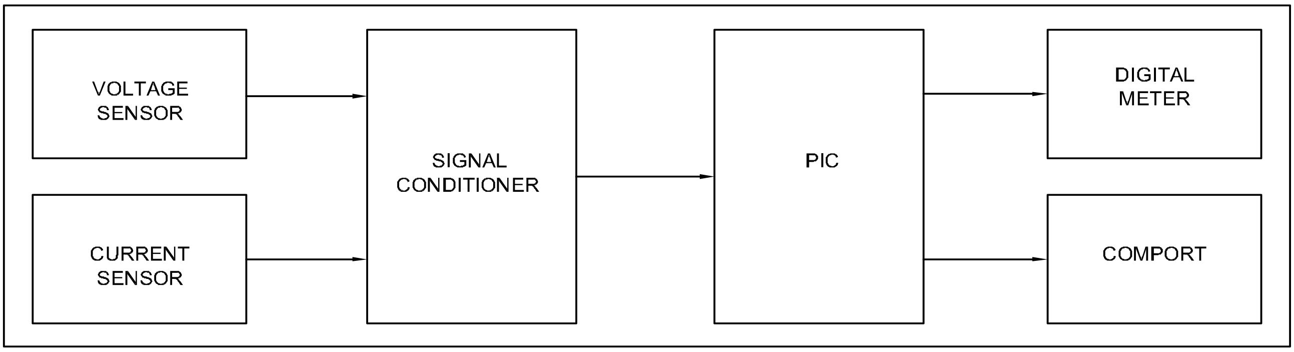
- Less accuracy
- Many methods for error correction
- Percentage error is more
- Installation is difficult
- No interface capability to external devices

The above mentioned disadvantages are overcome in digital meter, such as more accuracy, error correction method is only by A/D converters, percentage of error is 0 (Zero), installation is more easier. The display makes energy reducing from time to time can be obtained.

Electronic (Digital energy meter)

This meters measure the energy using highly integrated components and it digitizs the instantaneous voltage and current in a high-resolution sigma-delta analogue to digital converter (ADC), gives the instantaneous power in watts. Integration over time gives energy used, measured in kilo-Watt hour. The block diagram for a digital meter is shown in Fig 1. The two sensors, voltage and current sensors are employed.

Fig 1



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The voltage sensor built around a step down element and potential divider network sensors both the phase voltage and load voltage.

The second sensor is a current sensor, which senses the current drawn by the load at any point in time .

It's inbuilt around a current transformer and other active devices (voltage comparator), which converts the sensed current to voltage for processing. The output from both sensors is then fed into a signal (voltage) conditioner which ensures matched voltage (or) signal level to the control circuit containing multiplexer. It enables sequential switching of both signal to the analogue input of the Peripheral Interface Controller (PIC).

The control circuit centred on a PIC integrated circuit. It contains ten bit analogue to digital converter (ADC), flexible to program and good for peripheral interfacing.

The ADC converts the analogue signals to its digital equivalent, both signals from the voltage and current sensors are then multiplied by the means of embedded software in the PIC.

The error correction is taken as the offset correction by determining the value of the input quality in the short circuited input and storing this value in the memory for use as the correction value device calibration.

The PIC is programmed in 'C' language. It stimulates to use the received data to calculate power consumption per hour, as well as the expected charges. These are displayed on the liquid crystal display (LCD) attached to the circuit.

Fig 2 shows the image of a digital energy meter.

Fig 2

DIGITAL TYPE

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Advantages

DIGITAL electronic meters are much more accurate than electromechanical meters. There are no moving parts and , hence, mechanical defects like friction are absent.

In addition, electronic energy meters come with indicating LEDs for phase/ neutral ok, earth/leakage loss, kilowatt-hour pulse etc.

3-phase energy meter

Objectives: At the end of this lesson you shall be able to
- **list the various types of 3-phase energy meters**
- **describe the construction and working of a 3-phase 3-wire induction type energy meter**
- **describe the construction and working of a 3-phase 4-wire induction type energy meter**
- **state the application of a 3-phase 3-wire and 3-phase 4-wire energy meter.**

3-phase energy meters: Even though different types of energy meters are available, the induction type energy meter is most commonly used because it is simple in construction, less in cost and requires less maintenance. The function of a 3-phase energy meter is similar to that of a single phase energy meter

The three phase energy meter is required to measure the energy consumed in 3-phase loads whether balanced or unbalanced. The three phase energy can be measured by three separate single phase energy meters or by 3-phase energy meters.

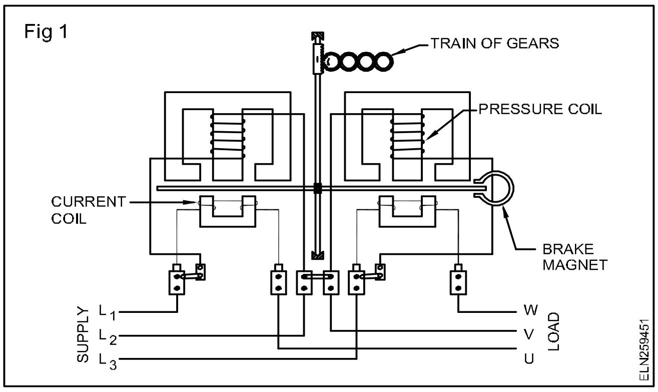
Types of 3-phase energy meters

There are two types of 3-phase energy meters mainly.

- Three phase 3-wire energy meters (3-phase 2- element energy meter)
- Three phase 4-wire energy meters (3-phase 3- element energy meter)

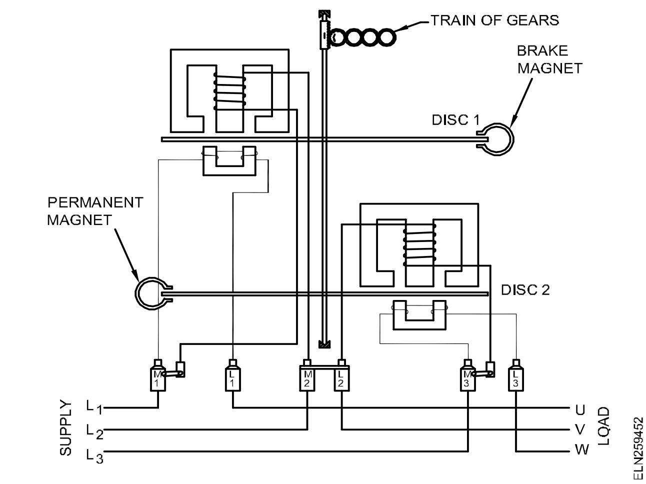
Two element 3-phase energy meters: This energy meter works on the principle of measurement of power by the two wattmeter method. Two elements of a current coil and two elements of a potential coil are used in this energy meter. These assemblies can be arranged on the different sectors in a horizontal position (Fig 1) with a single aluminium disc which rotates between the poles of a single braking magnet.

Fig 1



The two elements can also have individual driving discs on a common spindle. In this case they will have individual braking magnets (Fig 2). The second type usually preferred by the manufacturers due to the construction simplicity.

Fig 2

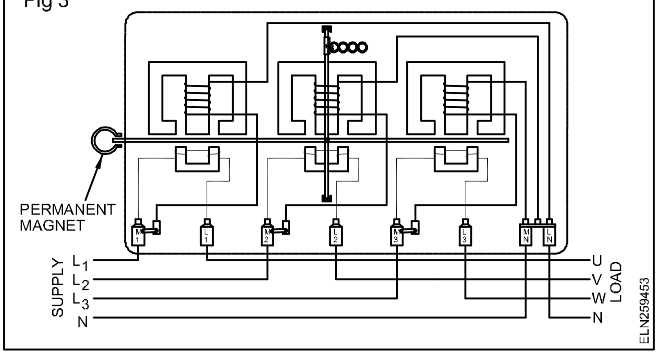


In both the cases the driving torque produced by individual elements are summed up. The recording mechanism which is attached to the train of gears i.e., cyclometer or counter type dial shows the sum of the energies that has passed through the elements. The two element energy meter is only suitable for a 3-phase 3-wire system but can be used for both balanced and unbalanced loads.

3-element 3-phase energy meter: This works on the same principle as that of the 3 wattmeter method of power measurement with a 3-phase load. Here 3 units, each with a current coil and a potential coil, are used. The potential coils of the 3 elements are connected in star to the supply lines with their common point connected to the neutral line of power supply.

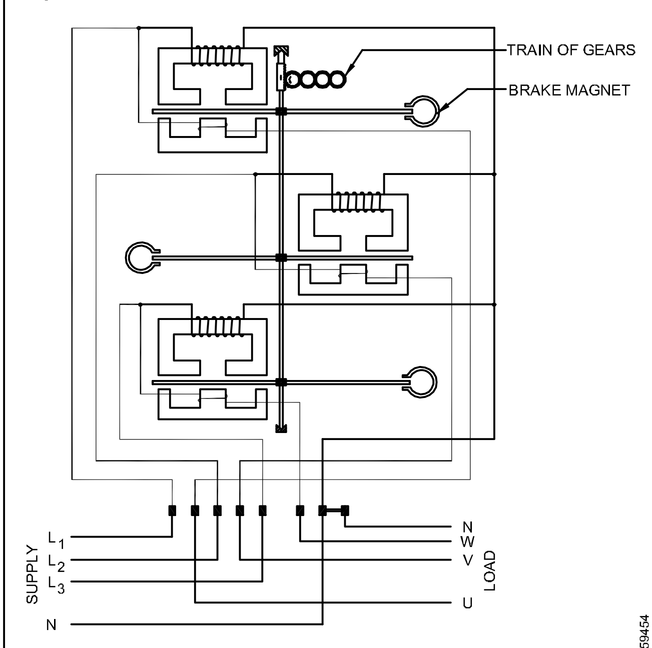
The current coils are connected in series to the individual lines. As is the case with the two element energy meter, these three elements can be arranged in the different sectors of a common single aluminium disc which serves as a rotating part connected to driving dial (Fig 3).

Fig 3



The three elements can also have a common spindle with three individual discs and braking magnets (Fig 4). Here also the 2nd type is usually preferred by manufacturers due to the easiness in construction. The driving torque produced by the three individual elements are summed up and the recording mechanism shows the sum of energies that has passed through the individual elements. This energy meter is suitable for the 3-phase 4-wire system.

Fig 4



3-ELEMENT 3-PHASE ENERGY METER

Application of 3-phase energy meter: A two element 3-phase energy meter is used with three phase loads in which a neutral is not used such as for an industry or irrigation pumpset motors etc. having three phase loads only or with an 11kV 3-phase 3-wire supply to an industry.

A 3-phase 4-wire element energy meter is used with three phase load in which balanced or unbalanced loads are connected with individual phases and neutral such as for a large domestic consumer or for an industry having lighting loads also.

Errors in energy meter

Objectives: At the end of this lesson you shall be able to

- **explain the errors caused by the driving system and the braking system in energy meters**
- **explain the different adjustments provided for correcting the errors in energy meters**
- **explain the method of determining the percentage error in the single phase energy meter**
- **state the recommendations of IS regarding percentage errors, load percentage and the power factor.**

Errors caused by the driving system.

Incorrect magnitude of fluxes: This may be due to abnormal values of current or voltage. The shunt magnet flux may be in error due to changes in resistance of coil or due to abnormal frequencies.

Incorrect phase angles: There may not be a proper relationship between the various phasors. This may be due to improper lag adjustment, abnormal frequencies, change in resistance with temperature etc.

Lack of symmetry in magnetic circuit: If the magnetic circuit is not symmetrical, a driving torque is produced which makes the meter creep.

Error caused by the braking system

They are:

- changes in the strength of the brake magnet
- changes in the disc resistance
- self-braking effect of series magnet flux
- abnormal friction of the moving parts.

Adjustments are provided for correcting the errors in the energy meters so that they read correctly and their errors are within acceptable limits.

Preliminary light load adjustment: The rated voltage is applied to the potential coil with no current through the current coil and the light load device is adjusted until the disc just fails to start. The electromagnet is slightly adjusted to make the holes in the disc to take a position in between the poles of the electromagnets.

Full load unity power factor adjustment: The pressure coil is connected across the rated supply voltage and the rated full load current at unity power factor is passed through the current coils. The position of the brake magnet is adjusted to vary the braking torque so that the meter revolves at the correct speed within the required limits of error.

LAG adjustments (Low power factor adjustments): The pressure coil is connected across the rated supply voltage and the rated full load current is passed through the current coil at 0.5 P.F. lagging. The lag device is adjusted till the meter runs at the correct speed.

Rated supply voltage: By adjusting the rated supply voltage, with the rated full load current and unity power factor, the speed of the meter is checked and the full load unity power factor and low power factor adjustments are repeated until the desired accuracy limits are reached for both the conditions.

Light load adjustment: The rated supply voltage is applied across the pressure coil and a very low current (about 5% of full load current) is passed through the meter at unity power factor. Light load adjustment is done so that the meter runs at the correct speed.

Full load unity power factor: Light load adjustments are again done until the speed is correct for both loads i.e. full load as well as light loads.

The performance: This is rechecked at 0.5 P.F. lagging.

Creep adjustment: As a final check on the light load adjustment, the pressure coil is excited by 110 percent of the rated voltage with zero load current. If the light load adjustment is correct, the meter should not creep under these conditions.

Methods of determining the percentage error in the energy meters.: There are two methods to determine percentage error in energy meters.

- One is the percentage by which the recorded energy differs from the true energy. From the number of revolutions and the constant given on the meter cover the recorded energy is calculated. The meter constant (K) is generally given as a certain number of revolutions per KWH at the rated voltage.

  Hence Recorded energy (KWH)

$$= \frac{\text{Revolutions}}{\text{Meter constant}}$$

True energy is calculated from the ammeter, voltmeter, power factor meter and time.

$$\text{Hence True energy} = \frac{E I \cos\phi \times t\,(\text{sec})}{1000 \times 3600}$$

where 't' is in seconds.

The true energy can also be obtained from the reading of the substandard energy meter connected in the circuit instead of the ammeter, voltmeter and power factor meter and the

$$\%\ \text{error} = \frac{\text{Recorded energy - True energy}}{\text{True energy}} \times 100$$

In the second method the constant of the meter is compared with the constant calculated from the standard meter readings and time (test constant). When the error is calculated by this method it is usual to express the constant in watt secs. per revolution, instead of revolutions per KWH.

$$\text{Meter constant (Watt secs/rev.)} = \frac{3600 \times 1000}{\text{Rev. / KWH}}$$

$$\text{Test constant} = \frac{E \times I \times T\,(\text{sec})}{\text{Rev.}}$$

$$\text{and}\ \%\ \text{error} = \frac{\text{Meter constant (T) - Test constant } (T_1)}{\text{Test constant } (T_1)} \times 100$$

By comparing time for certain revolutions of the rotor

$$\%\ \text{error} = \frac{T - T_1}{T_1} \times 100$$

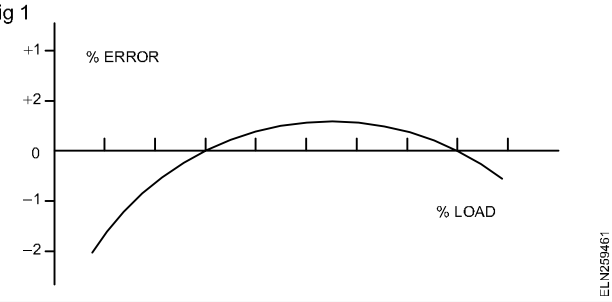
Where T= correct time for a given number of revolutions

$$= \frac{3600 \times 1000}{\text{Rev. / KWH}} \times \frac{\text{Rev.}}{\text{Watts}}$$

T_1 = actual time for the same number of revolutions as found by a stopwatch.

From the readings a curve is plotted for percentage error Vs. percentage load on the meter. If the meter records more than the true energy (i.e. runs fast) the error is +ve and if it reads less error is –ve. (Fig 1)

Fig 1



Recommendations as per BIS 722: As per Bureau of Indian Standards IS 722 (Part II 1977), a single phase energy meter should have the following ratings and accuracies.

- Standard basic current (I_b) 2.5, 5, 10, 20 and 30A.
- Rated maximum current (I_{max}) 200% of the rated basic current.
- Starting current at unity power factor shall be 0.5 of basic current.
- Limits of error shall be as follows.

Values of current	Power factor	%error limit
5% I_b	1	± 2.5
10% I_b to I_{max}	1	± 2
10% I_b	0.5 lagging	± 2.5
20% I_b to I_{max}	0.5 lagging	± 2

Multimeters

Objectives: At the end of this lesson you shall be able to

- **state what is a multimeter**
- **explain the construction of multimeter**
- **explain the working priniciple of analog multimeter**
- **explain the method of measuring direct / alternating voltages and current with a multimeter**
- **explain the method of measuring resistance by a multimeter**
- **explain the precautions to be observed while measuring voltage, current and resistance in the circuit.**

The three most commonly measured electrical quantities are current, voltage and resistance. Current is measured by an ammeter, voltage by a voltmeter and resistance by an ohmmeter.

A single instrument used for measuring all the above three quantities is known as a multimeter. It is a portable, multi range instrument.

It has a full scale deflection accuracy of ±1.5 %. The lowest sensitivity of multimeters for AC voltage range is 5 K ohms/ volts and for the DC voltage range it is 20 K ohms/volts. The lowest range of DC is more sensitive than the other ranges.

Figs 1a and 1b show typical multimeters.

Construction of a multimeter

Fig 1

(a)

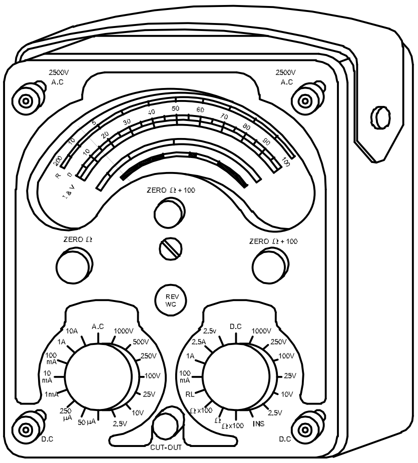
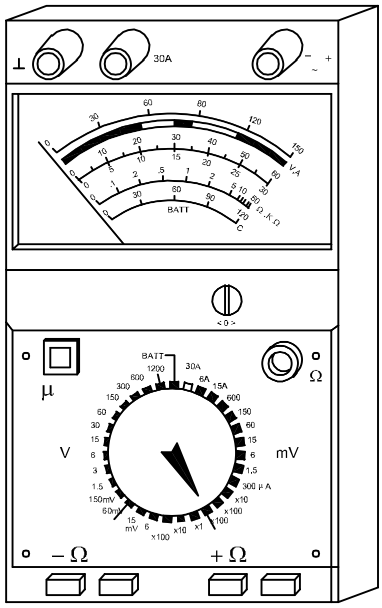


Fig 1

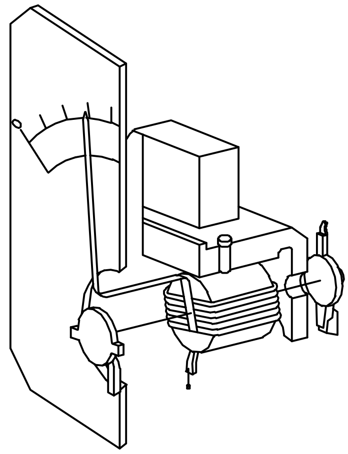
(b)



A multimeter uses a single meter movement (Fig 2), with a scale calibrated in volts, ohms and milliamperes. The necessary multiplier resistors and shunt resistors are all contained within the case. Front panel selector switches are provided to select a particular meter function and a particular range for that function.

On some multimeters, two switches are used, one to select a function, and the other the range. Some multimeters do not have switches for this purpose; instead, they have separate jacks for each function and range.

Fig 2



Batteries/cells fixed inside the meter case provide the power supply for the resistance measurement.

The meter movement is that of the moving coil system as used in DC ammeters and voltmeters. (Fig 2)

Rectifiers are provided inside the meter to convert AC to DC in the AC measurement circuit.

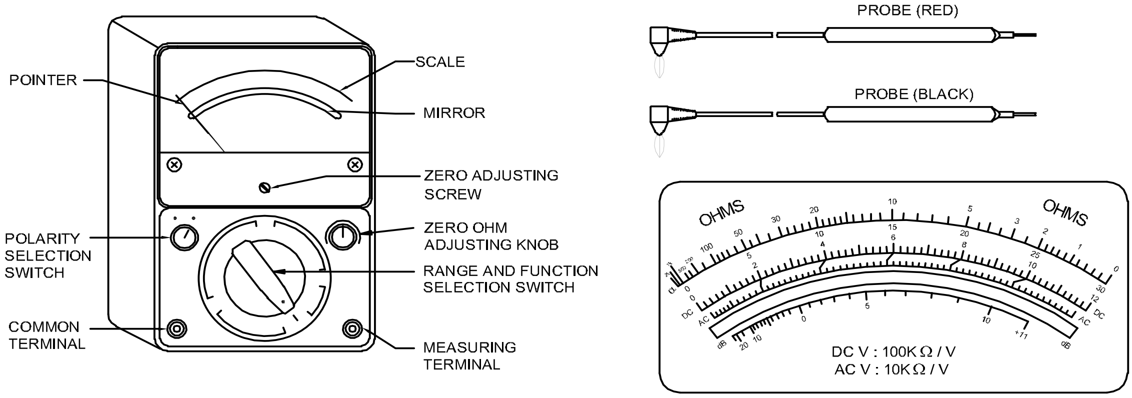
Parts of a multimeter

A standard multimeter consists of the main parts and controls (Fig 3).

Controls

The meter is set to measure the current, voltage (AC and

Fig 3



DC) or resistance by means of the FUNCTION switch. In the example given in Fig 4 the switch is set to mA, AC.

The meter is set to the required current, voltage or resistance range - by means of the RANGE switch. In

Fig 4

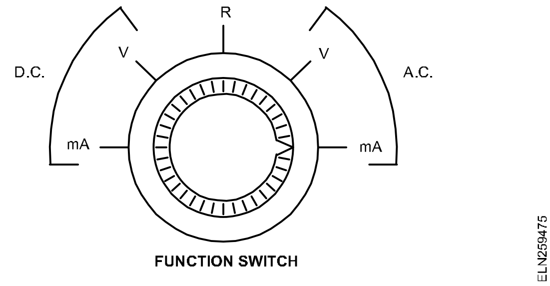
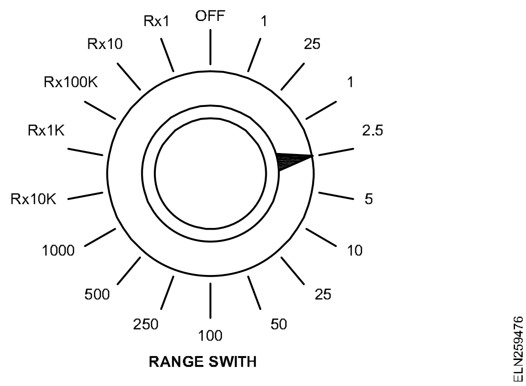


Fig 5, the switch is set to 2.5 volts or mA, depending on the setting of the FUNCTION switch.

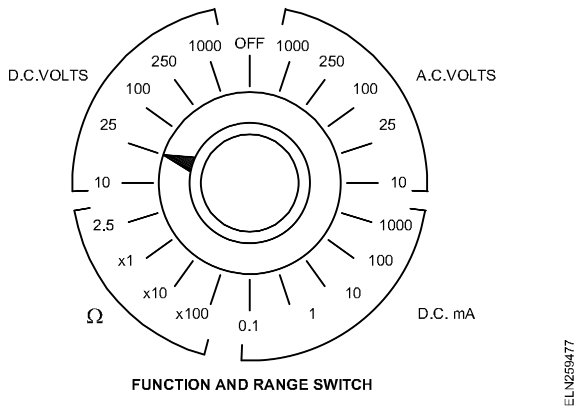
The example in Fig 6 shows the switch set to 25V DC of

Fig 5



a meter having the function and the range selected by a single switch.

Fig 6



The example in Fig 7 shows the switches set to 250V AC of a meter that uses two function/range switches, one for DC ranges and the other for AC and resistance (ohms) ranges.

Switches set to 100 mA DC. (Fig 8)

Switches set to resistance, ohms x 100 range. (Fig 9)

Fig 7

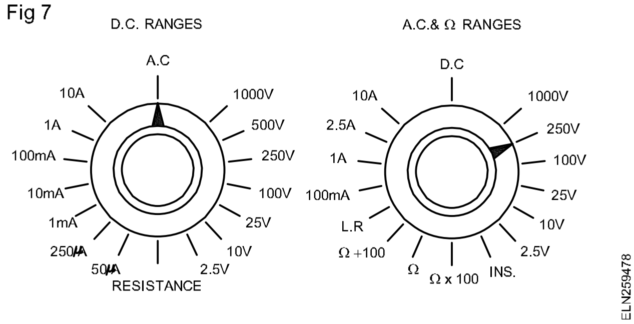


Fig 8

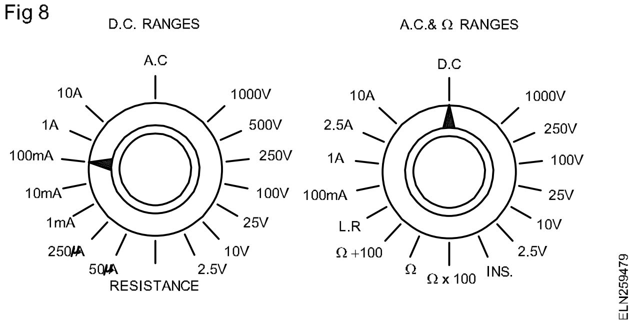
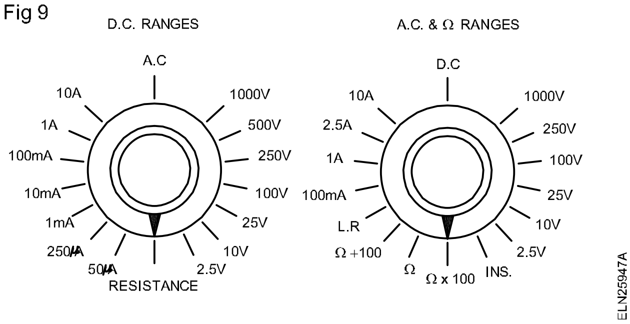


Fig 9

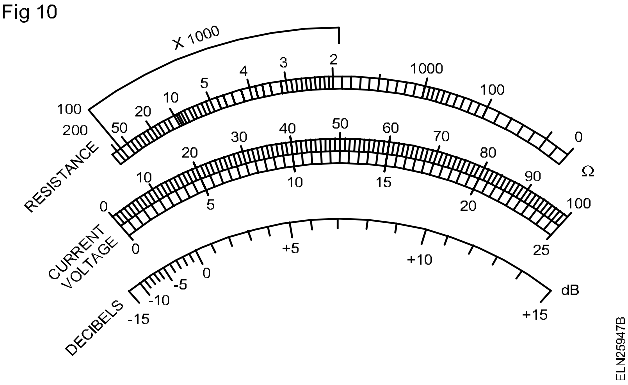


Scale of multimeter

Separate scales are provided for:

- resistance
- voltage and current.(Fig 10)

Fig 10



The scale of current and voltage is uniformly graduated.

The scale of the ohmmeter is non-linear. That is, the divisions between zero and infinity (¥) are not equally spaced. As you move from zero to the left across the scale, the divisions become closer together.

The scale is usually ‘backward’, with zero at the right.

Principle of working

A circuitry when working as an ammeter is shown in Fig 11.

Shunt resistors across the meter movement bypass current in excess of 0.05 mA at fsd. A suitable value of shunt resistor is selected through the range switch for the required range of current measurement.

A circuitry when working as a voltmeter is shown in Fig 12.

The voltage drop across the meter coil is dependent on the current and the coil resistance. To indicate voltages greater than 50 mV at fsd as per the circuit, multiplier resistances of different values are connected in series with the meter movement through the range switch for the required range of measurement.

A circuitry when working as an ohmmeter is shown in Fig 13.

To measure resistance, the leads are connected across the external resistor to be measured (Fig 13). This connection completes the circuit, allowing the internal battery to produce current through the meter coil, causing deflection of the pointer, proportional to the value of the external resistance being measured.

Zero adjustment

When the ohmmeter leads are open, the pointer is at full left scale, indicating infinite (¥) resistance (open circuit). When the leads are shorted, the pointer is at full right scale, indicating zero resistance.

The purpose of the variable resistor is to adjust the current so that the pointer is at exactly zero when the leads are shorted. It is used to compensate for changes in the internal battery voltage due to aging.

Multiple range

Shunt (parallel) resistors are used to provide multiple ranges so that the meter can measure resistance values from very small to very large ones. For each range, a different value of shunt resistance is switched on. The shunt resistance increases for the higher ohm ranges and is always equal to the centre scale reading on any range. These range settings are interpreted differently from those of the ammeter or voltmeter. The reading on the ohmmeter scale is multiplied by the factor indicated by the range setting.

> **Remember, an ohmmeter must not be connected to a circuit when the circuit’s power is on. Always turn the power off before connecting the ohmmeter.**

Fig 11

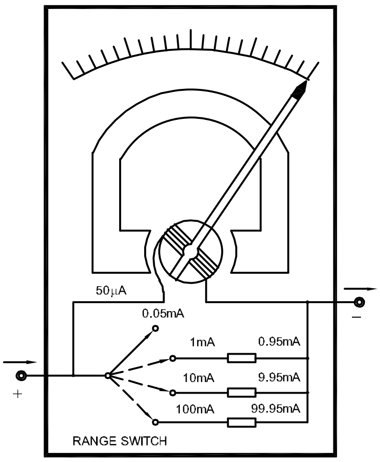


Fig 12

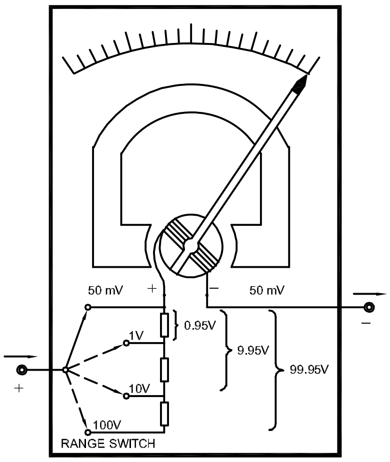
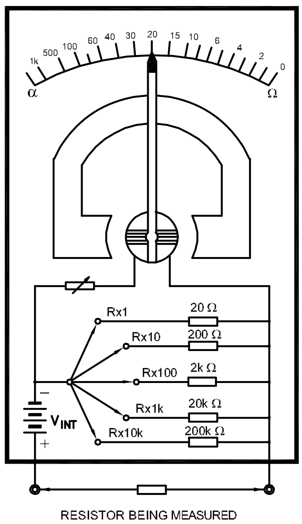


Fig 13



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Digital multimeters

Objectives: At the end of this lesson you shall be able to
- **distinguish between the analog and digital multimeter**
- **explain the method of measurement of voltage by using digital multimeter**
- **list and explain the types of digital multimeter**
- **state the application of digital multimeters**

Types of multimeters

Analogue types

- Selector switch type
- Multi-plug type

Digital types

- Selector switch type
- Auto-ranging type
- LCD display

Analogue type multimeters

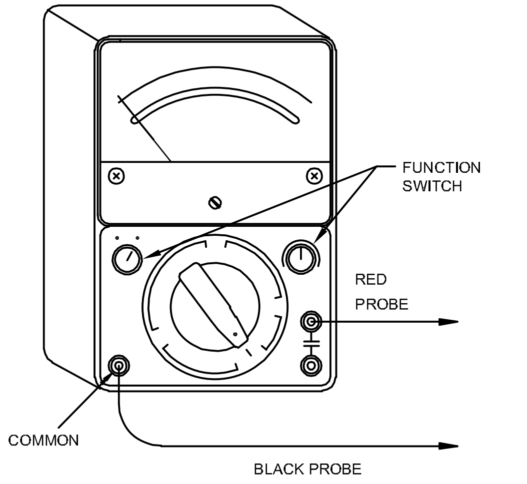
They have a meter movement mechanism, a calibrated scale and a pointer. Reading is obtained by looking at the position of the pointer on the scale.

The multimeter explained earlier is an analog type. (Fig 1)

In a digital multimeter the meter movement is replaced by a digital read out (Fig 2 and 3). This readout is similar to that used in electronic calculators. The internal circuitry of the digital multimeter is made up of digital, integrated circuits. Like the analog-type multimeter, the digital multimeter has a front panel switching arrangement.

The quantity measured is displayed in the form of a four digit number, with a properly placed decimal point. When DC quantities are measured, the polarity is identified by means of a + or sign displayed to the left of the number.

Fig 1



The quantity measured is displayed in the form of a four digit number with a properly placed decimal point. When DC quantities are measured the polarity is identified by '+ve' or '-ve' sign displayed to the left of the number indicating the probes are connected correctly by +ve sign and probes are reversely connected by -ve sign.

Fig 2

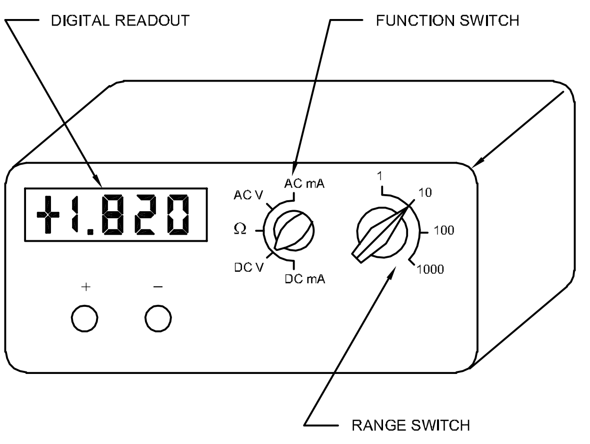
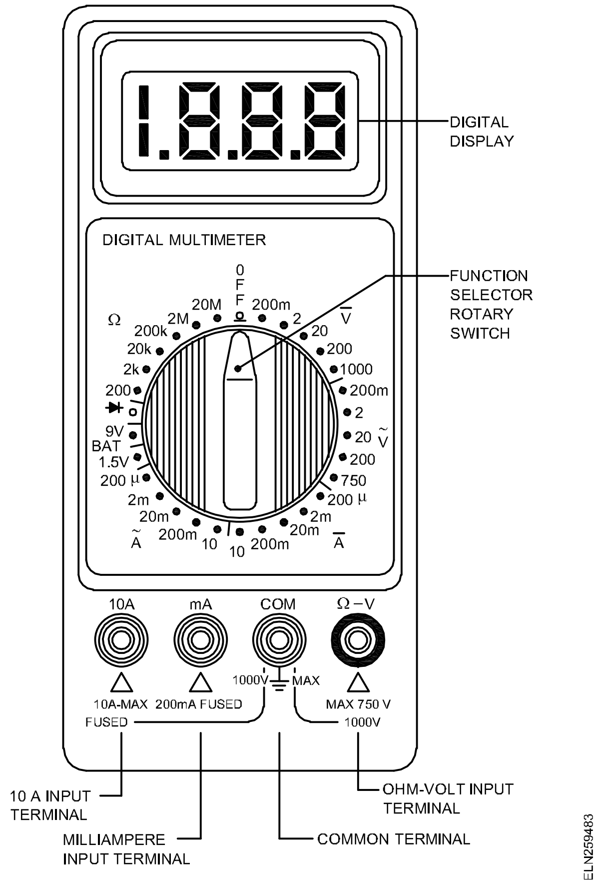


Fig 3



DMM functions: The basic functions found on most DMMs are the same as those on analouge multimeters. That is it can measure:-

- ohms
- DC voltage and current
- AC voltage and current

Some DMMs provide special functions such as transistor or diode test, power measurement, and decibel measurement for audio amplifier tests.

DMM displays: DMMs are available with either LCD (liquid -crystal display) or LED (light-emitting diode) read-outs. The LCD is the most commonly used read-out in battery-powered instruments due to the fact that it draws very small amount of current.

A typical battery-powered DMM with an LCD read-out operates on a 9V battery that will last from a few hundred hours to 2000 hours and more. The disadvantages of LCD read-outs are that (a) they are difficult or impossible to see in poor light conditions, and (b) they are relatively slow response to measurement changes.

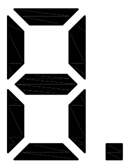
LEDs, on the other hand, can be seen in the dark, and respond quickly to changes in measured values. LED displays require much more current than LCDs, and, therefore, battery life is shortened when they are used in portable equipment.

Both LCD and LED-DMM displays are in a seven segment format (Fig 4).

Many meters have 3 1/2 digit in their display. For example a 3 1/2 digit multimeter has three digit positions that can indicate from 0 through 9 and one digit position that can indicate only a value of 1. This latter digit, called the half-digit, is always the most significant digit in the display.

For example, suppose a DMM is reading 0.999 volt (Fig 5a), if the voltage increases by 0.001V to 1V, the display correctly 1.000V (Fig 5b). The 1 is the half-digit. Thus, with 3 1/2 digits, a variation of 0.001V, can be observed.

Fig 4



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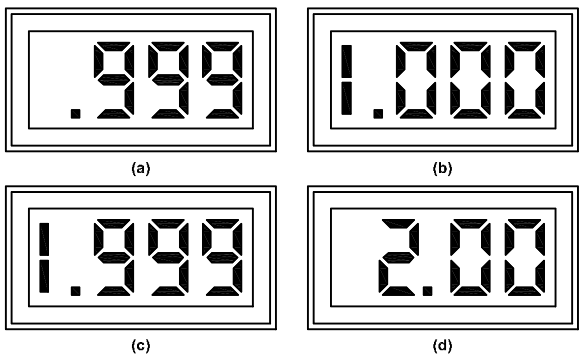
Now, suppose the voltage increases to 1.999V, this value is indicated on the meter (Fig 5c). If the voltage increases by 0.001V to 2V, the half-digit cannot display the ‘2’, so the display shows 2.00. The half-digit is blanked and only three digits are active, as indicated in Fig 5d. DMMs with displays of 4 1/2 through 8 1/2 digits are also available.

Fig 5



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Multimeter: Safety precautions: While using a multimeter safety is an important technical skill. When measuring electricity, you are dealing with an invisible and often a lethal force. Voltage levels above 30V can kill. The following safety precautions should always be taken.

- Never use the ohmmeter section on a live circuit.
- Never connect the ammeter section in parallel with a voltage source.
- Never overload the ammeter or voltmeter sections by attempting to measure currents or voltages far in excess of the range switch setting.
- Check the meter test leads for frayed or broken insulation before working with them. If damaged insulation is found the test leads should be replaced.
- Avoid touching the bare metal clips or tips of the test probes.
- Whenever possible, remove the supply before connecting the meter test leads into the circuit.
- When connecting the meter test leads to live circuits, work with one hand hanging at your side to lessen the danger of accidental shock.
- To lessen the danger of accidental shock, disconnect the red meter test leads first and then the common test lead (black) after the test is completed.

Applications of Digital multimeter: A multimeter is used for testing and fault finding in electrical/electronic circuits, electrical appliances and machines. A multimeter is a portable handy instrument used for

- checking continuity of circuit, appliances and devices.
- measuring/checking the supply presence at the source
- for testing components like capacitors, diodes, and transistors for checking their condition.
- measuring the current drawn by the circuit to infer its condition
- measuring resistance of the electrical appliances and devices for checking their condition.

Note: Some meters have provision also for temperature measurement with suitable sensing probes.

Comparison of Analog and Digital multimeters

Analog type	Digital Type
Instrument has moving parts. Care should be exercised in handling the meter.	There are no moving parts
Position of use is fixed and should not be altered.	Can be used in any position
Reading error due to parallax is possible.	No reading error as they have numerical display.
Actual value of indication is obtained by computation.	No need to compute as the value is directly indicated.
Manual zero setting for resistance measurement is required.	Zero setting is automatic for resistance measurement.
Auto range setting is not possible.	Auto-ranging instruments are available.
It can track short term variations and trends in measured quantity.	Not possible. The response is slow.
Indication of measured quantity by the movement of pointer over the graduated scale.	Digital numerical read out.
Loads the measuring circuit.	Practically no loading.

Calibration of analog multimeter

Objectives: At the end of this lesson you shall be able to
- **state briefly the function of analog and digital multimeter**
- **state the function of the parts of analog multimeter**
- **state the procedure to calibrate the analog multimeter.**

Analog multimeter

A multimeter is an instrument for measuring resistance (ohmmeter), voltage (voltmeter) and current (ammeter). All these meters (ohmmeter, voltmeter, and ammeter) are combined to a single meter called as multimeter as short for multiple meter. Others also call it VOM meter. Fig 1

Fig 1

ELN259491

The primary types of multimeters are analog and digital multimeter. Digital multimeter converts the measured variables into a digital signal and displays numerical value on screen. while a analog multimeter, uses a needle which deflects to show the value it can be a bit difficult to use because of its multiple function and its scale is non-linear.

Multimeter parts

Multimeter Scale

- A scale with set of numerical values used to read the measured variables. The upper scale is for measuring resistance and the lower scale for measuring voltage and current

Pointer

- It indicates the value of electrical quantity being measured

Selector knob

- A selector switch that allows to choose functions to use.

Test probe

- The input part of the multimeter. Red probe for positive and black probe for common.

Zero ohm adjuster

- A part of the multimeter where it is adjusted when it's pointer will not point to zero.

Calibration

- Set the multimeter to its ohmmeter function it is located at lower right portion of selector knob.

Multipliers are used to increase or change the scaling of Ohm meter for better resolution

- Select the selector knob to multiplier.
- Shunt the test probes of the multimeter. the pointer must point to zero scale because there is nothing to measure.
- If it is not pointing to zero, calibrate it to set to zero. Locate the zero ohm adjuster and rotate the knob until it points to zero.
- Now, pointer is pointing at zero scale. It means it is ready to use.

For other multiplier like x10 (or) x100, repeat the procedure to calibrate again

Phase-sequence indicator (Meter)

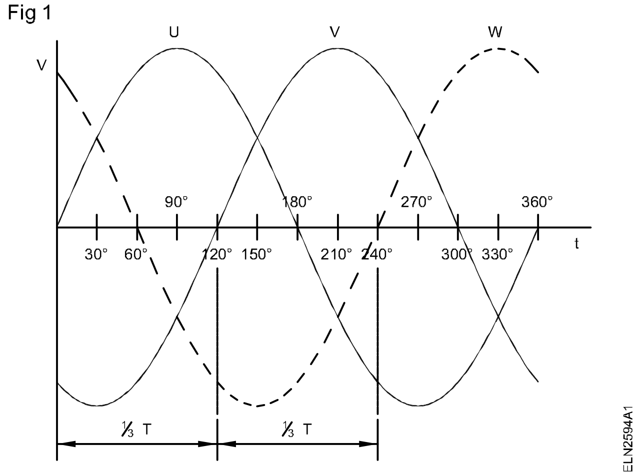
Objectives: At the end of this lesson you shall be able to
- **describe the method of finding the phase sequence of a 3-phase supply using a phase-sequence indicator**
- **state the method of using phase sequence indicator with choke & lamp and capacitor & lamp.**

Review

A three-phase alternator contains three sets of coils positioned 120° apart and its output is a three-phase voltage as shown in Fig 1. A three-phase voltage consists of three voltage waves, 120 electrical degrees apart.

At a time 0, phase U is passing through zero volts with positively increasing voltage. (Fig 1) V follows with its zero crossing $\frac{1}{3}$ of the period later and the same applies to W with respect to V. The order in which the three-phases attain their maximum or minimum values is called the phase sequence. In the illustration given here the phase sequence is U,V,W.

Fig 1



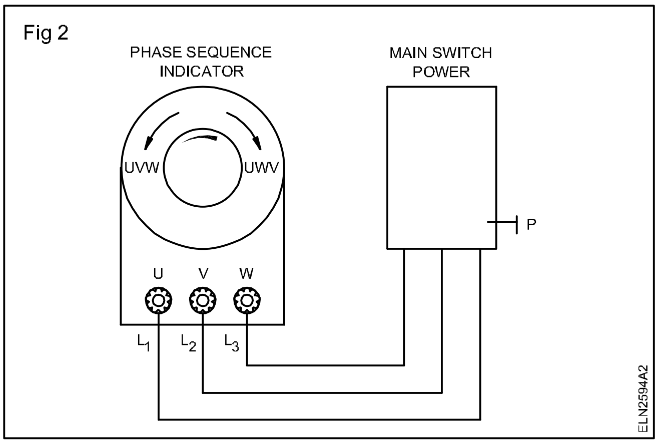
Importance of correct phase sequence: Correct phase sequence is important in the construction and connection of various three-phase systems. For example, correct phase sequence is important when the outputs of three-phase alternators must be paralleled into a common voltage system. The phase `U' of one alternator must be connected to phase `U' of another alternator. The phase `V' to phase `V' and phase `W' to phase `W' must be similarly connected to each other.

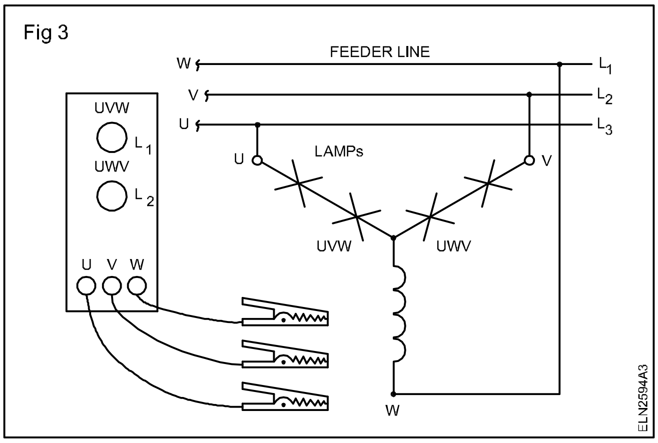
In the case of an induction motor, reversal of the sequence results in the reversal of the direction of motor rotation which will drive the machinery the wrong way.

Phase-sequence indicator(meter)**:** A phase-sequence indicator (meter) provides a means of ensuring the correct phase-sequence of a three-phase system. The phase-sequence indicator consists of 3 terminals `UVW' to which three-phases of the supply are connected. When the supply is fed to the indicator a disc in the indicator moves either in the clockwise direction or in the anticlockwise direction.

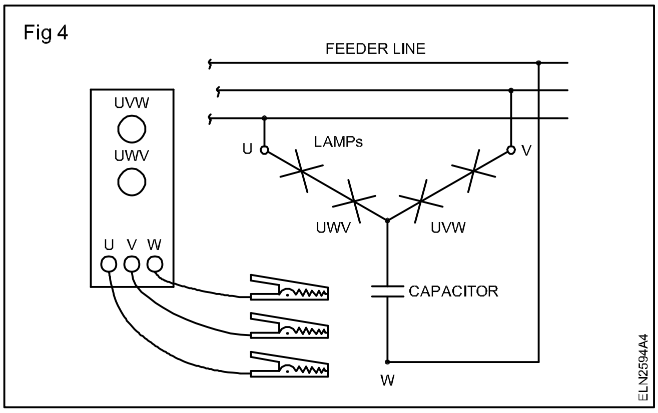
The direction of the disc movement is marked with an arrowhead on the indicator. Below the arrowhead the correct sequence is marked (Fig 2). The phase sequence of the three-phase system may be reversed by interchanging the connections of any two of the three phases.

Phase-sequence indicator using choke and lamps: The phase-sequence indicator consists of four lamps and an inductor connected in a star formation (Y). A test lead is connected to each leg of the `Y'. One lamp is labelled U-V-W, and the other is labelled U-W-V. When the three leads are connected to a three-phase line, the brighter lamp indicates the phase sequence (Fig 3).





Phase-sequence indicator using capacitor & lamps: The phase-sequence indicator consists of four lamps and a capacitor connected in a star formation (Y). A test lead is connected to each leg of the `Y'. One pair of lamps are labelled U-V-W,and the other pair are labelled U-W-V. When the three leads are connected to a 3-phase line, the brighter lamp indicates the phase sequence. (Fig 4)



Frequency meter

Objectives: At the end of this lesson you shall be able to
- **state the types of frequency meters**
- **describe the principle, construction and working of a mechanical resonance (vibrating reed) type frequency meter**
- **describe the construction and working principle of an electrical resonance type frequency meter**
- **describe the construction and working principle of a ratiometer type frequency meter.**

The following types of frequency meters are used for measuring power frequencies.

- Mechanical resonance type
- Electrical resonance type
- Electro-dynamic type
- Electro-dynamometer type
- Weston type
- Ratiometer type
- Saturable core type

Apart from the above power frequency meters, there are other types of equipment, like electronic frequency counters, frequency bridges, stroboscope and oscilloscope which are used for measuring a wide range of frequencies.

The explanation given here is for three types of power frequency meters only as indicated below.

They are :

- mechanical resonance type
- electrical resonance type
- ratiometer type.

The trainees are advised to refer to books on electrical measuring instruments for learning about the other types of frequency meters.

Mechanical resonance type frequency meter (vibration reed type)

Principle: The vibration reed type frequency meter shown in Fig 1 works on the principle of natural frequency. Every object in the world has its natural frequency, depending upon its weight and dimensions. When an object is kept in a vibrating medium, it starts vibrating, if the frequency of the medium attains the natural frequency of the object.

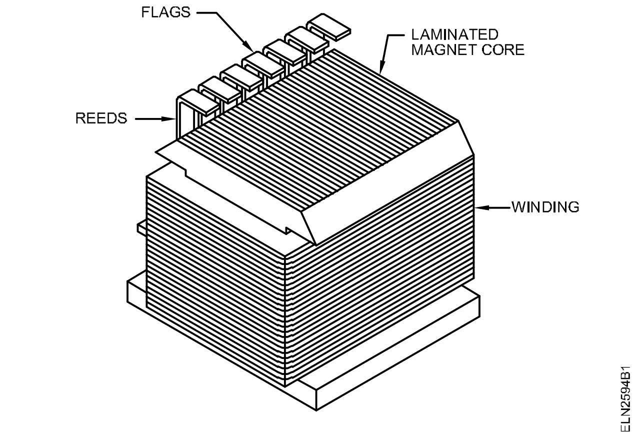


Fig 1

If the vibrations are not controlled, the object may even get totally destroyed. A good example of this phenomenon is the shattering of window glass panes due to the vibration caused by low flying aircraft.

Construction: Mechanical resonance type frequency meters consist of an eletromagnet and a set of metallic reeds arranged in front of the electromagnet. The frequency meter is connected across the supply like a voltmeter, taking care about the voltage rating (Fig 2) .

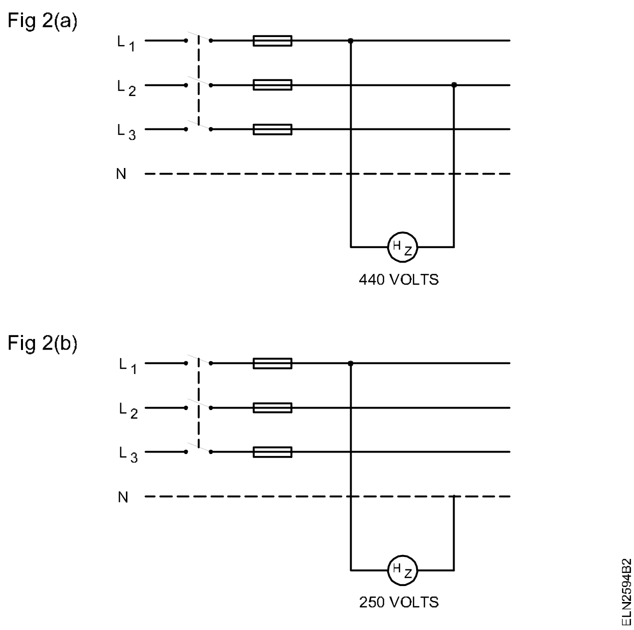


Fig 3 shows the shape of the reed and these reeds are of about 4mm wide and 0.5 mm thick. One end of the reed is fitted on a base, and the other overhanging end carries a white painted surface as the indicator and sometimes referred to as flag.

The reeds are arranged in a row and the natural frequency of the reeds differs by 1/2 cycle. This 1/2 cycle difference is possible between the reeds due to the difference in the weights of the reeds. The reeds are arranged in an ascending order (Fig 4a), and generally the natural frequency of the centre reed is the same as that of the supply frequency (50Hz).

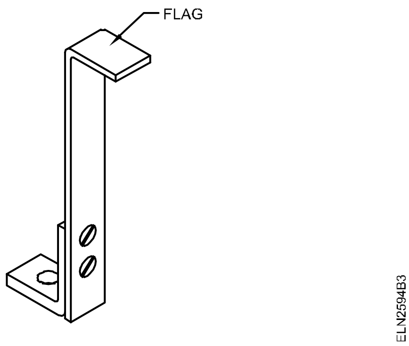


Fig 3

Working: When the frequency meter is connected to the supply, the electromagnet produces a magnetic field which alternates at the rate of the supply frequency. The reed, which has its natural frequency coincident with that of the alternating magnetic field, vibrates more than the adjacent reeds Fig 4(b).

The flag of this vibrating reed makes it possible to note the frequency of the supply from the scale marking of the frequency meter. Though the other reeds also vibrate, Fig 4(b), their magnitude will be much less than the reed whose natural frequency is exactly in coincidence with the supply frequency.

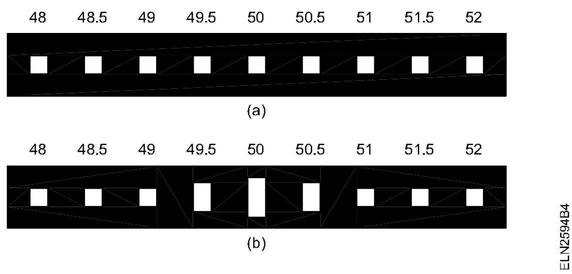


Fig 4

Advantages and disadvantages

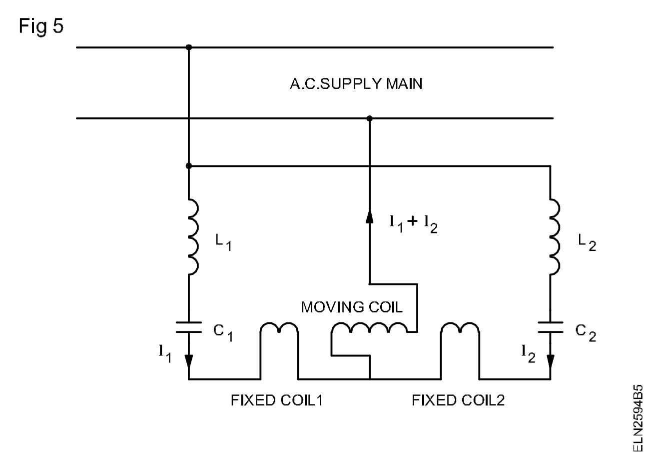
The reed type frequency meter has the following advantages.

The indications are independent of i) the wave form of the applied voltage and ii) magnitude of the applied voltage, provided that the voltage is not too low. At a low voltage the flag indication of the reed will not be reliable.

The disadvantages are the meter cannot read closer than half the cycle frequency difference between adjacent reeds and the accuracy greatly depends upon the proper tuning of the reeds.

Electrical resonance frequency meter - Electro dynanometer type

Construction: This meter consists of two fixed coils and one moving coil, connected to the supply mains (Fig 5). The fixed coil (1) is connected to the mains through a resonant circuit consisting of an inductor L_1 and a capacitor C_1. Similarly the fixed coil (2) is connected to the resonant circuit consisting of the inductor L_2 and the capacitor C_2.



The resonant circuit of the fixed coil (1) is tuned for a frequency f_1 and say 45 Hz, which is lower than the tuned frequency f_2, say, 60Hz of the fixed coil 2. The moving coil carries the vector sum of current I_1 and I_2 of the two fixed coils.

Working: When the meter is connected to the supply, whose frequency is to be measured, the fixed coils carry out of phase currents, depending upon the magnitude of the frequency. For example, at 50Hz supply frequency, the current in the fixed coil (1) will be inductive (lagging current as its resonant frequency is lower than 50Hz) and the current in fixed coil (2) will be capacitive (leading current as its resonant frequency is higher than 50Hz).

At this instant, the inductive current in the fixed coil (1) and the capacitive current in the fixed coil (2) will have the same magnitude but will have opposite phases. Hence, they will cancel each other, and no current flows through the moving coil, resulting in no torque.

The pointer, therefore, will be at the centre position where 50Hz is marked on the dial. At frequencies lower than 50Hz, the movement of the pointer is influenced by the current in the fixed coil (1) and shows correspondingly by lower frequencies, and at frequencies higher than 50Hz, the pointer is influenced by the current in the fixed coil (2) and shows correspondingly higher frequencies.

This meter has a small iron vane mounted in the moving system for producing the controlling torque.

Advantages: The scale of the instrument spreads to about 90°and can be used for power frequency measurements.

DIsadvantages: The frequency range of the instrument is limited by the values of L and C.

Ratiometer type frequency meter

Construction: This meter has a frequency dial on which a pointer moves to indicate the frequency. It has two moving coils X and Y, fixed at right angles to each other, mounted on a spindle and kept between the strong field of a permanent magnet (Fig 6).

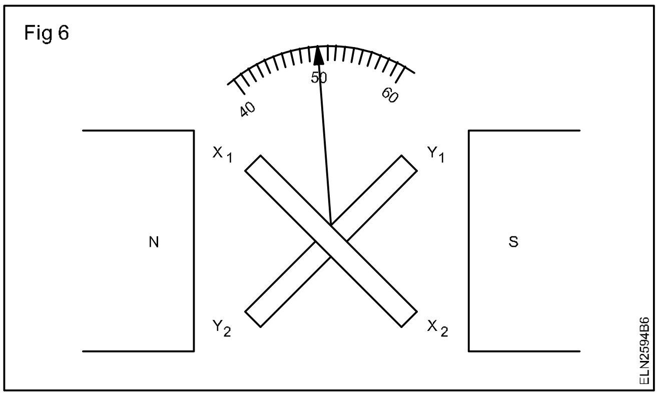
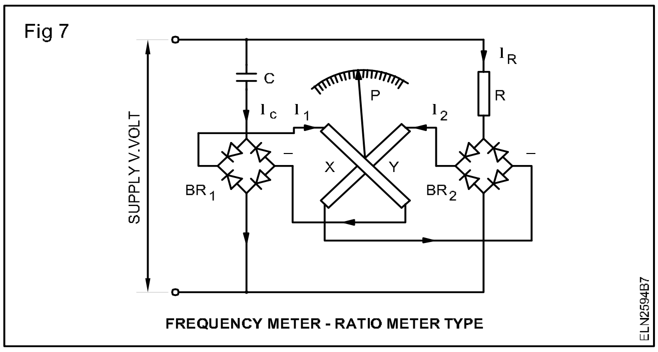


Figure 7 shows the circuit connections of the ratiometer type frequency meter.

The moving coils X and Y are connected to the supply through their respective rectifiers and passive components (Fig 7). The direct current I_1 flowing through 'X' represents the R.M.S. value of the capacitor current I_c as rectified by BR_1, in the same way, the current I_2 flowing through 'Y' represents the RMS value of the resistance current I_R as rectified by BR_2.



Working: The current through the coil depends upon the supply frequency. At higher frequency, the current through the coil X is higher whereas the current through coil `Y' is independent of the frequency. The torque developed in the coil depends upon the interaction between the permanent magnetic field and the resultant field created by the coil currents.

The coils 'X' and 'Y' will exert almost equal torque at the predetermined supply frequency making the pointer to be at the centre of the scale where the supply frequency is marked. On the other hand, at higher frequencies the increased current in coil 'X' produces more torque and moves the pointer to a higher frequency position of the dial or vice versa.

Advantages:

This meter has the following advantages.

- It has a linear scale.
- The meter is independent of the supply voltage and, hence, is used for a fairly wide range of voltages.

Disadvantages

As the values of the capacitor 'C' and the resistor 'R' decide the range of frequency to be measured, this meter cannot be used for a wide range of frequencies, unless a set of C and R values are selected through a range switch.

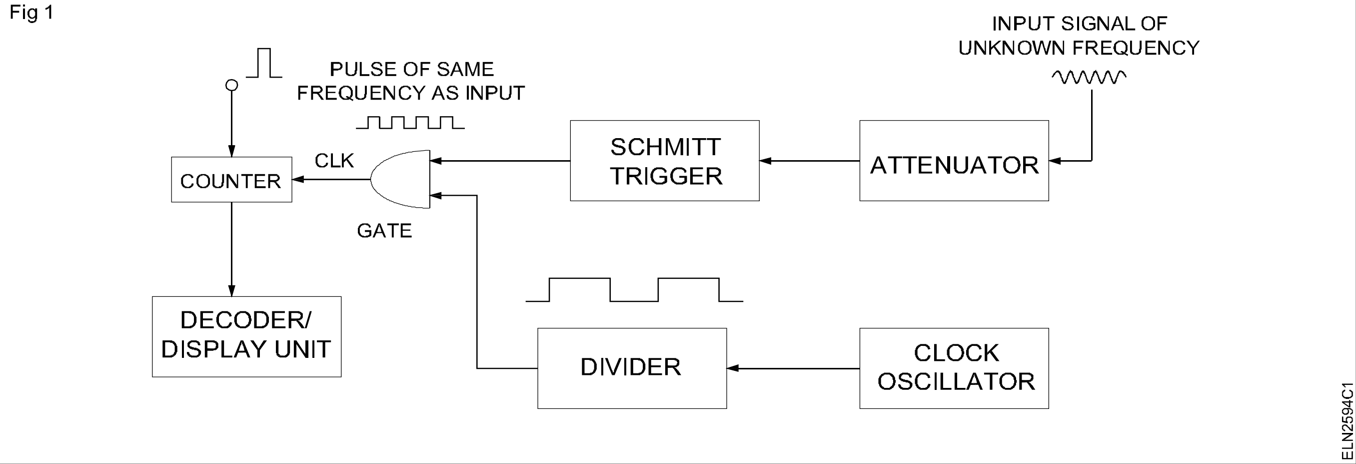
Digital Frequency Meter

Objectives: At the end of this lesson you shall be able to
- **state the function of digital frequency meter**
- **describe the block diagram of digital frequency meters.**

A frequency counter is a digital instrument that can measure and display the frequency of any periodic waveform. It operates on the principle of gating the unknown input signal into the counter for a predetermined time.

If the unknown input signal were gated into the counter for exactly 1 second, the number of counts allowed into the counter would be the frequency of the input signal. The term gated comes from the fact that an AND or an OR gate is employed for allowing the unknown input signal into the counter to be accumulated. Fig 1

Fig 1



Discription of block diagram:

The simplified form of block diagram of frequency counter is in Fig 1. It consists of a counter with its associated display/decoder circuitry, clock oscillator, a divider and an AND gate. The counter is usually made up of cascaded Binary Coded Decimal(BCD) counters and the display/ decoder unit converts the BCD outputs into a decimal display for easy monitoring.

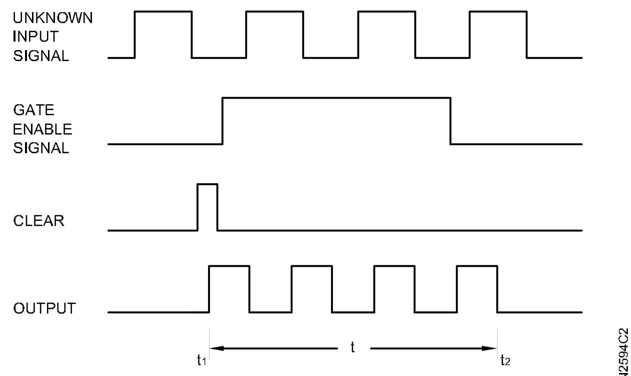
A GATE ENABLE signal of known time period is generated with a clock oscillator and a divider circuit and is applied to one leg of an AND gate.

The unknown signal is applied to the other leg of the AND gate and acts as the clock for the counter. The counter advances one count for each transition of the unknown signal, and at the end of the known time interval, the contents of the counter will be equal to the number of periods of the unknown input signal that have occurred during time interval, t.In other words, the counter contents will be proportional to the frequency of the unknown input signal.

For instance if the gate signal is of a time of exactly 1 second and the unknown input signal is a 600-Hz square wave, at the end of 1 second the counter will counts up to 600, which is exactly the frequency of the unknown input signal

The wave form in Fig 2 shows that a clear pulse is applied to the counter at t_0 to set the counter at zero. Prior to t_1, the GATE ENABLE signal is LOW, and so the output of the AND gate will be LOW and the counter will not be counting. The GATE ENABLE goes HIGH from t_1 t_0 t_2 and during this time interval $t=(t_2 - t_1)$ the unknown input signal pulses will pass through the AND gate and will be counted by the counter

Fig 2



DIFFERENT WAVEFORMS IN A FREQUENCY COUNTER

After t_2, the AND gate output will be again LOW and the counter will stop counting. Thus, the counter will have counted the number of pulses that occurred during the time interval, t of the GATE ENABLE SIGNAL, and the resulting contents of the counter are a direct measure of the frequency of the input signal

Power factor meter

Objectives: At the end of this lesson you shall be able to
- **state the disadvantage of the indirect method of measuring power factor**
- **state the different types of power factor meters**
- **explain the construction and connection of 3-phase dynamometer type power factor meter**
- **explain the construction, connection and operation of a 3-phase moving iron type power factor meter**
- **explain the construction, connection and operation of a single phase moving iron type power factor meter.**

Power factor of a single phase AC circuit can be calculated by the formula

$$P.F. = \frac{Power}{EI}$$

provided an ammeter, a voltmeter and a wattmeter are connected to the circuit.

On the other hand, for measuring power factor in a balanced 3-phase circuit we have to use the formula

$$P.F. = \frac{3\text{-phase power}}{3E_{PH}I_{PH}} \text{ or } \frac{3\text{-phase power}}{\sqrt{3}E_L I_L}$$

However when the, 3-phase circuit is unbalanced, the above formula cannot be used.

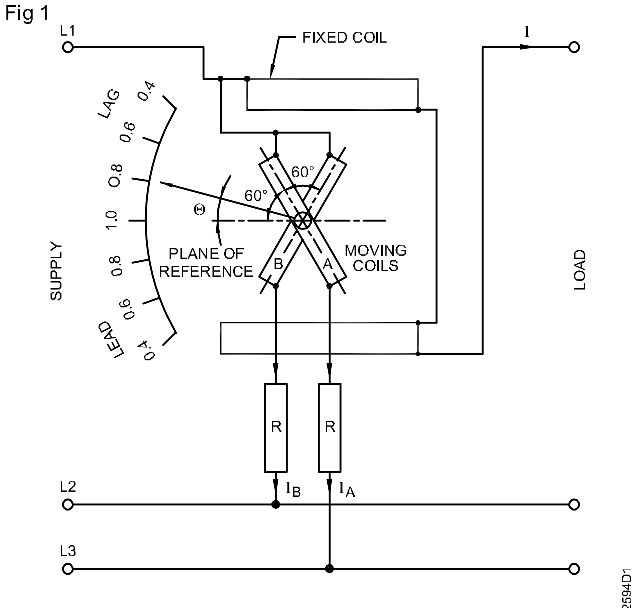
This indirect method has the following disadvantages.

- Low accuracy due to the number of meters
- Reading errors
- Cumbersome connections
- Involves calculation every time when the load changes and hence not suitable for changing load.

To get the instantaneous reading of the power factor, direct reading P.F. meters are used which are reasonably accurate.

3-phase dynamometer type power factor meter for balanced load: Fig 1 shows the construction and connections of a 3-phase power factor meter used for balanced loads.

Fig 1



DYNAMOMMETER TYPE THREE PHASE POWER FACTOR METER

In this meter, the field coils are connected in series with the load along with one phase. The two moving coils are rigidly attached to each other at an angle of 120°. These coils are connected to two different phases. A resistance is connected in series with each coil.

Phase splitting through reactance is not necessary since the required phase displacement between currents in the two moving coils can be obtained by the supply itself.

Operation of the meter is in the same way as in a single phase meter. However this meter is suitable only for balanced loads.

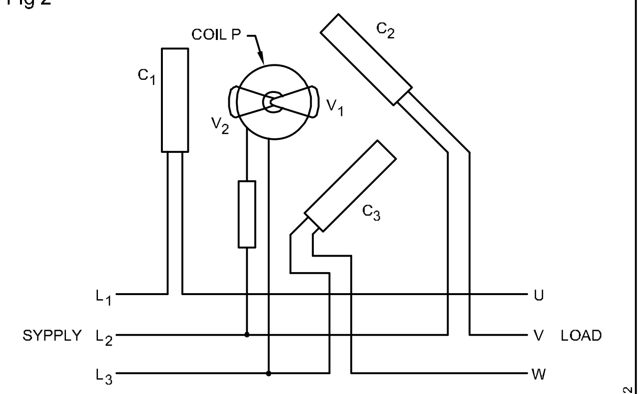
Since the currents in the two moving coils are both affected in the same way by any change in frequency or wave-form, this meter is independent of frequency and wave-form.

Moving iron power factor meters: This type of power factor meter is more popular than the dynamometer type due to the following advantages.

- Torque-weight ratio (working forces) is large compared to the dynamometer type meter.
- As all the coils are fixed there is no ligament connection necessary.
- The scale can be extended to 360°.
- This meter is simple and robust in construction.
- Comparatively cheaper in cost.

Fig 2 shows the construction and connection of a moving iron type power factor meter used for balanced loads.

Fig 2



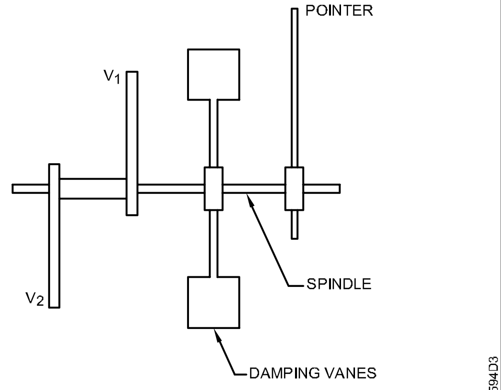
MOVING IRON TYPE POWER-FACTOR METER FOR A BALANCED 3-PHASE LOAD

There are three similar coils at C_1, C_2 and C_3 placed 120° degrees apart and connected to 3-phase supply directly (Fig 2) or through the secondary of the current transformers. Coil P is placed in the middle of the three coils C_1, C_2 and C_3 and connected in series with a resistance across two lines of the supply. Inside the coil B there are are two vanes V_1, and V_2 mounted at the ends of a freely moving spindle but kept at 180° to each other. The spindle also has damping vanes and the pointer (Fig 3).

The rotating magnetic field produced by the three coils C_1, C_2 and C_3 interacts with the flux produced by the coil P. This causes the moving system to take up an angular position depending upon the phase angle of the current.

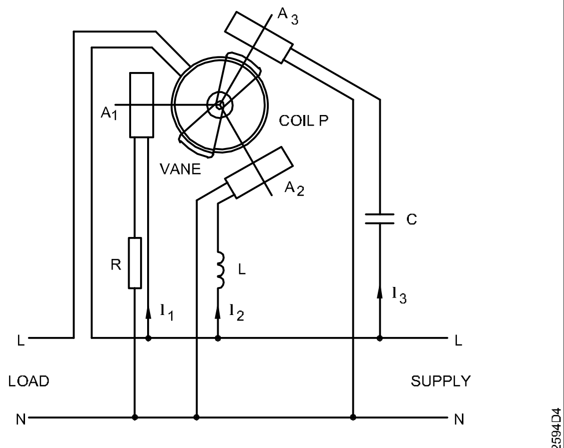
Single phase moving iron power factor meter: A single phase moving iron power factor meter (Fig 4) uses a phase splitting network comprising of a capacitor, an inductor and a resistor.

Fig 3



ARRANGEMENT OF THE SPINDLE

Fig 4



SINGLE PHAGE MOVING IRON TYPE POWER FACTOR METER

3-phase power factor meters for unbalanced load: For measurement of power factor in 3-phase unbalanced systems 2-element or 3-element power factor meters with each element with a current coil and pressure coil is used. The pressure coils are (moving coils) similar to that of single phase P.F. meters are mounted one below the other on a single spindle. The pointer shows the resultant power factor.

Low power factor meter: Power factor meters are generally available to read power factor from 0.5 lag-unity - 0.5 lead. Low power factor meters specially constructed to read power factor 0.0 lag to unity power factor are also used.

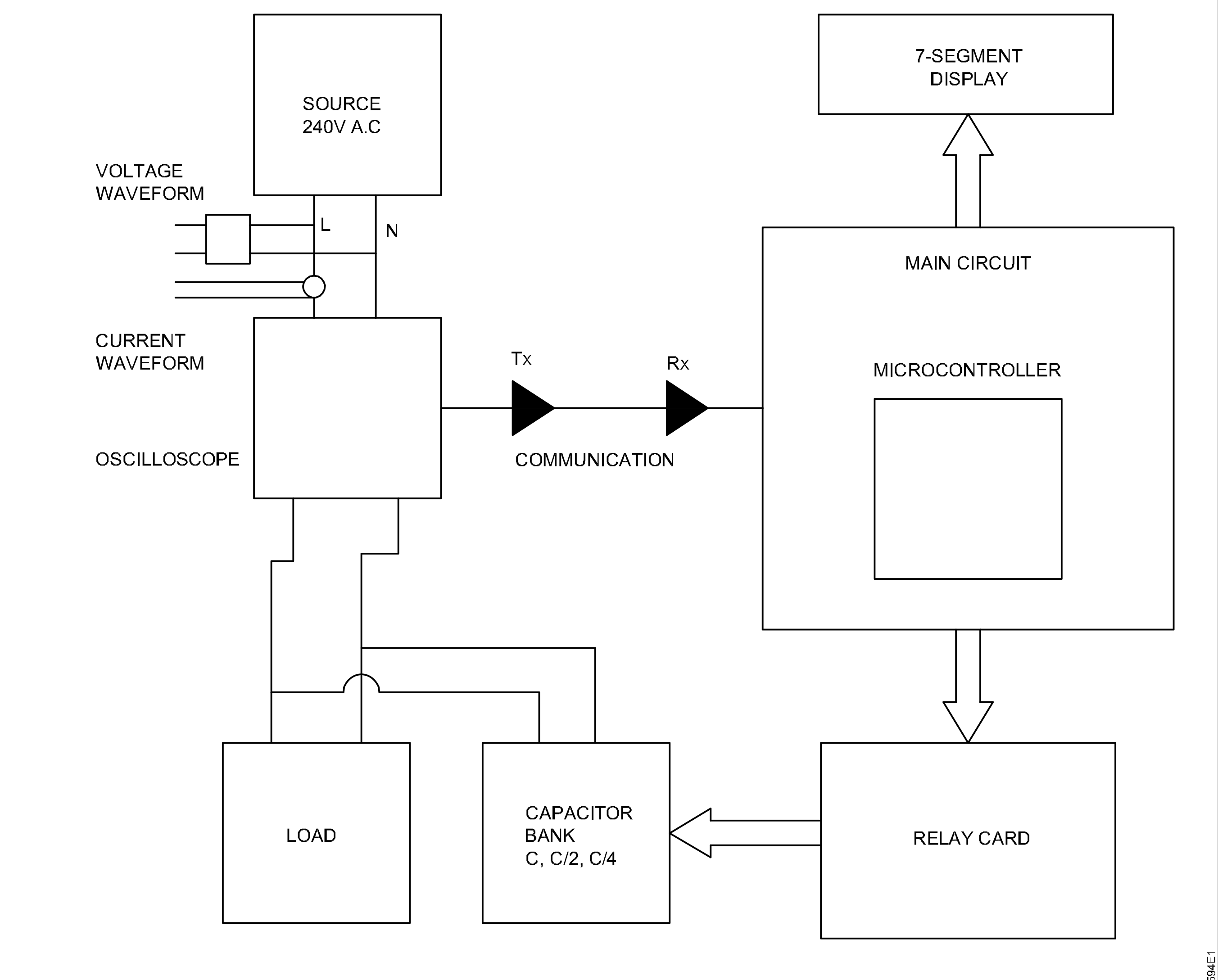
Digital Power Factor Meter

Objectives: At the end of this lesson you shall be able to
- **describe the block diagram of power factor**

Digital power factor meter:

The Fig 1 Shows the block diagram of digital power factor meter.

Fig 1



BLOCK DIAGRAM OF APFC

The power factor meter is used to calculate the present power factor of the system. The power factor is corrected using the true power technique. The power factor value so obtained is communicated to the microcontroller via the pins TX and RX.

The program fed to the microcontroller then analyses the power factor. The power factor gets displayed on the 7 segment display connected to the microcontroller. If the power factor is above the pre-set value, then no action in microcontroller and the relays will remain in their normal positions of NO and NC. Once the power factor lowers to a value below the pre-set mark, the signal is sent to relay card

The relay card consists of relays along with LED's for detecting the operation of relays. The input to relays is sent via an opto-coupler and then through a current amplifier before it reaches the relay. The particular relay operates and connects the respective capacitor bank to it. The operates and connects the respective capacitor bank to it. The operation of relay is detected by the LED thereby leading to emission of light from the LED

The microcontroller has been programmed in such a way that out of the three relays, it will make the relay or combination of relays in such a way that the capacitor banks are included which correct the power factor in the best possible way to the best possible value. The capacitor banks are preset as C, C/2 and C/4, which have been created using series combinations of capacitors of value C.

A long with these, a current transformer and a voltage transformer have been provided so as to analyse the particular wave forms at different instants of time with the help of an oscilloscope. The image of the digital PF meter is shown in Fig 2

Fig 2

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Measurement of 3 phase power by single and two wattmeters

Objectives: At the end of this lesson you shall be able to
- **explain the measurement 3 phase power using single wattmeter**
- **explain the measurement of 3 phase power using two wattmeters**
- **calculate the power factor by two wattmeter method power measurement.**

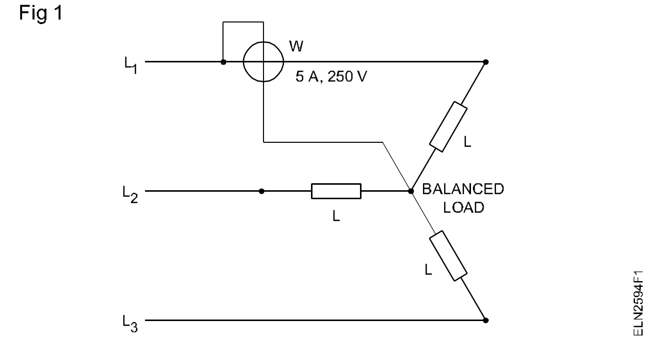
The measurement of power: The number of wattmeters used to obtain power in a three-phase system depends on whether the load is balanced or not, and whether the neutral point, if there is one, is accessible

- Measurement of power in a star-connected balanced load with neutral point is possible by a single wattmeter
- Measurement of power in a star or delta-connected, balanced or unbalanced load (with or without neutral) is possible with two wattmeter method

Single wattmeter method: Fig 1 shows the circuit diagram to measure the three-phase power of a star-connected, balanced load with the neutral point accessible the current coil of the wattmeter being connected to one line, and the voltage coil between that line and neutral point. The wattmeter reading gives the power per phase. So the total is three times the wattmeter reading.

$P = 3E_P I_P \cos\varphi = 3P = 3W$

Fig 1



The two wattmeter method of measuring power

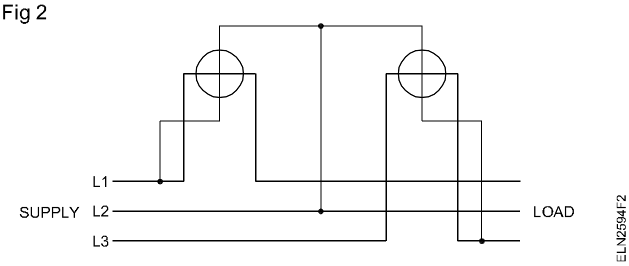
Power in a three-phase, three-wire system is normally measured by the `two-wattmeter' method. It may be used with balanced or unbalanced loads, and separate connections to the phases are not required. This method is not, however, used in four-wire systems because current may flow in the fourth wire, if the load is unbalanced and the assumption that $I_U + I_V + I_W = 0$ will not be valid.

The two wattmeters are connected to the supply system (Fig 2). The current coils of the two wattmeters are connected in two of the lines, and the voltage coils are connected from the same two lines to the third line. The total power is then obtained by adding the two readings:

$$P_T = P_1 + P_2.$$

Consider the total instantaneous power in the system $P_T = P_1 + P_2 + P_3$ where P_1, P_2 and P_3 are the instantaneous values of the power in each of the three phases.

Fig 2



$$P_T = V_{UN}\, i_U + V_{VN}\, i_V + V_{WN}\, I_W$$

Since there is no fourth wire, $i_U + i_V + i_W = 0$; $i_V = -(i_U + i_W)$.

$$P_T = V_{UN} i_U - V_{VN}(i_U + i_W) + V_{WN}\, i_W$$
$$= i_U(V_{UN} - V_{VN}) + i_W(V_{WN} - V_{UN})$$
$$= i_U V_{UV} + i_W V_{WV}$$

Now $i_U V_{UV}$ is the instantaneous power in the first wattmeter, and $i_W V_{WV}$ is the instantaneous power in the second wattmeter. Therefore, the total mean power is the sum of the mean powers read by the two wattmeters.

It is possible that with the wattmeters connected correctly, one of them will attempt to read a negative value because of the large phase angle between the voltage and current for that instrument. The current coil or voltage coil must then be reversed and the reading given a negative sign when combined with the other wattmeter readings to obtain the total power.

At unity power factor, the readings of two wattmeter will be equal. Total power = 2 x one wattmeter reading.

When the power factor = 0.5, one of the wattmeter's reading is zero and the other reads total power.

When the power factor is less than 0.5, one of the wattmeters will give negative indication. In order to read the wattmeter, reverse the pressure coil or current coil connection. The wattmeter will then give a positive reading but this must be taken as negative for calculating the total power.

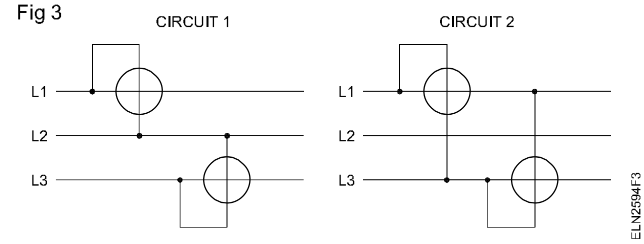
When the power factor is zero, the readings of the two wattmeters are equal but of opposite signs.

Self-evaluation test

1 Draw a general wiring diagram for the two-wattmeter method of three-phase power measurement.

2 Why is it desirable, in practice, to use the two-wattmeter method? (Fig 3)

Fig 3



3 Why can the two-wattmeter method not be used in a three-phase, four-wire system with random loading?

4 Which of the above circuits is used for the two-wattmeter method of power measurement?

Power factor calculation in the two -wattmeter of measuring power

As you have learnt in the previous lesson, the total power $P_T = P_1 + P_2$ in the two-wattmeter method of measuring power in a 3-phase, 3-wire system.

From the readings obtained from the two wattmeters, the tan ϕ can be calculated from the given formula

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}$$

from which ϕ and power factor of the load may be found.

Example 1: Two wattmeters connected to measure the power input to a balanced three-phase circuit indicate 4.5 KW and 3 KW respectively. Find the power factor of the circuit.

Solution

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)}$$

$P_1 = 4.5$ KW
$P_2 = 3$ KW
$P_1 + P_2 = 4.5 + 3 = 7.5$ KW
$P_1 - P_2 = 4.5 - 3 = 1.5$ KW

$$\tan\phi = \frac{\sqrt{3} \times 1.5}{7.5} = \frac{\sqrt{3}}{5} = 0.3464$$

$\phi = \tan^{-1} 0.3464 = 19^0 6'$

Power factor Cos $19^0 6'$ = 0.95

Example 2: Two wattmeters connected to measure the power input to a balanced three-phase circuit indicate 4.5 KW and 3 KW respectively. The latter reading is obtained after reversing the connection of the voltage coil of that wattmeter. Find the power factor of the circuit.

Soultion

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)}$$

$\phi = \tan^{-1} 8.66 = 83^o.27'$

since power factor (Cos $83^o 27'$) = 0.114.

Example 3: The reading on the two wattmeters connected to measure the power input to the three-phase, balanced load are 600W and 300W respectively.

Calculate the total power input and power factor of the load.

Solution

Total power = $P_T = P_1 + P_2$

$P_1 = 600$W.

$P_2 = 300$W.

$P_T = 600 + 300 = 900$

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(600 - 300)}{600 + 300} = \frac{\sqrt{3} \times 300}{900}$$

$$= \frac{\sqrt{3}}{3} = \frac{1}{\sqrt{3}} = 0.5774$$

$\phi = \tan^{-1} 0.5774 = 30^o$

Power factor = Cos 30^o = 0.866.

Example 4: Two wattmeters connected to measure the power input to a balanced, three-phase load indicate 25KW and 5KW respectively.

Find the power factor of the circuit when (i) both readings are positive and (ii) the latter reading is obtained after reversing the connections of the pressure coil of the wattmeter.

Solution

a P_1= 25 KW

P_2= 5 KW

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(25 - 5)}{25+5}$$

$$= \frac{\sqrt{3}\times 20}{30} = \frac{\sqrt{3}\times 2}{3} = \frac{2}{\sqrt{3}} = 1.1547$$

ϕ = $\tan^{-1}$ 1.1547 = 49°6'

Power factor (Cosϕ) = Cos 49°6' = 0.6547

b P_1= 25 KW

P_2= –5 KW

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)} = \frac{\sqrt{3}(25 - (-5))}{25+(-5)}$$

$$= \frac{\sqrt{3}\ (25+5)}{25-5} = \frac{\sqrt{3}\times 30}{20}$$

$$= \frac{\sqrt{3}\times 3}{2} = 2.5980$$

ϕ = $\tan^{-1}$ 2.5980= 68°57'

Power factor = Cos 68° 57' = 0.3592