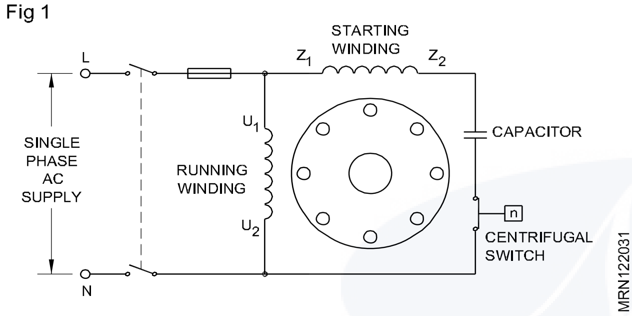
Capacitor-start, induction-run motor

Objectives: At the end of this lesson you shall be able to
- **explain with a diagram the working of an AC single phase, capacitor-start, induction-run motor**
- **explain the characteristic and application of a capacitor- start, induction-run motor.**

A drive which requires a higher starting torque may be fitted with a capacitor-start, induction-run motor as it has excellent starting torque as compared to the resistance-start, induction-run motor.

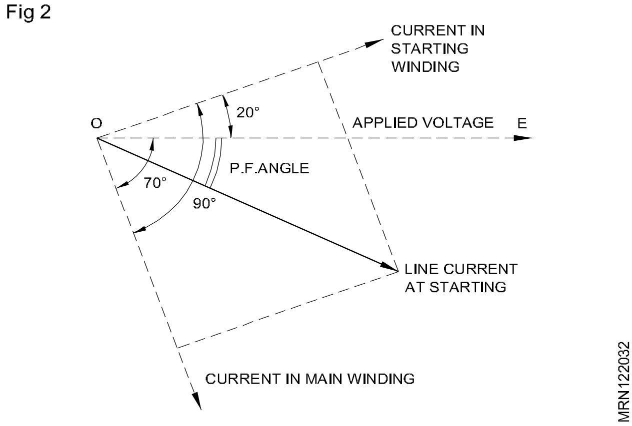
Construction and working: Fig 1 shows the schematic diagram of a capacitor-start, induction-run motor. As shown, the main winding is connected across the main supply, whereas the starting winding is connected across the main supply through a capacitor and a centrifugal switch. Both these windings are placed in a stator slot at 90° electrical degrees apart, and a squirrel cage type rotor is used.

Fig 1



As shown in Fig 2, at the time of starting, the current in the main winding lags the supply voltages by about 70° degrees, depending upon its inductance and resistance. On the other hand, the current in the starting winding due to its capacitor will lead the applied voltage, by say 20° degrees.

Fig 2



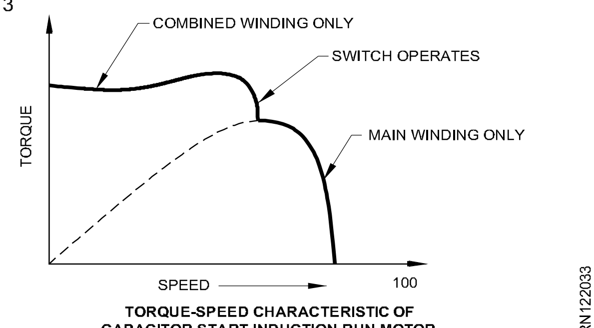
Hence, the phase difference between the main and starting winding becomes near to 90 degrees. This in turn makes the line current to be more or less in phase with its applied voltage, making the power factor to be high, thereby creating an excellent starting torque.

However, after attaining 75% of the rated speed, the centrifugal switch operates opening the starting winding, and the motor then operates as an induction motor, with only the main winding connected to the supply.

Reversing the direction of rotation: In order to reverse the direction of rotation of the capacitor start, induction-run motor, either the starting or the main winding terminals should be changed. This is due to the fact that the direction of rotation depends upon the instantaneous polarities of the main field flux and the flux produced by the starting winding. Therefore, reversing the polarity of any one of the fields will reverse the torque.

Characteristic: As shown in Fig 2, the displacement of current in the main and starting winding is about 80/90 degrees, and the power factor angle between the applied voltage and line current is very small. This results in producing a higher power factor and an excellent starting torque, several times higher than the normal running torque, as shown in Fig 3. The running torque adjusts itself with load by varying inversely with respect to speed as shown in the characteristic curve in Fig 3.

Fig 3



TORQUE-SPEED CHARACTERISTIC OF CAPACITOR START INDUCTION RUN MOTOR

Application: Due to the excellent starting torque and easy direction-reversal characteristic, these machines are used in belted fans, blowers, dryers, washing machines, pumps and compressors.

Capacitors used in single phase capacitor motors

Objectives: At the end of this lesson you shall be able to
- **state the precautions to be followed while using a capacitor in a single phase capacitor motor**
- **explain the methods of testing capacitors.**

A capacitor is a device which can store electrical energy in the form of electrostatic charge. However the main purpose of the capacitor in the single phase motors is to split the phase for producing the rotating magnetic field.

In addition, they also draw the leading current, thereby improving the power factor.

Precautions to be followed while using a capacitor in a single phase capacitor motor: Paper or electrolytic capacitors of non-polarized types are used for starting AC capacitor type motors. These capacitors have special marking for use in AC circuits, and will not have polarity marking. Paper or electrolytic capacitors for use in DC circuits have polarity markings. They must not be used in AC circuits as the reversal of AC voltage will heat up the capacitor, producing enormous gas inside the can, thereby blowing it into pieces.

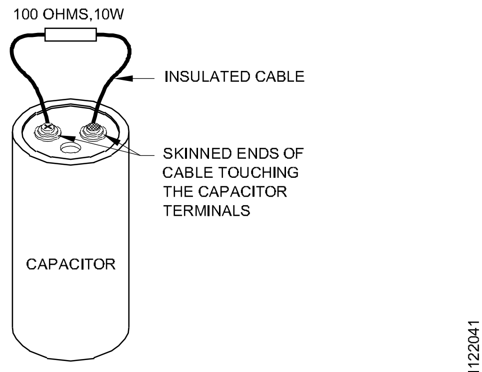
The AC voltage rating inscribed on the capacitor will have two ratings. One for working voltage and another for the maximum value of voltage. Working voltage refers to the normal R.M.S. rating of the supply mains while the maximum rating will be AC peak voltage which will be $\sqrt{2}$ times the rated R.M.S. voltage. Hence, while replacing a capacitor, a careful scrutiny of voltage rating is essential, as otherwise the capacitor may fail and may also explode.

The duty cycle is another important point to be checked. In most of the capacitors, the marking will indicate whether it is for intermittant (short duty) or continuous (long duty) rating. Though continuous rated capacitors can be used for intermittant rating, never an intermittant (short duty) rating capacitor should be used for continuous rating. This has some relation with the centrifugal switch operation, frequency of starting and stopping and load. When the load is heavy or the centrifugal switch is not proper, there will be a chance for the starting winding, along with the capacitor, to be in the main circuit for a long time. In such cases the capacitor, which is intermittant rated, will fail due to overheating. This should be checked when the capacitor fails often in a specified capacitor-start motor.

The capacity of the capacitor, which is given in microfarads, should be the same as is specifed by the manufacturer of the motor. A lower value will result in poorer starting torque and high starting currents, whereas a higher rating may not allow the speed to reach the rated value resulting in the starting winding to be in main line for a long time there by ending in poor operation and efficiency. In capacitor-start, capacitor-run motors, there will be two capacitors. As the starting capacitor will be 5 to 15 times of the rating of the running capacitor, and will also be of intermittant-rated electrolytic type, when compared to the running capacitor, which will be of continuous-rated, oil-filled type. Due care should be taken while connecting these capacitors in the motor, avoiding wrong selection and connection.

While handling a capacitor, due care should be taken to avoid shocks. A good capacitor can hold its charge for several days, and when touched, may give a severe shock. Hence, before touching any terminal of the capacitor, which is in use, the electrical charge should be discharged through a test lamp or through a 100 ohms 10 watts resistor as shown in Fig 1. Direct shorting of the capacitor terminals for discharging should be avoided as far as possible as this results in creating an enormous strain to the inner parts of the capacitor and it may fail.

Fig 1

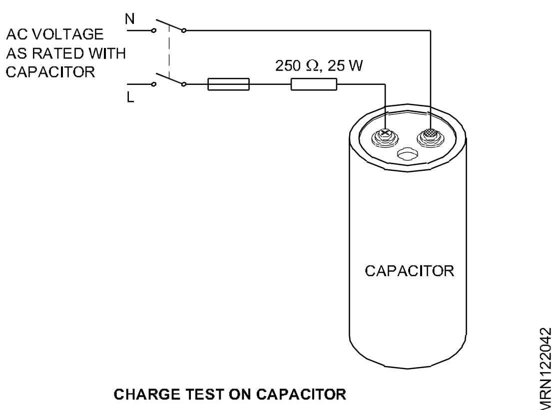


METHOD OD DISCHARGING A CAPACITOR

Method of testing capacitors: Before removing a capacitor from the motor connection for testing, it should be discharged to avoid fatal shocks. The following methods are recommended for testing the large value paper, electrolytic or oil-filled capacitors.

Charge-discharge test: Check the working voltage indicated on the capacitor. If the value is equal or more than that of the usual, single phase voltge, say 230V AC 50 Hz, we can connect it to the supply through a 100 ohms, 25 watts resistor as shown in Fig 2. Preferably, keep the capacitor, while testing on line voltage, inside a covered cardboard box or in a wooden box. Sometimes, if the capacitor is defective, it may explode and cause injury to you. Switch on the circuit for about 3-4 seconds. Then switch `OFF' the supply, and remove the supply terminals carefully with the help of an insulated pliers, without touching the capacitor terminals. Then, short the capacitor terminals with the help of a screwdriver. A bright spark is an indication that the capacitor is working. A dull spark or no spark indicates the capacitor is weak or open. On the other hand, no sparks while touching with the supply terminals indicate that the capacitor is opened. In the case of low capacity capacitors, the spark will be very feeble even if the capacitor is in good condition. Further, this check or the ohmmeter test described in the next para, does not indicate the de-rated value of the capacitor. Hence a capacity check is necessary as will be explained later.

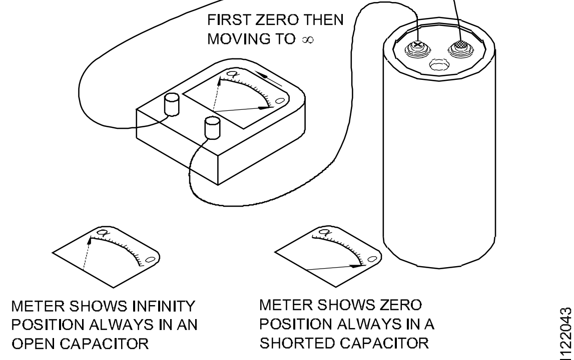
Fig 2



CHARGE TEST ON CAPACITOR

Ohmmeter test: Before using the ohmmeter, the capacitor should be thoroughly discharged to avoid damage to the ohmmeter. Set the range of the ohmmeter to resistance and adjust to zero ohms. Touch the terminals of the capacitor and watch the deflection of the meter. If the needle deflects towards zero and then moves towards infinity, the capacitor is working. Reverse the test leads and test it again, the needle will do the same thing again in a good capacitor. If the capacitor is open, the needle will not go to zero position but will remain in infinity side. On the other hand, in a shorted capacitor, the needle will be in zero position but will not go to infinity side at all. These results are illustrated in Fig 3.

Fig 3

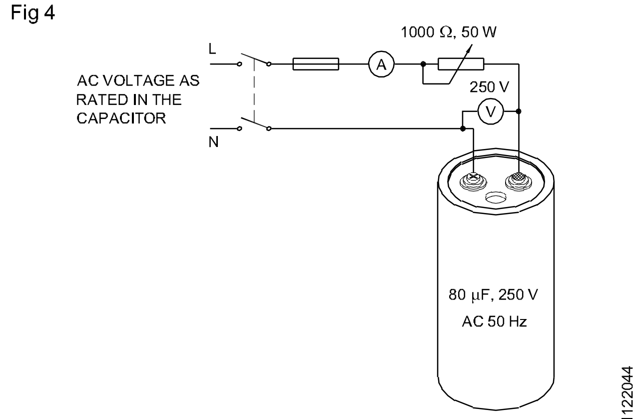


TESTING A CAPACITOR WITH A MULTIMETER

Capacity test: Connection should be as shown in Fig 4. Keep the resistance value maximum at the time of switching `on' to protect the ammeter. Keep the capacitor inside a cardboard or wooden box to avoid injury in case of explosion. The ammeter (I) and voltmeter (V) readings are to be taken when the resistor is completely cut out from the circuit. From the meter readings, the capacity rating of the capacitor in microfarads can be calculated.

If the capacity is 20 percent more or less than the notified value, replace it.

Fig 4



CAPACITY TEST ON CAPACITOR

Capacity of capacitor in CF Farad $= \dfrac{I}{2\pi FV}$

Capacity in microfarad $C_{mf} = \dfrac{I \times 10^6}{2\pi FV}$

$= \dfrac{3182 \times I}{V}$ microfarads.

Insulation test on capacitors: According to BIS 1709-1984 recommendations, the insulation test conducted between the shorted capacitor terminals and the metal can, when measured by a 500V megger/insulation tester, should not be less than 100 megohms. If the can is of insulating material, the measurement could be made between the capacitor terminals and the metal strap holding the can.

Capacitor-start, capacitor-run motor

Objectives: At the end of this lesson you shall be able to
- **distinguish between the single and two-value, capacitor-start, capacitor-run motors**
- **draw the schematic diagram of a permanent capacitor motor, state its characteristic and use**
- **draw the schematic diagram of a capacitor-start, capacitor-run motor, state its characteristic and use.**

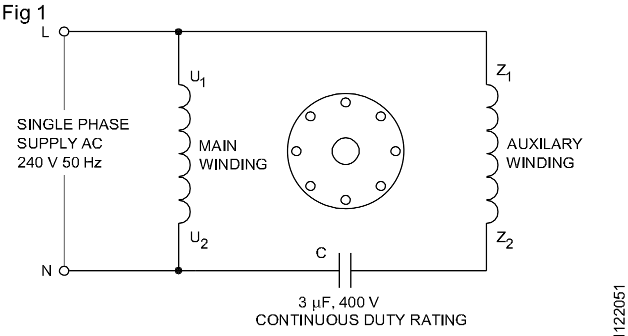
Capacitor-start, capacitor-run motors are of two types as stated below.

– Permanent capacitor motor (Single value capacitor motor)

– Capacitor-start, capacitor-run motor (Two-value capacitor motor)

Permanent capacitor motor: This type of motor is shown in Fig 1 which is most commonly used in fans. This motor is preferred in drives where the starting torque is not required to be high, while at the same time elimination of the centrifugal switch in the motor is necessary for easy maintenance. The capacitor is connected in series with the auxiliary winding, and remains so throughout the operation. These capacitors should be of oil-type construction and have continuous duty rating.

Fig 1

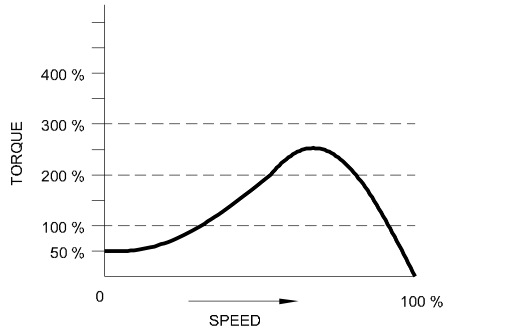


CIRCUIT DIAGRAM OF PERMANENT CAPACITOR MOTOR

To avoid low efficiency, the capacity of the condensers is kept low, which, in turn, brings down the starting torque to about 50 to 80% of the full-load torque.

The torque-speed characteristic of the motor is shown in Fig 2. This motor works on the same principle as the capacitor-start, induction-run motor with low starting torque but with higher power factor, during starting as well as in running.

Fig 2



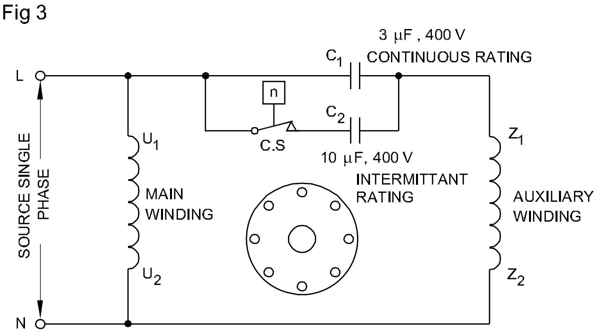
TORQUE-SPEED CHARACTERISTIC OF PERMANENT CAPACITOR MOTOR

This motor is most suitable for drives, which require a lower torque during start, easy changes in the direction of rotation, stable load operation and higher power factor during operation. *Examples* - fans, variable rheostats, induction regulators, furnace control and arc welding controls. This motor is cheaper than the capacitor-start, induction-run motor of the same rating.

Capacitor-start, capacitor-run motors: As discussed earlier capacitor-start, induction-run motors have excellent starting torque, say about 300% of the full load torque, and their power factor during starting is high. However, their running torque is not good, and their power factor, while running, is low. They also have lesser efficiency and cannot take overloads.

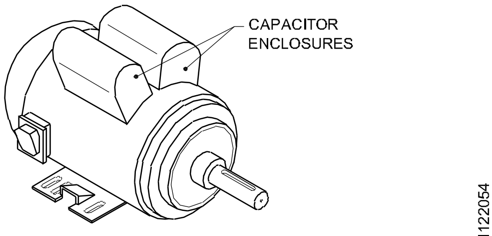
These problems are eliminated by the use of a two-value capacitor motor in which one larger capacitor of electrolytic (short duty) type is used for starting, whereas a smaller capacitor of oil-filled (continuous duty) type is used for running, by connecting them with the starting winding as shown in Fig 3. A general view of such a two-value capacitor motor is shown in Fig 4. This motor also works in the same way as a capacitor-start induction-run motor, with the exception, that the capacitor C1 is always in the circuit, altering the running performance to a great extent.

Fig 3



SCHEMATIC DIAGRAM OF A CAPACITOR-START CAPACITOR-RUN MOTOR

Fig 4



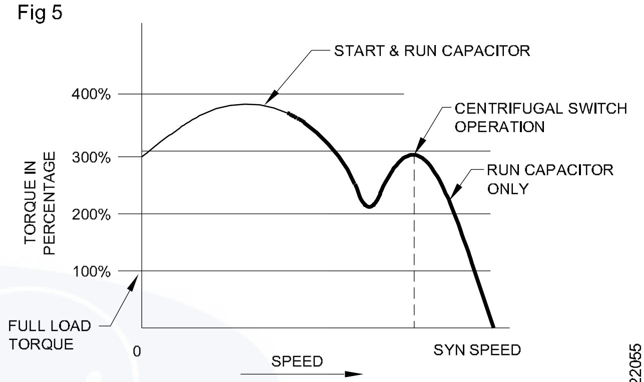
CAPACITOR-START CAPACITOR-RUN MOTOR

The starting capacitor which is of short-duty rating will be disconnected from the starting winding with the help of a centrifugal switch, when the starting speed attains about 75% of the rated speed.

Characteristic

The torque-speed characteristic of this motor is shown in Fig 5. This motor has the following advantages.

Fig 5



TORQUE-SPEED CHARACTERSTIC OF CAPACITOR-START CAPACITOR-RUN MOTOR

- The starting torque is 300% of the full load torque.
- The starting current is low, say 2 to 3 times of the running current.
- Starting and running P.F. are good.
- Highly efficient running.
- Extremely noiseless operation.
- Can be loaded up to 125% of the full-load capacity.

Application

These motors are used for compressors, refrigerators, air-conditioners etc. where the duty demands a higher starting torque, higher efficiency, higher power factor and overloading. These motors are costlier than the capacitor-start, induction- run motors of the same capacity.

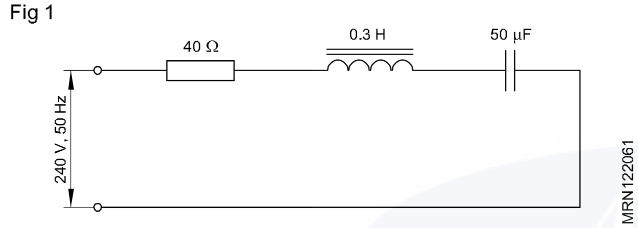
R L C series circuit

Objectives: At the end of this lesson you shall be able to
- **calculate the resulting reactance in the RLC series circuit**
- **calculate the impedance of the RLC series circuit.**

Assume an AC single phase circuit consisting a resistance, inductor and capacitor in series. Various parameters could be calculated as shown in the example.

Example *:* The value of the components shown in Fig 1 is R = 40 ohms L = 0.3 H and C = 50mf. The supply voltage is 240 V 50 Hz. Calculate the inductive reactance, capacitance reactance, net reactance, impedance, current in the circuit, voltage drops across the R, L and C power factor, active power, reactive power and apparent power. Also draw the impedance triangle, voltage triangle and power triangle.

Fig 1



Calculate the resulting reactance in RLC circuit : Inductance and capacitance have directly opposite effects in an AC circuit. The voltage drop caused by the inductive reactance of the coil leads the line current by 90°. The voltage drop across the inductor coil and the capacitor are 180 degrees apart and oppose each other. To calculate the net reactance in the above example:

Inductive reactance

$$X = 2\pi fL = 314 \times 0.3 = 94.2\ \Omega$$

Capactive reactance

$$X = \frac{1}{2\pi fC} = \frac{1}{314 \times 0.00005} = \frac{1}{0.0157} = 63.69\ \Omega$$

Net reactance $= X_L - X_C = 94.2 - 63.69 = 30.51\ \Omega$

Calculate the impedance: From the circuit given above the impedance can be found. The impedance is the resultant combination resistance and reactance. In this circuit, the impedance is the combination of the 40 ohms resistance and 30.51 W resultant reactance. The impedance for this circuit is

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{40^2 + 30.51^2}$$

$$= \sqrt{1600 + 930.86} = \sqrt{2530.86} = 50.30\ \Omega$$

Power and power factor in AC single phase system

Objectives: At the end of this lesson you shall be able to
- **state the relationship between power and power factor in single phase circuits**
- **state the principle and function of AC single phase wattmeter(dynamometer type).**

The power in a DC circuit can be calculated by using the formulae.

- P = E x I watts
- P = E^2/R watts.

The use of the above formulae in AC circuits will give true power only if the circuit contains pure resistance. Note that the effect of reactance is present in AC circuits.

Power in AC circuit: There are three types of power in AC circuits.

- Active power (True power)
- Reactive power
- Apparent power

Active power (True power)**:** The calculation of active power in an AC circuit differs from that in a direct current circuit. The active power to be measured is the product of V x I x Cos q where Cos q is the power factor (cosine of the phase angle between current and voltage). This indicates that with a load which is not purely resistive and where the current and voltage are not in phase, only that part of the current which is in phase with the voltage will produce power. This can be measured with a wattmeter.

Reactive power: With the reactive power (wattless power)

P_q = V x I x Sin q

only that part of the current which is 90° out of phase (90° phase shift) with the voltage is used in this case. Capacitors and inductors, on the other hand, alternatively store energy and return it to the source. Such transferred power is called reactive power measured in volt/ampere reactive or vars. Unlike true power, reacitve power can do no useful work.

Apparent power: The apparent power, P_a = V x I.

The measurement can be made in the same way as for direct current with a voltmeter and ammeter.

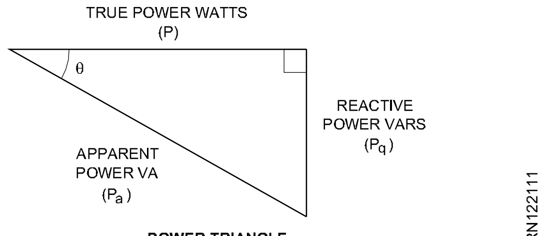
It is simply the product of the total applied voltage and the total circuit current and its unit is volt-ampere (VA).

The power triangle: A power triangle identifies three different types of power in AC circuits.

- True power in watts (P)
- Reactive power in vars (P_q)
- Apparent power VA (P_a)

The relationship among the three types of power can be obtained by referring to the power triangle. (Fig 1)

Fig 1



POWER TRIANGLE

Therefore

$P_a^2 = P^2 + P_q^2$ volt-amperes (VA)

where `P_a' is the apparent power in volt-ampere (VA)

`P' is the true power in watts (W)

P_q is the reactive power in volt-amperes reactive. (VAR)

Wattmeter

A power measuring meter, called a wattmeter, can be connected into a circuit to measure power instead of making two measurements and then calculating the power. The power dissipated can be read directly from the scale of the meter.

The wattmeter takes the power factor of the circuit into account and always indicates true power.

Principle: A wattmeter consists of two stationary coils connected in series, and one moving coil. (Fig 2) The stationary coils, wound with many turns of thick wire, have a low resistance. The moving coil. (Fig 2) wound with many turns of fine wire, has high resistance. For power measurements, the moving coil is connected across the source voltage with a series resistance of high value which determines the current through this coil in phase and proportional to voltage. The fixed coil is connected in series with the load, which can carry the load current.

The interaction of the two magnetic fields, produced by the fixed and moving coils, will cause the moving coil and its pointer to rotate in proportion to the voltage (across the load) and current (through the load).

Wattmeter types

- Dynamometer type
- Induction type
- Electrostatic type

Electro-dynamometer type wattmeter: The wattmeter has got four terminals, and they are marked as 'M' 'L' for the current coils and `V_1 V_2' for the pressure coils (Fig 3). Generally the current coil terminals 'M' and 'L' are thick in size compared to the pressure coil terminals 'V_1' and 'V_2'.

Fig 2

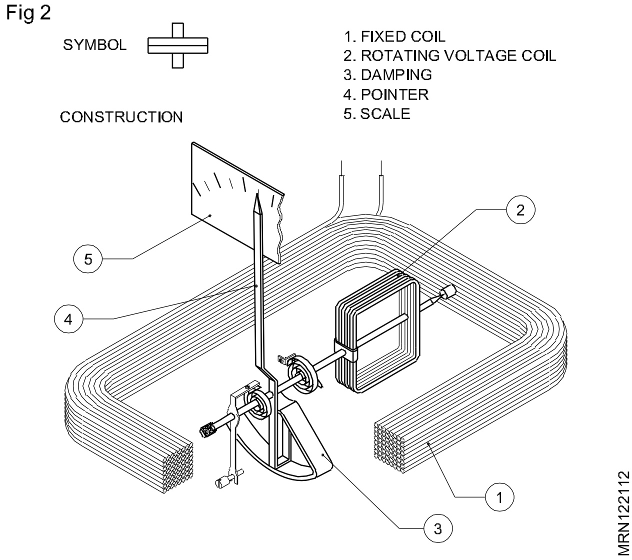
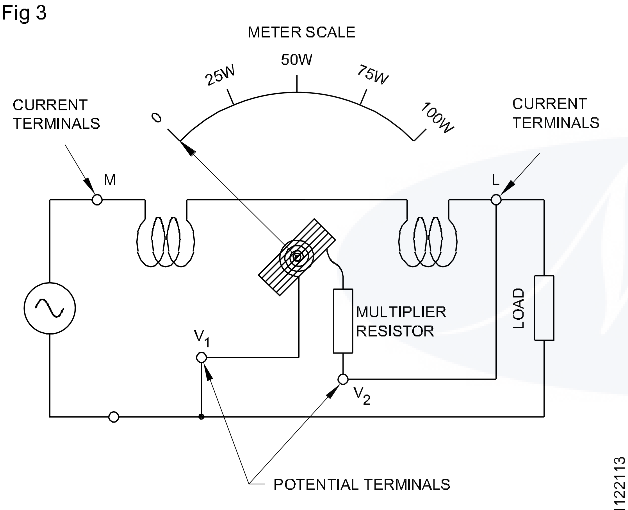


Fig 3



MOVEMENT USED AS A WATTMETER

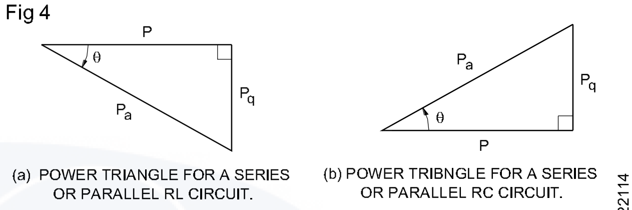
The dynamometer type of wattmeter can be used for both AC and DC power measurements, whereas the induction type wattmeter is used for AC power measurement only. The electrostatic type wattmeter is used for DC power measurements only.

Power factor: The ratio of the true power delivered to an AC circuit compared to the apparent power that the source must supply is called the power factor of the load. If we examine any power triangle (Fig 4), you may see the ratio of the true power to the apparent power is the cosine of the angle θ.

$$\text{Power factor} = \frac{P}{P_a} = \cos\theta$$

From the equation, you can observe that the three powers are related and can be represented in a right-angled power triangle, from which the power factor can be obtained as the ratio of true power to apparent power. For inductive loads, the power factor is called lagging to distinguish it from the leading power factor in a capacitive load. (Fig 4)

Fig 4



(a) POWER TRIANGLE FOR A SERIES OR PARALLEL RL CIRCUIT.

(b) POWER TRIBNGLE FOR A SERIES OR PARALLEL RC CIRCUIT.

POWER TRIANGLES SHOWING THAT $\frac{P}{P_a}$=COS θ

A circuit's power factor determines how much current is necessary from the source to deliver a given true power. A circuit with a low power factor requires a higher current than a unity power factor circuit.

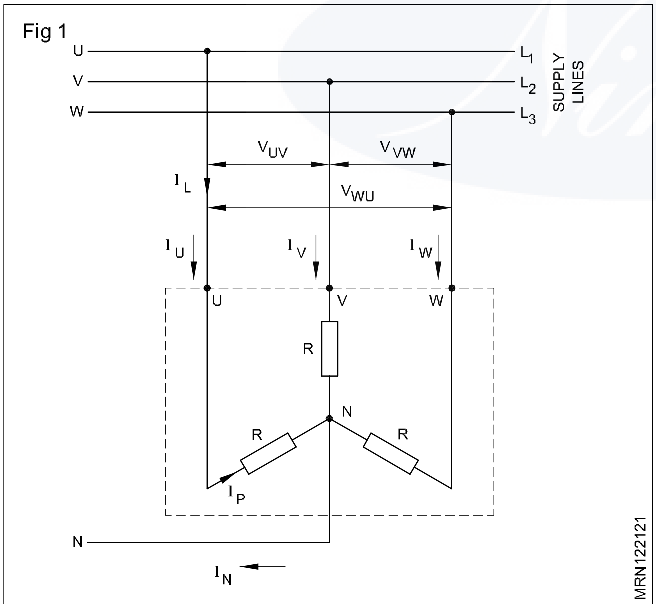
Systems of connection in 3-phase AC

Objectives: At the end of this lesson you shall be able to
- **explain the star and delta systems 1of connection**
- **state phase relationship between line and phase voltages in a star connection**
- **state and describe the relationship between phaseand line current in a star connection**
- **state the relationship between phase and line voltage in a delta connection**
- **state and describe the relationship between phase and line current in a delta connection.**

Methods of 3-phase connection: If a three-phase load is connected to a three-phase network, there are two basic possible configurations. One is `star connection' (symbol Y) and the other is `delta connection' (symbol D).

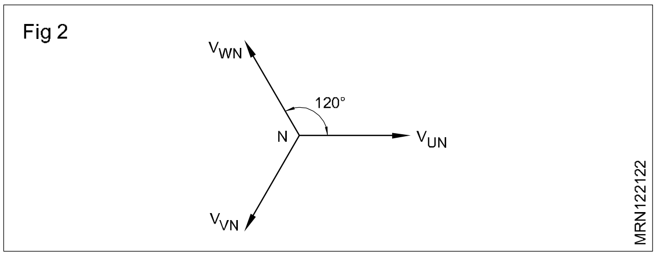
Star connection: In Fig 1 the three-phase load is shown as three equal magnitude resistances. From each phase, at any given time, there is a path to the terminal points U, V, W of the equipment, and then through the individual elements of the load resistance. All the elements are connected to one point N: the `star point'. This star point is connected to the neutral conductor N. The phase currents i_U, i_V, and i_W flow through the individual elements, and the same current flows through the supply lines, i.e. in a star connected system, the supply line current (I_L) = phase current (I_P).

Fig 1



The potential difference for each phase, i.e. from a line to the star point, is called the phase voltage and designated as V_P. The potential difference across any two lines is called the line voltage V_L. Therefore, the voltage across each impedance of a star connection is the phase voltage V_P. The line voltage V_L appears across the load terminals U-V, V-W and W-U and designated as V_{UV}, V_{VW} and V_{WU} in the Fig 2. The line voltage in a star-connected system will be equal to the phasor sum of the positive value of one phase voltage and the negative value of the other phase voltage that exist across the two lines.

Fig 2

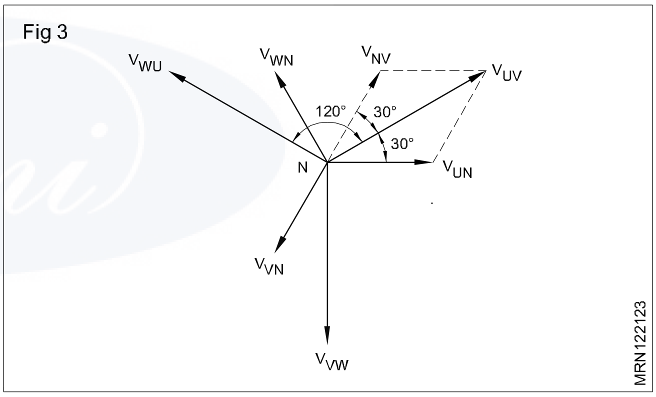


Thus

$$V_L = V_{UV} = (\text{phasor } V_{UN}) - (\text{phasor } V_{VN})$$
$$= \text{phasor } V_{UN} + V_{VN}.$$

In the phasor diagram (Fig 3)

Fig 3



$$V_L = V_{UV} = V_{UN} \text{ Cos } 30^o + V_{NV} \text{ Cos } 30^o$$

$$\text{But Cos } 30^o = \frac{\sqrt{3}}{2}.$$

$$\text{Thus as } V_{UN} = V_{VN} = V_P$$

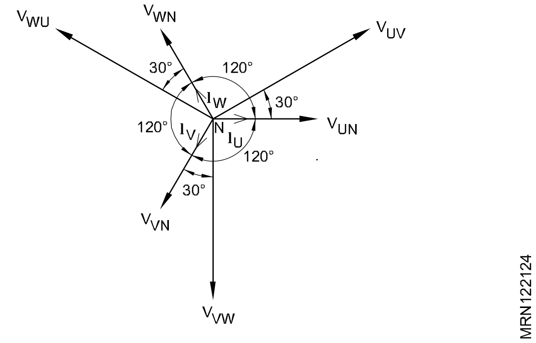
$$V_L = \sqrt{3}\ V_P.$$

This same relationship is applied to V_{UV}, V_{VW} and V_{WU}.

In a three-phase star connection, the line voltage is always $\sqrt{3}$ times the phase-to-neutral voltage. The factor relating the line voltage to the phase voltage is $\sqrt{3}$.

The voltage and current relationship in a star connection is shown in the phasor diagrams. (Fig 4) The phase voltages are displaced 120° in phase with respect to each other.

Fig 4



Derived from these are the corresponding line voltages. The line voltages are displaced 120^0 in phase with respect to each other. Since the loads in our example are provided by purely resistive impedances, the phase currents I_P (I_U, I_V, I_W) are in phase with the phase voltages V_P (V_{UN}, V_{VN} and V_{WN}). In a star connection, each phase current is determined by the ratio of the phase voltage to the load resistance R.

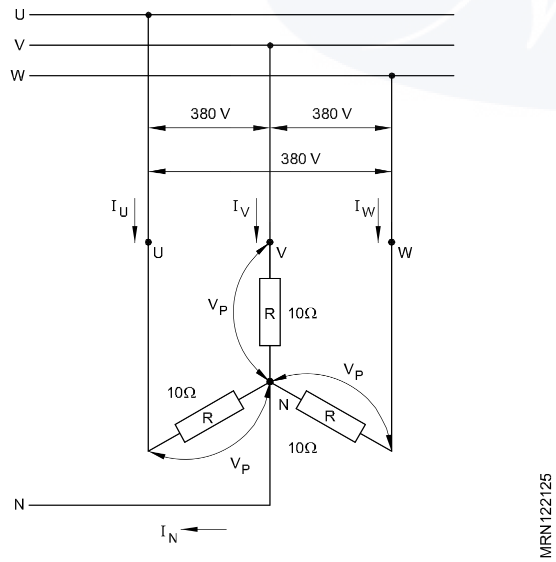
Example *1*: What is the line voltage for a three-phase, balanced star-connected system, having a phase voltage of 240V?

$$V_L = \sqrt{3}\,V_P = \sqrt{3} \times 240$$

$$= 415.7\text{V}.$$

Example *2*: What is the magnitude of each of the supply line currents for the circuit shown in Fig 5?

Fig 5



Because of the arrangements of a star connection there is a voltage

$$V_P = \frac{380}{1.73} = 220\text{ V}$$

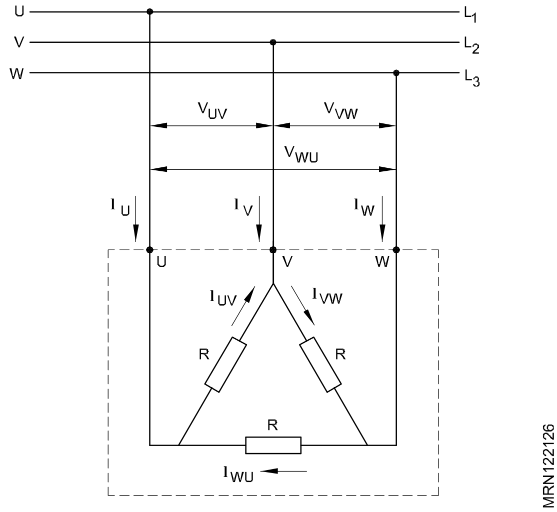
across each of the purely resistive loads R.

The three-supply line currents have the same magnitude since the star-connected load is balanced, and they are given by

$$I_U = I_V = I_W = \frac{V_P}{R} = \frac{220}{10} = 22\text{A} = I_L = I_P$$

Delta connection: There is a second possible arrangement for connecting a three-phase load in a three-phase network. This is the delta or mesh connection (D).(Fig 6)

Fig 6



The load impedances form the sides of a triangle. The terminals U, V and W are connected to the supply lines of the L_1, L_2 and L_3.

In contrast to a star connection, in a delta connection the line voltage appears across each of the load phases.

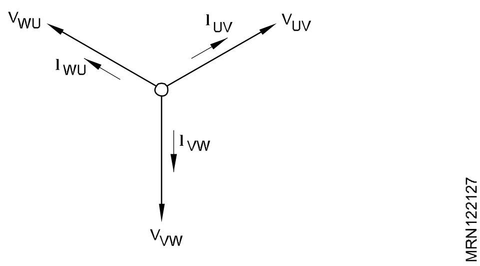
The voltages, with symbols V_{UV}, V_{VW} and V_{WU} are, therefore, the line voltages.

The phase currents through the elements in a delta arrangement are composed of I_{UV}, I_{VW} and I_{WU}. The currents from the supply lines are I_U, I_V and I_W, and one line current divides at the point of connection to produce two phase currents.

The voltage and current relationships of the delta connection can be explained with the aid of an illustration. The line voltages V_{UV}, V_{VW} and V_{WU} are directly across the load resistors, and in this case, the phase voltage is the same as the line voltage. The phasors V_{UV}, V_{VW} and V_{WU} are the line voltages. This arrangement has already been seen in relation to the star connection.

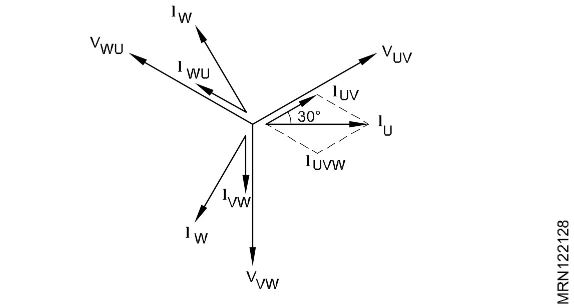
Because of the purely resistive load, the corresponding phase currents are in phase with the line voltages. (Fig 7) Their magnitudes are determined by the ratio of the line voltage to the resistance R.

Fig 7



On the other hand, the line currents I_U, I_V and I_W are now compounded from the phase currents. A line current is always given by the phasor sum of the appropriate phase currents. This is shown in Fig 8. The line current I_U is the phasor sum of the phase currents I_{UV} and I_{UW}. (See also Fig 8)

Fig 8



Hence, $I_U = I_{UV} \cos 30^\circ + I_{UW} \cos 30^\circ$

But $\cos 30^\circ = \frac{\sqrt{3}}{2}$.

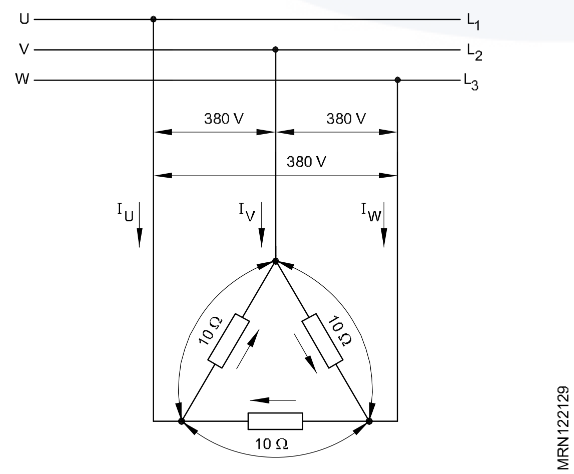
Thus $I_L = \sqrt{3}\, I_{ph}$

Thus, for a balanced delta connection, the ratio of the line current to the phase current is $\sqrt{3}$.

Thus, line current = $\sqrt{3}$ x phase current.

Example *3:* What are the values of the line currents, I_U, I_V and I_W in the above example? (Fig 9)

Fig 9



Solution

Since the load is balanced (i.e. the resistance of each phase is the same), the phase currents are of equal magnitude, and are given by the ratio of the line voltage to the load phase resistance

$$I_{UV} = I_{VW} = I_{WU} = \frac{V_P}{R} = \frac{V_L}{R} = \frac{380}{10} = 38A.$$

Thus, the phase current in the case of delta is 38A. Expressed in words:

$$\text{Phase current} = \frac{\text{line or phase voltage}}{\text{phase resistance}}$$

The line current is $\sqrt{3}$ times the phase current.

Therefore the line current is

$I_U = I_V = I_W = \sqrt{3}$ x 38A = 1.73 x 38A = 66A.

Example *4:* Three identical coils, each of resistance 10 ohms and inductance 20mH is delta connected across a 400-V, 50Hz, three-phase supply. Calculate the line current.

For a coil,

reactance $X_L = 2pfL = 2 \times 3.142 \times 50 \times \frac{20}{1000} = 6.3$ ohms.

Impedance of a coil is thus given by

$$Z = \sqrt{(R^2 + X^2} = \sqrt{(10^2 + 6.3^2)} = 11.8 \text{ ohms.}$$

For a delta connected system, according to equation

$V_L = V_P$.

Thus $V_P = 400V$.

Hence the phase current is given by

$$I_P = \frac{V_P}{Z} = \frac{400}{11.8} = 33.9\ A.$$

But for a delta connected system, according to equation,

$I_L = \sqrt{3}\, I_P = \sqrt{3}$ x 33.9 = 58.7A.

Application of star and delta connection with balanced loads

An important application is the `star-delta change over switch' or star-delta starter.

For a particular three-phase load, the line current in a delta connection is three times as great as for a star connection for a given line voltage, i.e. for the same three-phase load (D line current) = 3 (Y - line current).

This fact is used to reduce the high starting current of a 3-phase motor with a star-delta change over switch.

Application of star connection: Alternators and secondoary of distribution transformers, have their three, single-phase coils interconnected in star.

Neutral in 3-phase system

Objectives: At the end of this lesson you shall be able to
- **explain the current in neutral of a 3-phase star connection**
- **state the method of producing artificial neutral in a 3-phase delta connection**
- **state the method of earthing the neutral.**

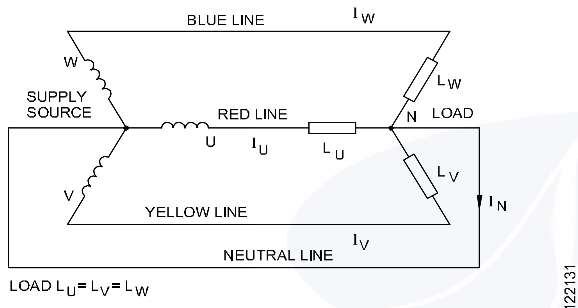
Neutral: In a three-phase star connection, the star point is known as neutral point, and the conductor connected to the neutral point is referred as neutral conductor.

Current in the neutral conductor: In a star-connected, four-wire system, the neutral conductor N must carry the sum of the currents I_U, I_V and I_W. One may, therefore, get the impression that the conductor must have sufficient area to carry a particularly high current. However, this is not the case, because this conductor is required to carry only the phasor sum of the three currents.

I_N = phasor sum of I_U, I_V and I_W

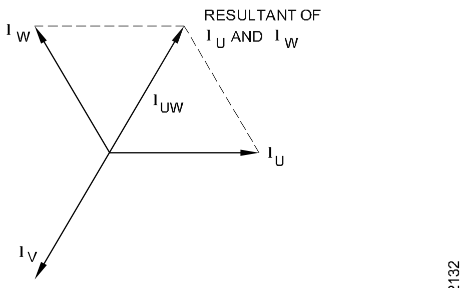
Fig 2 shows this phasor addition for a situation where the loads are balanced and the currents are equal. The result is that the current in the neutral line I_N is zero.

Fig 1



THREE-PHASE SUPPLY AND LOAD

Fig 2



FOR A BALANCED LOAD THE RESULTANT OF I_W AND I_U IS EQUAL IN MAGNITUDE BUT OPPOSITE TO I_V.

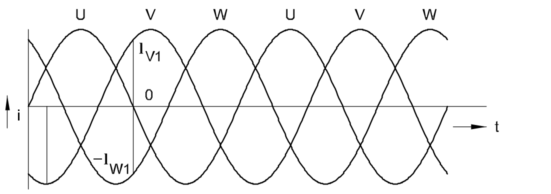
This can also be shown for the other instantaneous values.

At a particular instant in time, t_1, the instantaneous value $i_U = 0$ (Fig 3), i_V and i_W, have equal magnitudes, but they have opposite signs,i.e. they are in opposition and the phasor sum is zero. Taking the other values of t, it can be seen that the sumof the three phase currents to equal to zero.

Therefore, for a balanced load the neutral conductor carries no current.

With unequal value the phase currents are different in magnitude and the neutral current is not zero. Then a `neutral' current I_N does flow in the neutral conductor, but this, however, is less than any of the supply line currents.

Fig 3



RESULTANT OF THREE-PHASE CURRENTS

Thus, neutral conductors, when they are used, have a smaller cross-section than the supply lines.

Effect of imbalance: If the load is not balanced and there is no neutral conductor, there is no return path for the sum of the phase currents which will be zero. The phase voltages will not now be given by the line voltage divided by $\sqrt{3}$, and will have different values.

Earthing of neutral conductor: Supply of electrical energy to commercial and domestic consumers is an important application of three-phase electricity. For `low voltage distribution' - in the simplest case, i.e. supply of light and power to buildings - there are two requirements.

1 It is desirable to use conductors operating at the highest possible voltage but with low current in order to save on expensive conductor material.

2 For safety reasons, the voltage between the conductor and earth must not exceed 250V.

A voltage distribution system according to criterion 2, only possible with a low line voltage below 250 V. However, this is contrary to criterion 1. On the other hand, with a star connection, a line voltage of 400V is available. In this case, there is only 230V between the supply line and the neutral conductor. Criterion 1 is satisfied and, to comply with 2, the neutral conductor is earthed.

ndian Electricity Rules: I.E.Rules insist that the neutral conductor must be earthed by two separate and distinct connections to earth. Rule No.61(1)(a), Rule No.67(1)(a) and Rule No.32 insist on the identification of neutral at the point of commencement of supply at the consumer's premises, and also prevent the use of cut outs or links in the neutral conductor. BIS stipulate the method of earthing the neutral. (Code No.17.4 of IS 3043-1966)

Cross-sectional area of neutral conductor: The neutral conductor in a 3-phase, 4-wire system should have a smaller cross-section. (half of the cross-section of the supply lines).

Artificial neutral: Normally neutral conductors are available with a 3-phase, 4-wire system only. Neutral conductors are not drawn for a 3-phase, 3-wire system. Neutral conductors are also not available with the delta-connected supply system.

A neutral conductor is required for measuring phase voltage, energy, power to connect indicating lamps, etc. An artificial neutral for connecting indicating lamps can be formed by connecting them in star. (Fig 4) Artificial neutral for instruments can be formed by connecting additional resistors in star. (Fig 5)

Fig 4

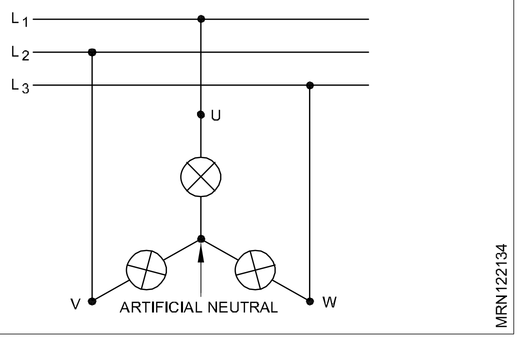
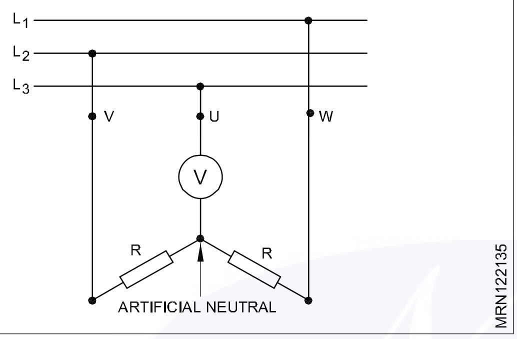


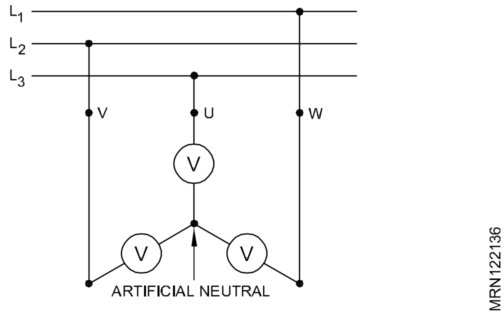
Fig 5



In this method, the value of R must be equal to the resistance of the voltmeter. The same method can be used while measuring power or energy by connecting resistors of equal resistance as of potential coil.

When three instruments of a similar kind are in use, their pressure coils can be connected to form an artificial neutral. (Fig 6)

Fig 6



This type of neutral cannot allow a large current. When earthing of a delta-connected system is required, neutral earthing compensators are used. These can sink or source large currents while keeping neutral to phase voltages constant.

IS 3043 Code No.17, provide a method to obtain neutral for earthing purposes by an earthing compensator.