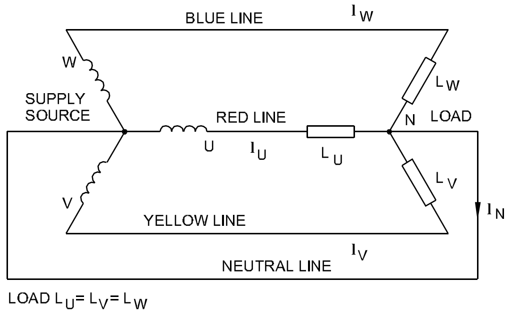
Neutral in 3-phase system

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**
- **explain the behaviour of 3ϕ system when neutral open.**

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 (Fig 1).

Fig 1



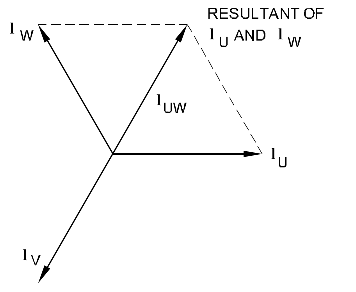
THREE-PHASE SUPPLY AND LOAD

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. This can also be shown for the other instantaneous values.

Fig 2

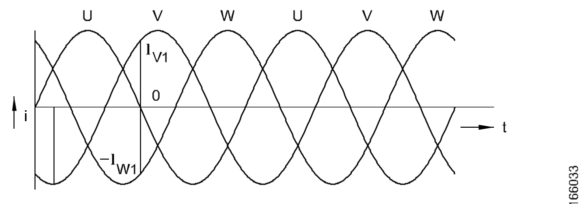


FOR A BALANCED LOAD THE RESULTANT OF I_W AND I_U IS EQUAL IN MAGNITUDE BUT OPPOSITE TO I_V.

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.

Fig 3



RESULTANT OF THREE-PHASE CURRENTS

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. 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 415V is available. In this case, there is only 240V between the supply line and the neutral conductor. Criterion 1 is satisfied and, to comply with 2, the neutral conductor is earthed.

Indian 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

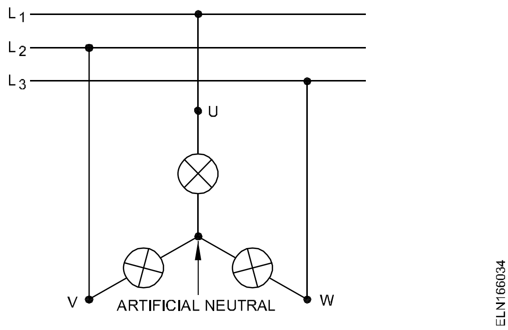
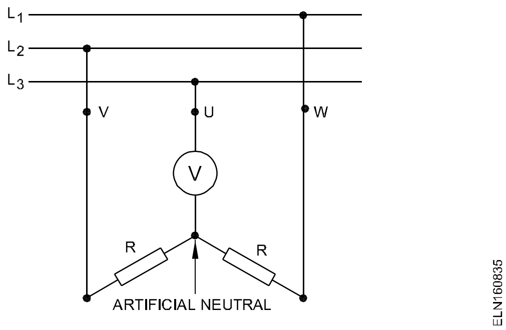


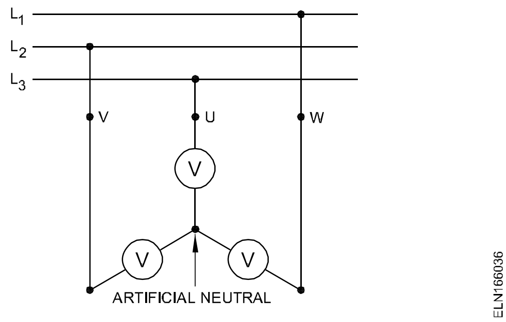
Fig 5



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.

Power in star and delta connections

Objectives: At the end of this lesson you shall be able to
- **explain active, appparent and reactive power in AC 3 phase ϕ**
- **explain behaviour of unbalanced and balance load**
- **state the method of earthing the neutral**
- **determine the power in 3-phase star and delta connected balanced load.**

Fig 1 shows the load of three resistances in a star connection. So the power must be three times as great as the single phase power.

$$P = 3V_pI_p.$$

If the quantities V_P and I_P in the individual phases are replaced by the corresponding line quantities V_L and I_L respectively, we obtain:

$$P = 3\frac{V_L}{\sqrt{3}}I_L.$$

(Because $V_P = V_L$, $\sqrt{3}$ and $I_p = I_L$)

Since $3 = \sqrt{3} \times \sqrt{3}$, this equation can be simplified to the form

$$P = \sqrt{3}\,V_LI_L$$

Note that power factor in resistance circuit is unity. Hence power factor is not taken into account.

Quantity	P	V_L	I_L
Unit	W	V	A

The power in this purely resistive load(ϕ=0°, cosϕ= 1) is entirely active power which is converted into heat. The unit of active power is the watt (W).

As the last formula shows, three-phase power in a star-connected load circuit can be calculated from the line quantities, and there is no need to measure the phase quantities.

$P = \sqrt{3} \times V \times I$ (Formula holds good for pure resistive load)

It is always possible, in practice, to measure the line quantities but the accessibility of the star point cannot always be guaranteed, and so it is not always possible to measure the phase voltages.

Three-phase power with a delta-connected load:

Fig 1

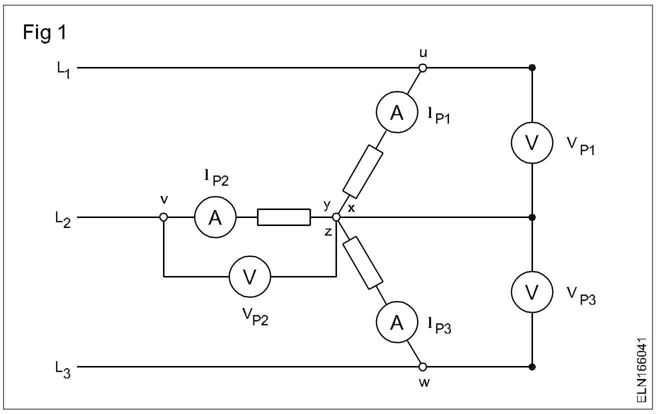
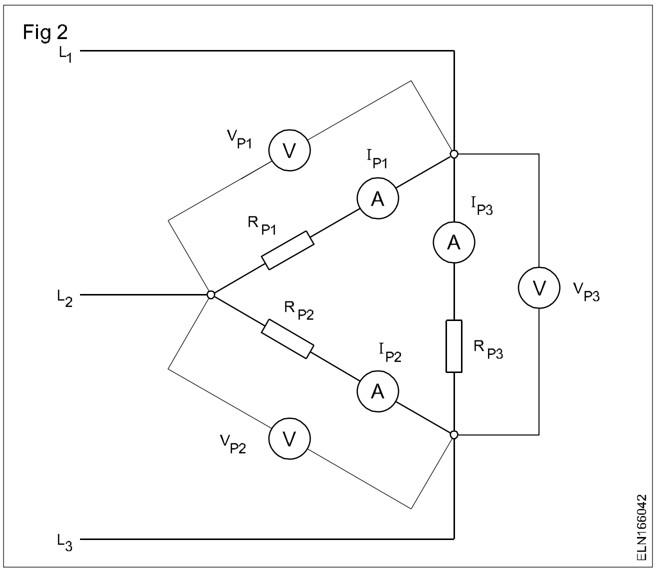


Fig 2 shows the load of three resistances connected in delta. Three times the phase power will be dissipated.

Fig 2



$$P = 3P_P = 3V_P I_P$$

If the quantities V_P and I_P are replaced by the corresponding line quantities V_L and I_L, we obtain:

Since, $V_L = V_P$

$$I_L = \sqrt{3} I_P \text{ and } I_P = \frac{I_L}{\sqrt{3}}$$

but since $3 = \sqrt{3} \times \sqrt{3}$, this equation can be simplified to the form:

$P = \sqrt{3} V_L I_L$. (Formula holds good for pure resistive load)

If we compare the two power formulae for the star and delta connections, we see that the same formula applies to both. In other words, the way in which the load is connected has no effect on the formula to be used, assuming that the load is balanced.

Active,reactive and apparent power: As you already know from AC circuit theory, load circuits which contain both resistance and inductance, or both resistance and capacitance, take both active and reactive power because of the phase difference existing between the voltage and current in them. If these two components of power are added geometrically, we obtain the apparent power. Precisely the same happens in each phase of the three-phase systems. Here we have to consider the phase difference f between the voltage and current in each phase.

Applying the factor $\sqrt{3}$, the components of power in a three-phase system follow from the formulae derived for single-phase, AC circuits, namely:

Apparent power	$S=VI$	$S = \sqrt{3} V_L I_L$	VA
Active power	$P=VI \cos\phi$	$P = \sqrt{3} V_L I_L \cos\phi$	W
Reactive power	$Q=VI \sin\phi$	$Q = \sqrt{3} V_L I_L \sin\phi$	var

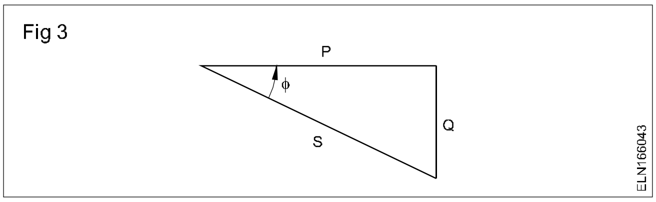
Finally, the well known relationships found in single-phase AC circuits apply also to three-phase circuits.

$$\cos\phi = \frac{\text{activepower}}{\text{apparentpower}} = \frac{P}{S}$$

$$\sin\phi = \frac{\text{reactivepower}}{\text{apparentpower}} = \frac{Q}{S}$$

This can also be seen from Fig 3.

Fig 3



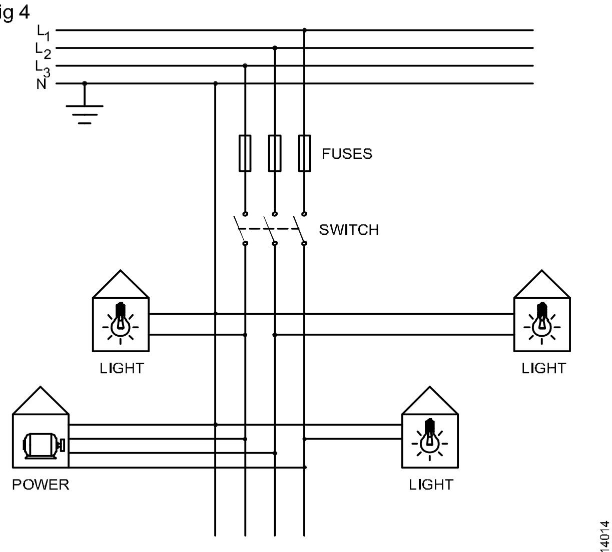
Cos ϕ is called the power factor, while sin ϕ is sometimes called the reactive power factor.

Unbalanced load: The most convenient distribution system for electrical energy supply is the 415/240 V four-wire, three-phase AC system.

This offers the possibility of supplying three-phase, as well as single-phase current, to users simultaneously. Supply to buildings can be arranged as in the given example. (Fig 4)

The individual houses utilize one of the phase voltages. L_1, L_2 and L_3 to N are distributed in sequence (light current). However, large loads (eg.three-phase AC motors) may be fed with the line voltage (heavy current).

Fig 4

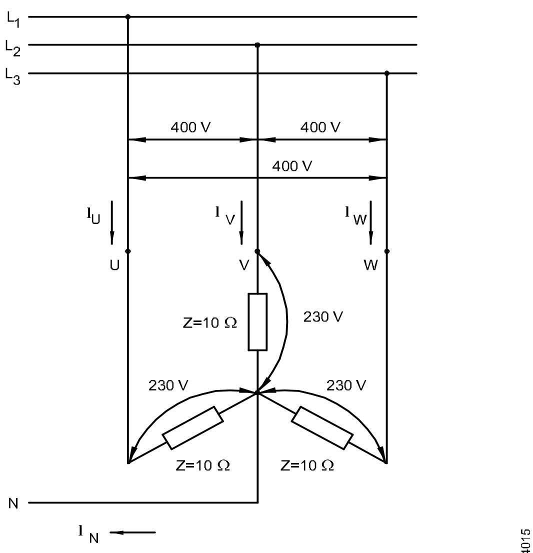


UNBALANCED LOAD

However, certain equipment which needs single or two phase supply can be connected to the individual phases so that the phases will be differently loaded, and this means that there will be unbalanced loading of the phases of the four-wire, three-phase network.

Balanced load in a star connection: In a star connection, each phase current is determined by the ratio of phase voltage and load impedance `Z'.

Fig 5



BALANCED STAR CONNECTED LOAD

This fact will now be confirmed by a numerical example.

A star-connected load consisting of impedances `Z' each of 10 ohms, is connected to a three-phase network with line voltage V_L = 415V. (Fig 5)

Because of the arrangements of a star connection, the phase voltage is 240V ($415/\sqrt{3}$).

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

$$I_U = I_V = I_W = V_P \div Z.$$

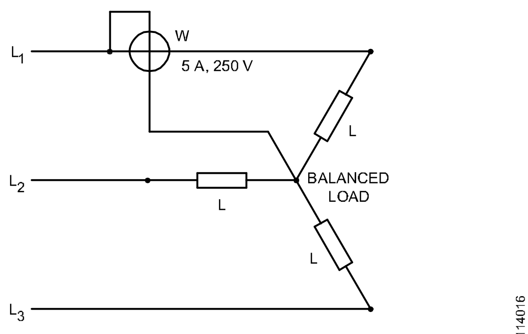
The measurement of power: The number of wattmeters used to obtain power in a three-phase system depends on whether the load is balanced or not, and whether the neutral point, if there is one, is accessible.

- Measurement of power in a 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 6 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.

Power/phase = $3V_PI_P \cos\theta = 3P = 3W$.

Fig 6



POWER MEASUREMENT - SINGLE WATTMETER

The two-wattmeter method of measuring power

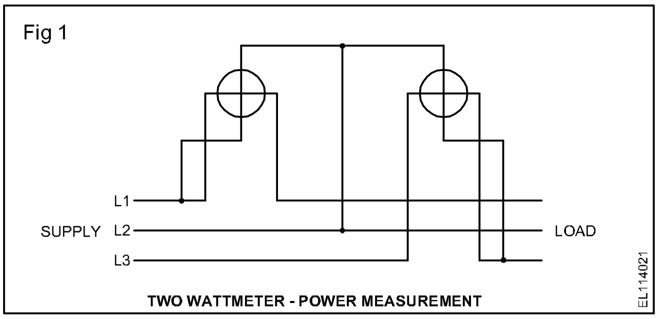
Objectives: At the end of this lesson you shall be able to:

- **measure 3-phase power using two single phase wattmeter**
- **calculate power factor from meter reading.**
- **explain the `two-wattmeter' method of measuring power in a three-phase, three-wire system**

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 as shown in Fig 1. 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.

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

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

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

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.

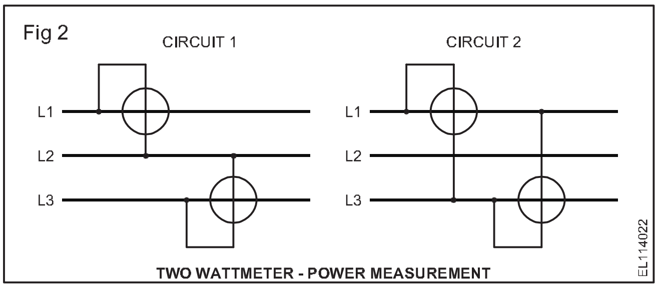
Self-evaluation test

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 2)

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-watmeter method 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 f can be calculated from the given formula

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

from which f 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

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

$P_1 = 4.5$ 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.

Solution

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

$$= \frac{\sqrt{3}(4.5 - (-3))}{(4.5 + (-3))}$$

$$= \frac{\sqrt{3}(4.5 + 3)}{(4.5 - 3)}$$

$$= \frac{\sqrt{3} \times 7.5}{1.5} = \sqrt{3} \text{ x } 5$$

$$= 1.732 \times 5 = 8.66.$$

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

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

Question 1: 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.

Question 2: 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

1 Total power = $P_T = P_1 + P_2$

$P_1 = 600W.$

$P_2 = 300W.$

$P_T = 600 + 300 = 900$ W

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

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

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

Power factor = Cos 30^o = 0.866.

2 a) $P_1 = 25$ KW

$P_2 = 5$ KW

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

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

$\phi = \tan^{-1} 1.1547 = 49^o 6'$

Power factor (Cosϕ) = Cos $49^o 6'$ = 0.6547

b) $P_1 = 25$ KW

$P_2 = -5$ KW

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

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

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

$\phi = \tan^{-1} 2.5980 = 68^o 57'$

Power factor = Cos $68^o 57'$ = 0.3592

Phase-sequence indicator (Meter)

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

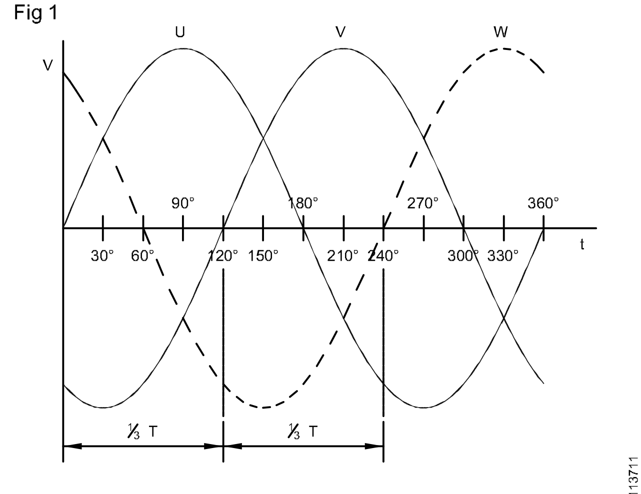
- **describe the method of finding the phase sequence of a 3-phase supply using a phase-sequence indicator**
- **explain the methods of finding phase sequence using lamps.**

Review

A three-phase alternator contains three sets of coils positioned 120^o 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 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



3 - PHASE OUTPUT VOLTAGE

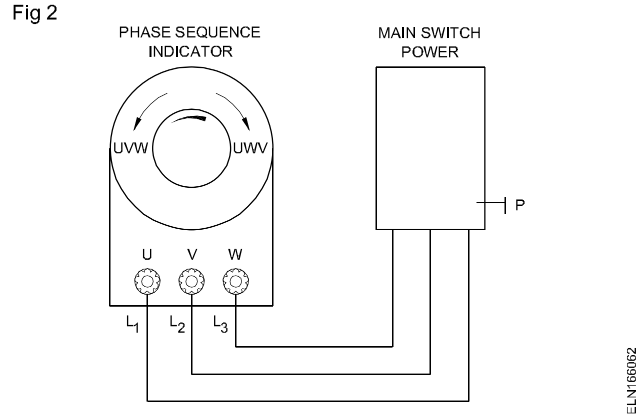
Importance of correct phase sequence: Correct phase sequence is important in the construction and connection of various three-phase systems. For example, correct phase sequence is important when the outputs of three-phase alternators must be paralleled into a common voltage system. The phase `U' of one 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)

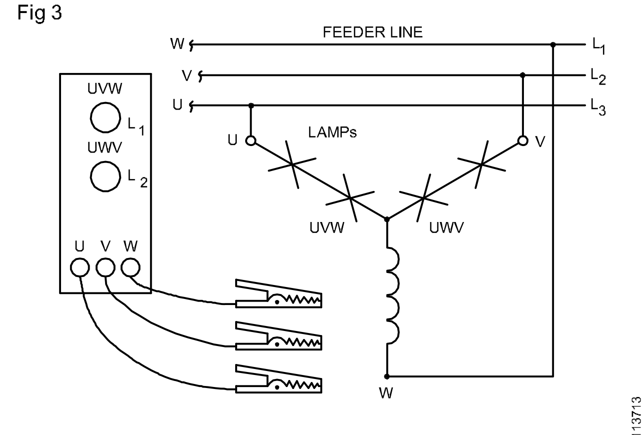
The phase sequence of the three-phase system may be reversed by interchanging the connections of any two of the three phases.

Fig 2



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)

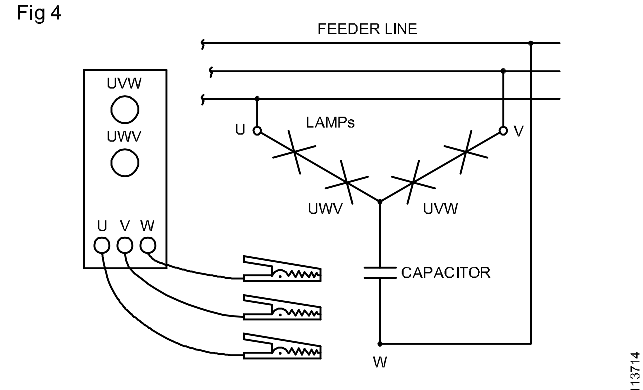
Fig 3



PHASE SEQUENCE INDICATOR USING CHOKE & LAMPS

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)

Fig 4



PHASE SEQUENCE INDICATOR USING CAPACITOR & LAMPS